Rainfall and Flood Frequency Analysis for Pahang River Basin, Malaysia

2010

Master's Thesis 2010

Ashenafi Wondimu Tekolla

Division of Water Resources Engineering

Department of Building and Environmental Technology

Lund University

Avdelningen för Teknisk Vattenresurslära

ISRN LUTVDG/TVVR-10/5012

ISSN-1101-9824

Rainfall and Flood Frequency Analysis in Pahang River Basin, Malaysia

August 2010

Copyright © Ashenafi Wondimu Tekolla

August 2010

Report TVVR 10/5012

Master of Science Thesis in Water Resources Engineering

Division of Water Resources

Lund University

Box 118 SE - 221 00 Lund

Sweden

Phone: +46 46 2220000

Web Address: http://www.tvrl.lth.se

Acknowledgement

I have great appreciations for my Supervisor, Prof. Cintia Bertacchi Uvo, who lifted me up to this level, for her patience and courage. Despite her busy schedule, she always took the time out to assist me.

I also want to thank Dr. Jan Høybye, for his supervision, and for providing extremely important data and information I was needed to complete this project.

I am also grateful to my teacher Dr. Rolf Larsson who facilitated a way to get data.

Finally I would like to thank to all family members back home in Ethiopia, my friends and classmates for their endless encouragement.

Abstract

In the past years different parts of the Pahang River basin have been affected by problems related to flooding. Many people died or were dislocated from their place, and government and private properties have been damaged causing huge impact on the country's economy. The main reason for this catastrophe is the lack of appropriate knowledge about the river basin's hydrology. The rapid industrialization and urbanization has led to deforestation and unplanned land use altering the rainfall-runoff relationship.

In this study, three main causes of flooding in the basin are analyzed: heavy local rainfall, extreme increase in river discharge and sea wave from South China Sea. The Royal city of Pekan is located at a place where these three causes have a high probability to happen, so the analysis will mainly focus on the area around Pekan (Lower Pahang basin).

The basin is exposed to two different monsoon winds drawing moist air either from the Indian ocean, or South China Sea. It also receives local convectional rainfall during the inter-monsoon period due to high temperatures in the lowlands. The spatial variability of rainfall in the basin is caused by the complex nature of topography integrated with the monsoon seasons. The basin's average annual rainfall is 2170mm.

Geographical Information System (GIS) was a used to delineate the watershed and extract terrain and physical feature of basin. Daily rainfall data of 39 year (1970-2008) from 12 meteorological stations located predominantly at the Lower Pahang basin used to analyze the spatial and temporal variability of rainfall. Different data analysis techniques has been used including Principal Component Analysis (PCA). The first principal Component (PC1) which describes 69% of the total variance is related to the northeast monsoon season rainfall, and the Second principal Component (PC2) which describes 29% of the variance is related to the convective rainfall occurring during the inter-monsoon season due to high temperature at the lowlands. Homogeneous rainfall sectors are then determined over the area with the annual rainfall pattern and grouped in three homogenous sectors. The result shoed that mountainous areas surrounding the basin and the southeast coast of the basin which is exposed to northeast monsoon wind receive a larger amount of rainfall compared to the lowland.

The increase in the river discharge is mainly dependant on the amount of precipitation that

falls on the mountainous areas where the intensity of rainfall is high and rainfall is quickly converted into runoff due to the steep slopes. River discharge increases in the monsoon seasons and mainly during northeast monsoon season. The flood frequency was performed using 37 years (1972-2008) of gauged records using Log-Pearson type III method. It showed that there is a 20% probability for the areas downstream of Lubuk-Paku to be flooded since the river discharge exceeds the maximum safe water level once in every 5 years.

Flood routing has been performed to estimate the peak discharge at any distance downstream of Lubuk-Paku because the river passes through many physical factors that can alter the flow hydrograph. There are lateral flow from the tributary river joining the river downstream of the last gauging station (Lubuk-Paku) and runoff generated from the sub-watersheds. The result showed that the hydrograph of the river flow is attenuated by approximately $200m^3/s$, and 24 hours lag in time.

Flood resulted from the effect of sea waves from the South China Sea is also important to analyze particularly at the southeast coast of the basin. The waves convey energy and momentum to the beach where they break. Upon breaking, the momentum is transferred to the water column resulting in longshore and onshore forces exerted on the water column and increases the water level in the river column which is said to be a wave setup (Robert, 2001). This helps to estimate the area of land susceptible to be flood due to the wave action. Gradually varied flow equation is used to estimate the effect of wave setup and showed that the water level at Pekan will increase by 0.5m above the dangerous water level.

Depending on the radius of curvature of the river channel and the velocity of the water, when the river passes through curved channels, the water level rises towards the outer bank than the inner bank due to centrifugal force on the water. The flow velocity is also faster at the outer bank of the river than the inner bank. This leads to a greater increase in water level towards the outer bank. According to the analysis the water level at the outer bank will increase approximately by an additional 0.5m in Pekan.

The results of this work are useful in flood control projects and assessment of flood characteristics of basins for best management practices such as flood protection and early warning process.

Contents

List of figures

List of tables

Abbreviations and Acronyms

AMSL	above mean sea level
DEM	Digital Elevation Model
GIS	Geographical Information System
IDF	Intensity Duration Frequency
JASL	Joint Archive Sea Level
OLR	Low Outgoing Radiation
PCA	Principal Component Analysis
PMP	Probable Maximum Precipitation
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
SRTM	Shuttle Radar Topographic Mission
SWL	Steel Water Level
UHSLC	University of Hawaii Sea Level Center

1. Introduction

Worldwide natural disasters are occurring every year and their impact and frequency seem to have increased in recent decades, mostly due to environmental degradation, brought on by human intervention to nature: deforestation, intensified and unplanned land use and increasing population (Vincent, 1997). Rapid urbanization and industrialization of the areas in the Pahang river basin have significant impact on the increment of damages caused by flood. The Department of Irrigation and Drainage in Malaysia stated that the recent flooding which has occurred in December 2007 was the largest flooding after more than 30 years since 1971(Hiew, 2008). Muhammad (2007) stated that the peak flow increased rapidly in the Pahang river basin because of natural land has been converted to be concrete surface and this phenomenon increases in the surface runoff.

The basin has been known for its large tropical forests reserve like Teman Negara at the northeast and the swamp forest at the southeast coast. But nowadays most of these forests have been changed into hard surfaces such as houses, concrete surfaces or asphalt roads due to rapid increase in population and urbanization. As a consequence, the basin has been affected by many flood related problems. The major flooding seasons are mainly related to Northeast monsoons which cause heavy rainfall.

1.1 Source of Flooding

According to Høybye (2009), there are three identified main sources of flooding in the basin:

1. **Heavy Local Rainfall**: - because of two monsoon winds which are blowing moist air from different directions depending on the season and local convective rainfall at the lowlands, the basin receives large amount of rainfall causing flash flood in different parts of the basin.

2. **Extreme Increase in River Discharge**: - During the monsoon seasons the mountains surrounding the basin receives substantial amount of rainfall. Because of the steepness of slope on the mountain and the intensity rainfall, the mountains send more runoff into the river which increases the river discharge and may lead to flooding.

3. **Sea Wave from South China Sea**: - the third source of flooding which is most common at the southeast coast of the basin is the sea wave from South China Sea. The broken wave at the surf zone increases the water level in the river column. This phenomenon is called the wave setup and the effect will propagate over a certain distance to upstream by increasing the water level in the river column gradually. As the water level rises above the river bank level, the water will spill out and flood the areas along the river.

1.2 Objective

The main objectives of this study are:

1. to identify the flood prone areas in the basin and investigate the risk and impacts of flooding on the areas along the river. The royal city, Pekan, is located near the river at the southeast coast is susceptible to all the three main sources of flood mention in the previous section.

2. To provide supportive information based on the result of the analysis to any concerned bodies such as the government, community, or river authorities in the basin.

1.3 Methodology

1.3.1 Watershed processing

The first step in doing any kind of hydrologic modeling involves delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, and stream network density. Traditionally this has been done manually by using contour maps. In this study Geographical Information System (GIS) and Arc Hydro tool is used for the delineation of watershed and sub-watersheds.

1.3.2 Rainfall Data Analysis

The Spatial variability analysis of rainfall in the basin has been performed using daily precipitation values of 39 years (1970-2008) from 12 meteorological stations which are predominantly located at the southeast coast of the basin. Different methods of data analysis have been used including; mean monthly rainfall, mean annual rainfall, Probable Maximum Precipitation, intensity Duration Curve, and Principal Component Analysis (PCA).

1.3.3 River Discharge Data Analysis

For the analysis of the river discharge data, daily river discharge data of a 37 year (1972-2008) from five gauging stations have been used. Three of the gauging stations are to be found along the main bank of the River and two of them are situated on the two tributaries rivers, on the River Chini and River Gelugor. Since the most flood prone areas are along the main river, the analysis emphasizes on the gauging stations located along the main bank of the river.

Different techniques have been undertaken for the analysis of river discharge records including : mean monthly river discharge to analyze the seasonal variation of river flow, mean annual river flow analysis to be acquainted with the historic pattern of the river flow, and flow frequency analysis to produce guidance about the expected behaviour of future river flow

River routing has been performed to estimate a river discharge at any distance downstream of Lubuk-Paku gauging station. Muskingum-Cunge method of flood routing techniques has been used since this method is suitable for river routing.

1.3.4 Hydrodynamic Effect of the Sea Wave from South China Sea

Since the third main source of flooding particularly at the southeast coast of the basin the wave from the South China Sea, the analysis of sea wave is important. To analyze the variability and seasonality of sea wave, hourly wave height data of 24 years (1984-2006) taken from Kuantan is used.

When the sea wave propagates to the surf zone, the wave breaks due to the shallow depth at the surf zone. The broken wave increase the water level in the river entrance called wave setup (Xuan, and Hisao, 2007). This increase in water level in the river column due to the wave setup propagates to the upstream by increasing the water level in the river due to the transfer of momentum. The gradual increase in water level in the river to the upstream is calculated using gradually varied flow equations which will be discussed in the fifth chapter. The water level rise at the river entrance can be attributed not only to wave setup, but also to backwater effect due to the constriction of the flow.

1.4 General Description about Pahang River Basin

The Pahang River basin is located in the Malaysia Peninsula between latitude 2° 48'45" - 3° 40' 24"N and longitude 101° 16' 31" - 103° 29' 34"E. The basin has a total area of 27000km2. The length of the river is estimated to be 440 km and it is a confluence of the River Jelai and River Tembeling from the upstream which join together at Kuala Tembeling, about 304 km from the river mouth at the east coast of Pahang state (Muhammad (2007).

River Jelai is one of the two main tributaries which drain from the eastern slope of Mountains Banjaran and Titiwangsa, the foot of Central mountain range. The Central Mountain ranges is the largest mountain in the Malaysia Peninsula and separates the Peninsula into an eastern and western.

River Tembeling originates from the Besar Mountain Range in the Northeast of the basin. For the purpose of fixing its length, however, the Tembeling and Pahang are considered as one river (Takeuchi,et al 2007). Other main tributaries of the River Pahang are Semantan, Teriang, Bera, Lepar, Gelugor, and Chini.

The two main natural reservoir sites in the basin are Lake Chini and Lake Bera. Lake Chini is surrounded by variously vegetated low hills and undulating lands which constitute the watershed of the lake and drains north easterly into Pahang River via the Chini River (Muhammad,et al.,1998). Lake Bera is located at the southwest in the basin and is the larger of the two lakes via area. It is shallow and seasonal flowing into the River Pahang via River Bera. This lake plays an important role in flood control, water flow regulation and also provides natural resources for local community. Hence, it is protected under the international RAMSAR CONVENTION, which was declared in November 1994(Takeuchi,et al 2007). However the lake is under threat of drying up in the near future as the water source disappears due to increasing conversion of natural forests to palm oil plantations, excessive siltation, and soil erosion caused by uncontrolled logging activities in the area (Takeuchi,et al 2007).

1.4.1 Topography

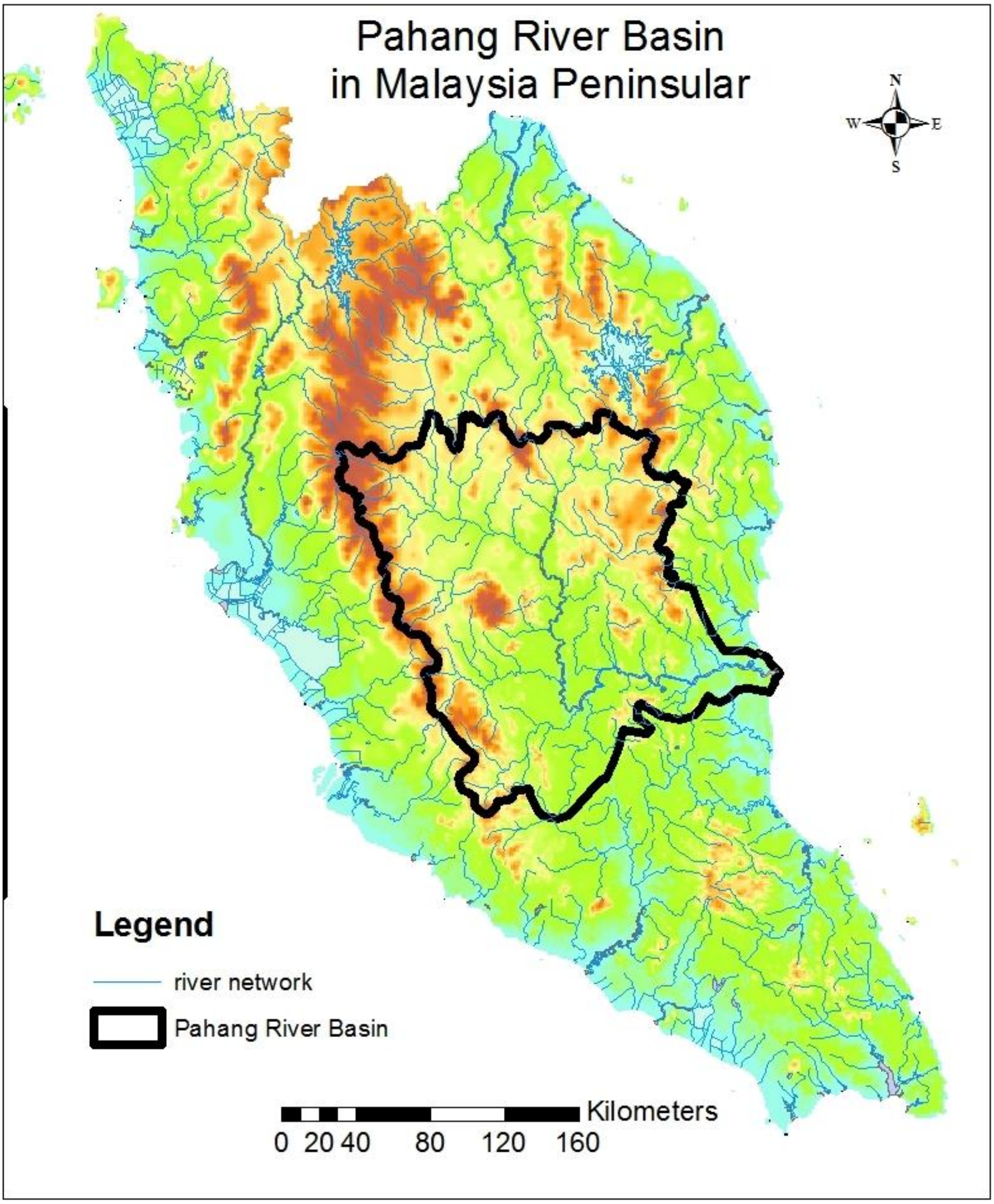


Figure 1-1 Location of the Pahang River basin in Malaysia (SRTM 2008)

As it is seen in the Figure 1-1 the topography of Peninsula Malaysia is dominated by a mountainous spine, known as the Central Range which runs from the Thailand border southwards to Negeri Sembilan, effectively separating the eastern and western part of the peninsula. There are also several mountains at the north and northeast that consist mainly of raised marine sediments with granitic intrusions. Mountain Tahan is the highest mountain in the Peninsular Malaysia with an elevation of 2190m located in the basin (Malaysian Wetland Working Group, 1982).

1.4.2 Land use

Though the basin has been known for its forest reserve, unsustainable logging and other forms of development activities are seriously threatening resulting in degradation of land in some areas (DWNP, 1987).

Agriculture sector mainly consists of cultivation of paddy, rubber, oil palm and cocoa plantations (Takeuchi,et al 2007). An area extending up to 6km to the north and south of River Pahang is gazette as Malay Reserve; unalienated land to be used by Malay people (Malaysia Wetland Working Group, 1982).

With regard to urbanization, although the overall level of urbanization in Peninsula Malaysia increased from 20.4 percent in 1950 to 29.4 percent in 1980 there were nevertheless considerable variations in the rate and tempo of urbanization. Between 1947 and 1957 all ten states with urban areas experienced an increase in the level of urbanization, but the largest increase is being registered in Pahang followed by Selangor The inflow of migrant into Pahang can be traced to be the major factors for the extensive land development program undertaken in Pahang (Sharon, 1992).

1.4.3 Climate

The climate of Pahang River Basin is mainly governed by the regime of Northeast and Southwest monsoon winds which vary in direction according to the season. Southwest monsoon which occurs between March and September, as the sun directly strikes above the equator, the land mass of Asia heat more than the Indian Ocean. The temperature difference between the land mass and the Indian Ocean creates wind that draws moist air from the ocean over the highland of the basin (Malaysian Wetland Working Group, 1988).

The Northeast monsoon wind which lasts from October to January occurs when the tilt of sun ray to the south of Equator. Northeast monsoon is a cyclical wave-like air mass that blows from the Asian continent towards the Indian Ocean and South East Asia. The cold winter in the Asian continent creates a high pressure air and concurrently hot summer over the south. This causes cold and strong wind to blow from the north-east direction of the Asian continent to low pressure region. This Monsoon season is mainly responsible for the heavy rain which hits the east coast of Pahang state and causes flooding (The Encyclopedia of earth, 2009).

The transition period in between the monsoons is known as the inter-monsoon period. During these periods the basin experiences low amount of rainfall. The driest months in the basin are June and July (Malaysian Meteorological Department, 2009).

Being in the tropics, the average temperature throughout the year is high (26^0C). But there is regional variation in temperature also. For example highlands in the Peninsula have got an annual average temperature of 18^{0}C. The average maximum relative humidity of the air varies between 94% and 100%, typical of the humid tropics (Malaysian Wetland Working Group, 1988).

.Table 1-1 Basic information about the Pahang river basin (catalogue of river UNESCO)

<table>
<tr><td colspan="4">Name: Pahang river</td></tr>
<tr><td>Location</td><td colspan="2">N 2^{0}48’45” to 3^{0}40’24”</td><td>E101^{0}16’31” to 103^{0}29’34”</td></tr>
<tr><td colspan="2">Area: 25,600km^3</td><td colspan="2">Length of main stream: 440km</td></tr>
<tr><td colspan="2">Origin: Mt.Tahan (2187m)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Outlet: the south China Sea</td><td colspan="2">Lowest point: river mouth(0m)</td></tr>
<tr><td colspan="4">Main geological features: shale, Mudstone, Limestone and rooks</td></tr>
<tr><td colspan="4">Main tributaries: Rembeling River(5050 km^2), and Jelai River (7320 km^2)</td></tr>
<tr><td colspan="4">The Main reservoirs: southern Abu Bakar Dam of TNB, Chini Lake and Bera Lake</td></tr>
<tr><td colspan="4">Mean annual Precipitation: 2170 mm (1971-2002)</td></tr>
<tr><td colspan="4">Mean annual runoff: 596m^3/sec at Lubok Paku (1973-2002)</td></tr>
<tr><td colspan="4">Population: 1,475,000, as of 2005</td></tr>
</table>

2. Watershed Processing and Spatial Rainfall Analysis

2.1 Watershed Processing

Performing hydrologic modelling involves delineating streams and watersheds, and get some basic watershed properties. This includes the area of watershed, slope, flow length, and stream network density (VenKatesh, M., 2009). With the availability of digital elevation models (DEM) and Arc Hydro tools in GIS, watershed properties can be extracted by automatic procedures. In this study Arc Hydro tools has been used to delineate watershed, sub-watersheds, stream networks and some other watershed characteristics that collectively describe the drainage patterns of a basin. Digital Elevation Model (DEM) which was used for this process is downloaded from http://hydrosheds.cr.usgs.gov/ . Hydrosheds is a mapping product that provides hydrographical information for regional and global-scale applications. It provides a suite of geo-reference data sets (vector and raster) at various scales. It is based on high-resolution elevation data obtained during a Space Shuttle flight for NASA’s Shuttle Radar Topography Mission (SRTM).

2.1.1 Terrain Pre-Processing

An Arc Hydro tools in GIS allows to perform terrain in either a step-by-step fashion or a batch mode. The step-by-step process is considered to be good as the output can be examined to correct the data set when necessary. All of the processing must be completed before watershed processing functions can be used. The step by step process involves 12 main steps before watershed processing can be started. Some of the main pre-processing steps will be discussed.

2.1.2 Fill Sink and Flow Direction

The depressions or pits in the raw raster data of Digital Elevation Model (DEM) are filled to the level of the surrounding terrain by making use of fill sinks utility of Arc Hydro tools. If cells with higher elevation surround a cell, the water is trapped in that cell and cannot flow. The fill sink function modifies the elevation value to eliminate this problem. This is important in order to determine the direction of descent steps for each terrain cell and the flow direction.

2.1.3 Flow Accumulation and Stream Direction

Upstream drainage area at a given cell can be calculated by multiplying the accumulated upstream number of cell by the cell area. This is important in order to create a stream definition. This step classifies all cells with an upstream flow accumulation greater than a user defined threshold of cells. The smaller the threshold chosen the greater is the number of sub basins delineated.

2.1.4 Flow Segmentation, Watershed Delineation and Polygon Processing

Stream Segmentation or links are sections of a stream that connect two successive junctions. This function creates a grid of stream segments that have a unique identification. Either a segment may be a head segment or it may be defined as segment between two segment junctions. All the cells in a particular segment have the same grid code that is specific to that segment. For every stream segment created so, a sub-watershed is delineated by using watershed delineation utility of the Arc Hydro tool.

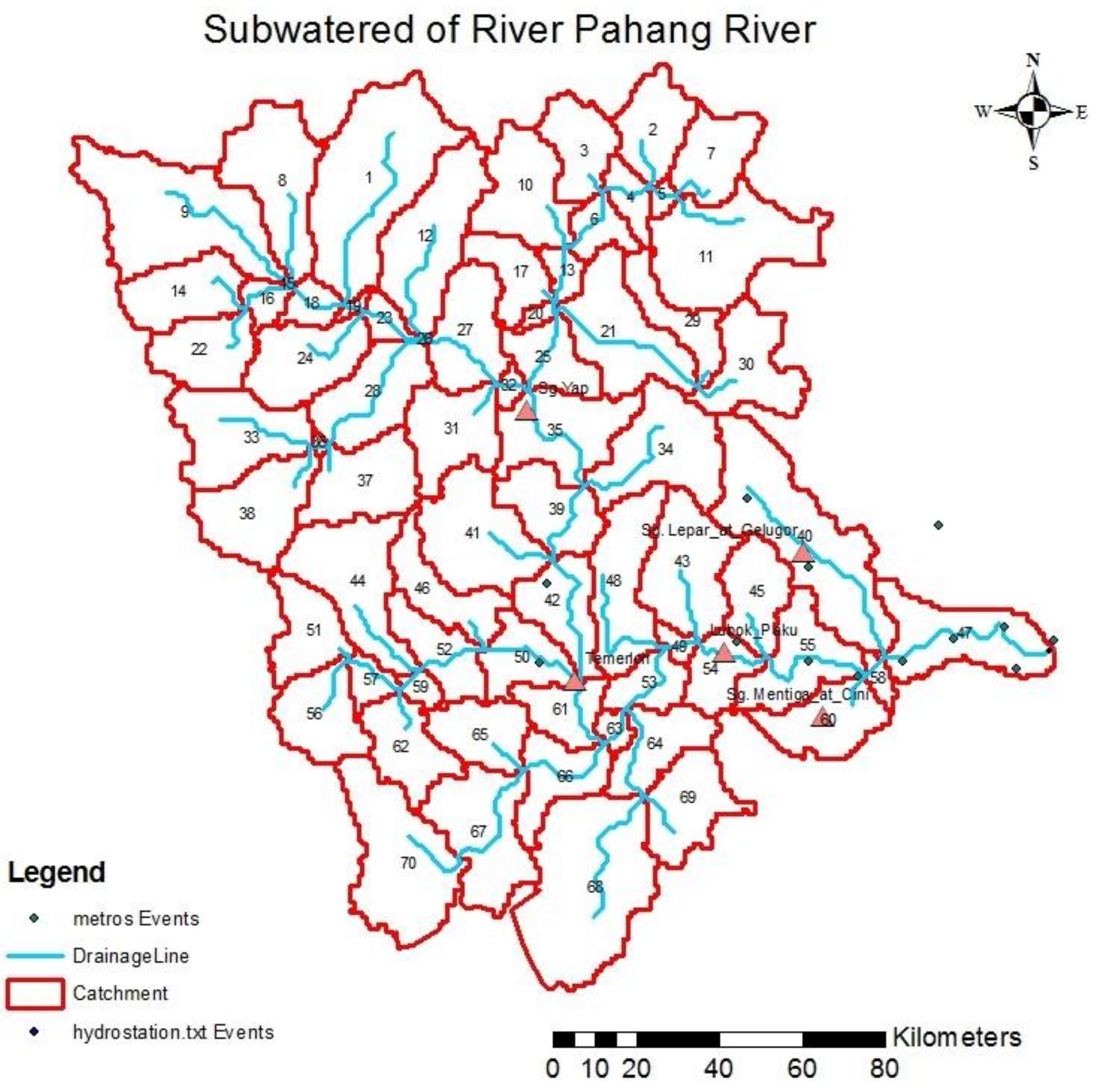


Figure 2-1 Sub-watershed delineation and polygon processing, each polygon represents the sub-watershed in the basin with the respective numbers. The area of the polygons can be seen in Appendix A. The total area of the entire basin is estimated to be 27000km^2.

The created grid base of the sub-basins are then vectorized, through the subsequent watershed polygon processing utility, into polygon vectors to result in polygons of different sizes as shown in the Figure 2-1.

2.1.5 The Stream Segment Processing and Watershed Aggregation

The terrain Processing ends with vectorizing the grid based streams into line vectors and aggregating the upstream sub-basins at every stream confluence. This step is performed with the aim of improving computational performance for interactively delineating sub-basins and enhances data extraction.

2.1.6 Watershed Processing

After the terrain processing is completed in Arc GIS, the extracted sub-watersheds is placed in project view where revision of sub-watersheds delineation is possible. The basin processing tools help to interactively combine or sub divide sub-watersheds. Accordingly, subdivision and recombining of each of the catchments is manipulated to result in three sub-basins as shown in Figure 2-2.

2.2 Spatial Rainfall Analysis in the Pahang River Basin

The earth’s climate is dynamic and naturally varies on seasonal, decadal, centennial, and longer timescales. Each ”up and down” fluctuation can lead to conditions which are warmer or colder, wetter or drier, more stormy or more quiescent (NOAA, 2007). These changes in climate may be due to persistent anthropogenic changes in the composition of the atmosphere or in land use (Bates et al., 2008)

The pattern of rainfall in the Pahang river basin is highly variable in spatial and temporal dimensions based on monthly, yearly, and monsoon temporal scales. To study the spatial and temporal variation of rainfall different approaches have been used including ; mean monthly, mean annual, Probable Maximum Precipitation, and Intensity-Duration-Frequency, and Principal Component Analysis (PCA) .

For this study a 39 year daily precipitation data of (1970-2008) from 12 meteorological stations which are located at the lower Sungai Pahang, has been used (see Figure 2-2). Geographical locations, data period, and mean annual rainfall values of all meteorological stations can be seen in Table 2-1.

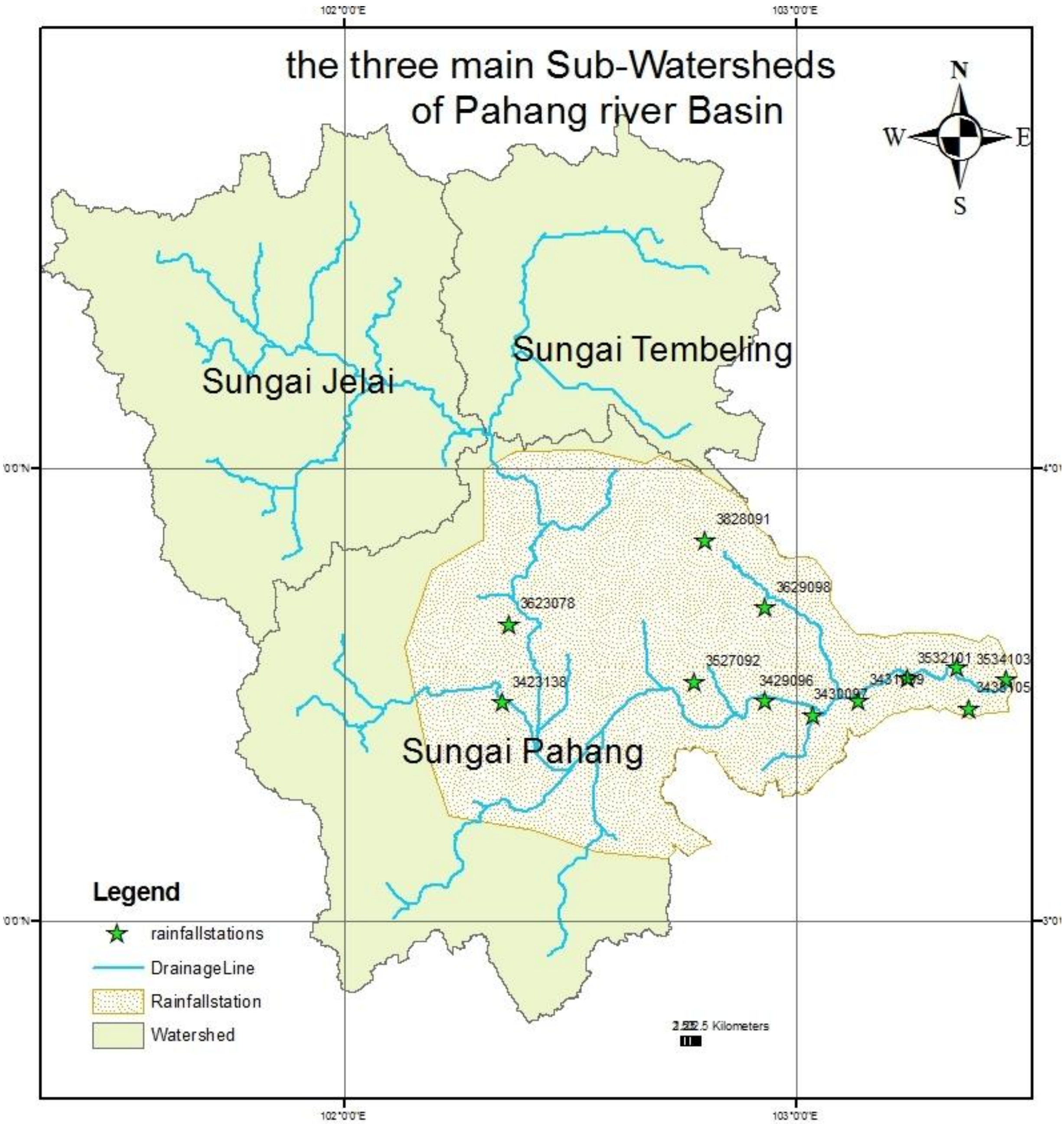


Figure 2-2 Three main sub-watersheds of Pahang River basin and 12 meteorological stations at the lower Sungai Pahang.

Table 2-1 The geographical coordinates, station number, data period, and the mean annual rainfall values of the meteorological stations.

Station	Station no	Latitude	Longitude	Data period	Mean (1970-2008) (mm/year)
Rumah Pam	3533102	3°33'40"	103°21'25"	1948-2008	2,444
Kg. Salong	3429096	3°29'10"	102°56'00"	1960-2008	1,950
Lubok Paku	3527092	3°31'10"	102°46'40"	1931-2008	2,127
Paya Membang	3430097	3°27'15"	103°02'25"	1960-2008	2,377
Kg.Serambi	3431099	3°29'50"	103°08'20"	1960-2008	2,577
Permatang Pauh	3433105	3°28'10"	103°23'00"	1968-2008	2,620
Kg.Temai Hilir	3532101	3°32'10"	103°14'50"	1948-2008	2,505
Kastam Kuala Pahang	3534103	3°32'00"	103°27'55"	1948-2008	2,504
Paya Bungor	3629098	3°41'30"	102°56'00"	1932-2008	2,188
Ladang Ulu Lepar	3828091	3°50'25"	102°48'00"	1972-2008	2,101
JKR Mentakab	3423138	3°29'00"	102°21'05"	1966-2008	1,887
Ldg. Sg. Tekal	3623078	3°39'20"	102°22'00"	1947-2008	1,914

2.2.1 Annual Mean Rainfall

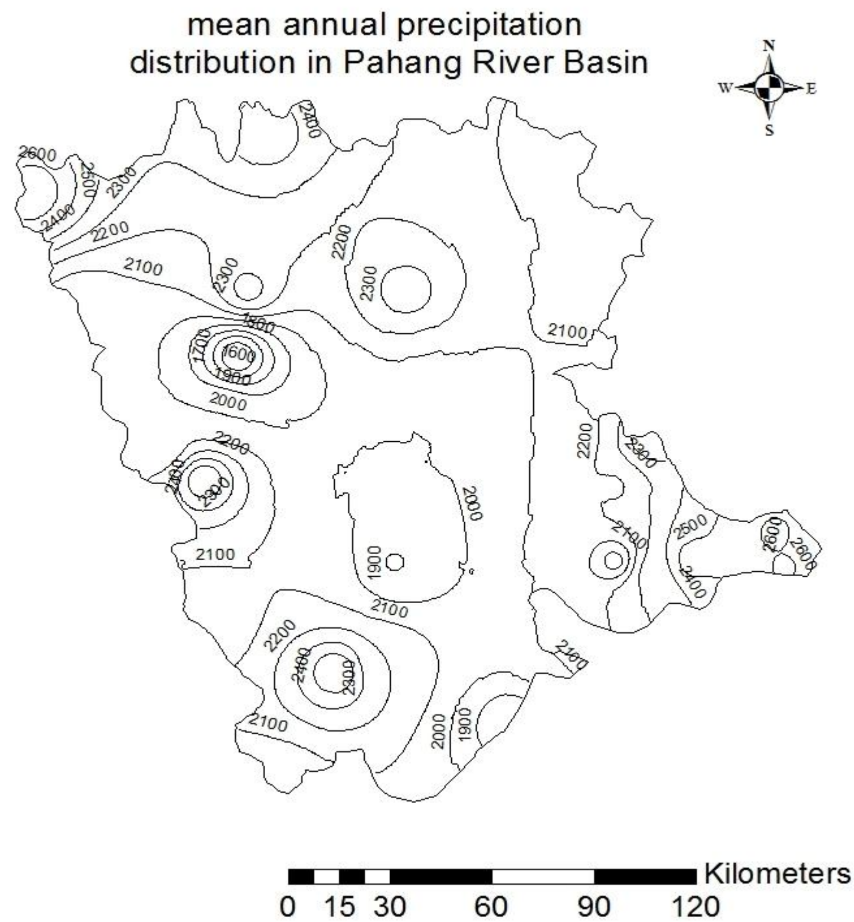


Figure 2-3 Mean annual rainfall distribution in the Pahang river basin

The basin has an average annual rainfall of 2170mm, the largest portion of the rainfall occurs between mid October - Januarys, during Northeast Monsoon season. As it is observed from Figure 2-3, the spatial variability of rainfall in the basin shows that the mean annual rainfall is high on the central mountain range at the west where one of the main tributary rivers, Jelai, is originated from and Besar mountain range at the northeast of the basin where River Tembeling is originates. Apparently Lowlands at the southeast coast receives heavy rainfall during the northeast monsoon season too.

2.2.2 Mean Monthly Rainfall

To investigate the variations of mean monthly rainfall distributions, two stations are considered as a representative. One from the southern east coast, Station 3534103, and one from the lowland, station 3623078 see Figure 2-4. In both stations the maximum rainfall is observed in December during the northeastern monsoon season. The maximum and minimum average monthly rainfall at the southeastern coast of the basin, Station 3534103, is 595.2mm in December and 89.9 mm in July respectively. And the maximum and minimum average monthly rainfall at the inland of the basin is 204mm in November and 104mm in February respectively.

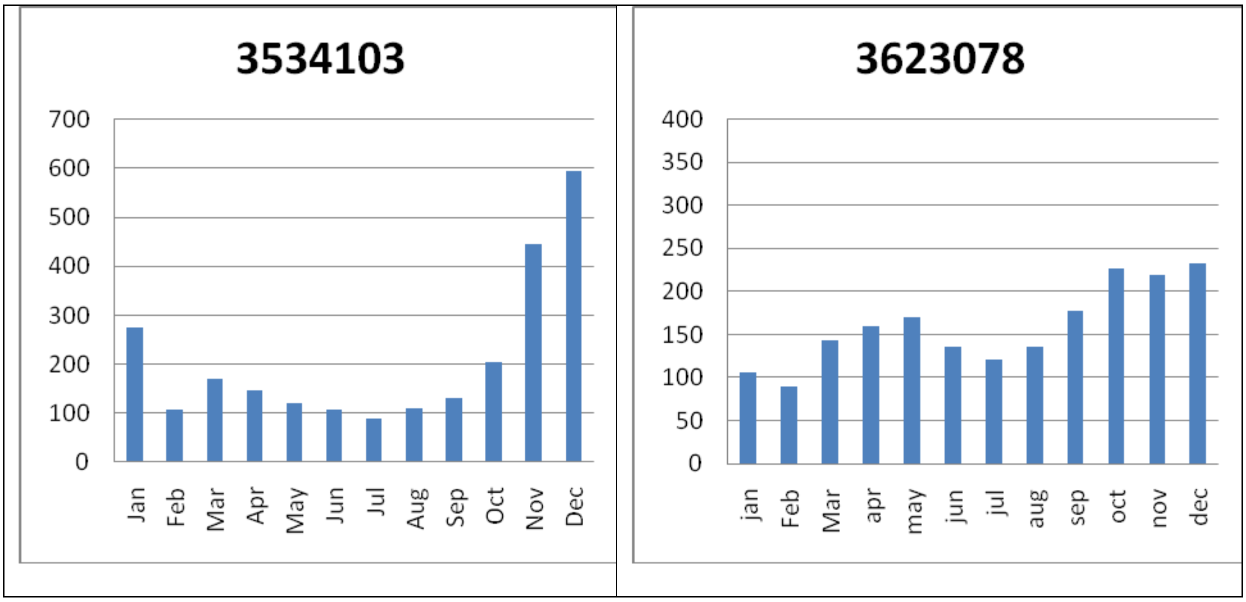


Figure 2-4 Average monthly precipitation from two meteorological stations (Stations 3534103 and 3623078) in the lower basin. Average monthly precipitation for other stations can be found in Appendix B.

The rainfall on the southeast coast region of the basin is mostly influenced by the Northeastern monsoon. The contribution monsoon seasons to the annual rainfall in different region shows that, at the southeast coast 52.8% and 29.4% in Northeast and southwest monsoon respectively. Totally 82.2% of the annual rainfall in this region falls during the two monsoon seasons.

The analysis result also reveals the fact that the inland region receives relatively small amount of rainfall than the highlands because the topographic barrier appears to block the monsoon winds. Tthe rainfall produced in the lowlands of Peninsula Malaysia is due to local convection caused by intense heating of the land surface.

2.2.3 Spatial Rainfall Variability with Respect to Distance Between the Meteorological Stations

To analyze the spatial variability of rainfall at different stations with respect to distance between meteorological stations, all meteorological stations have been correlated to each other and the correlation value plotted on the graph Figure 2-5. The spatial correlation function gives a quantitative measure of the rainfall variability within the meteorological stations in the study area. This process can be used to interpolate the properties to the areas where observations are not available, estimate the spatial averages from discrete observations, and for defining new stations where observations are the most efficient. The correlation may be plotted either depending on or both distance and direction (Uvo and Berndtsson, 1996). The spatial correlation between two station $z_1$and z_2 for time series *t* of rainfall was calculated as:

$$\gamma z_1, z_2, t = \frac{con\left(R_{z_1}t, R_{z_2}, t\right)}{\sqrt{\left(var\left(R_{z_1}, t\right) var\left(R_{z_2}, t\right)\right)}} \qquad (2-1)$$

Where

$\gamma z_1, z_2, t$ = the correlation coefficient between points z_1 and z_2 for time t;

R_{z_1}, t = the rainfall at meteorological station z_1 for time t.

R_{z_2}, t = the rainfall at meteorological station z_2 for time t.

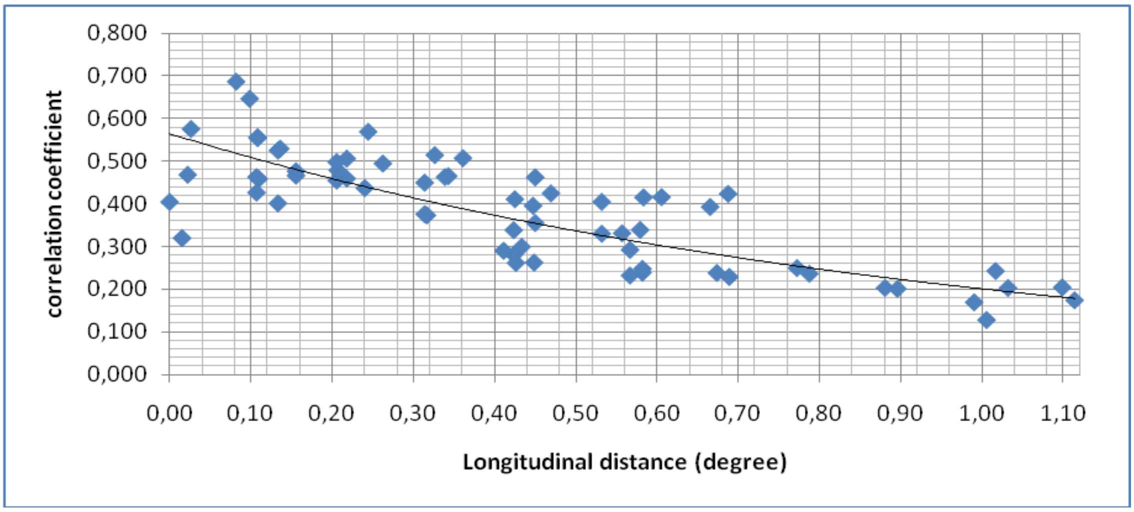


Figure 2-5 Correlation of the rainfall data for all Meteorological stations with respect to inter-station distance. Solid line has been fitted by regression.

The correlation value of all twelve meteorological stations with respect to each other indicates the resemblance of the reading of station. The graph is plotted using the longitudinal distance on X axis and correlation value on the Y axis.

A noticeable difference in correlation value has seen, which indicates the spatial variability of rainfall is distance dependence. As the distance between meteorological station increase the correlation value decreases and as the distance between the station decrease the correlation value increase (see Figure 2-5). The principal differences of the rainfall at different meteorological stations with respect to distance is raised from altitude difference and exposure of the southeast coastal lowlands to the northeast monsoon wind.

2.2.4 Probable Maximum Precipitation

Probable maximum precipitation (PMP) is a characteristic of rainfall at a particular location that can be used in designing water impounding structures. PMP is essential and required to estimate design flood so that the structures are safe from being overtopped by extreme flood events. Theoretically, PMP is defined as the greatest depth of precipitation for a given duration that is physically or meteorologically possible over a given station or area at a particular geographical location at a certain time of year" (World Meteorological Organization, 1986).

In calculating PMP the following points need to be taken into consideration.

- Since calculating PMP from short duration data series will cause error, it is recommended to have many historical storm events from the entire river basin.
- And since PMP is a local value for a specific location, the calculated values need to be interpolated to the entire study area and presented in an isohyetal map.

Meteorological factors that affect the PMP are local moisture availability, types of storm, relative storm efficiency, dew point temperature, altitude and latitude (World Meteorological Organization, 1986).

2.2.4.1 Methods to Calculate Probable Maximum Precipitation

There are two common approaches to calculate the PMP:

- Meteorological approach (World Meteorological Organization, 1973), requires more site-specific data and provides more reliable estimates than other methods. this method is a concept of physics of atmosphere mechanism that cause precipitation.
- Statistical approach using the Harshfield method (World Meteorological Organization, 1986) which requires data for annual maximum rainfall series in the region for required storm durations.

In this study the Harshfield method is used to calculate the probable maximum precipitation.

$$PMP = X_n + k\sigma \qquad (2-2)$$

PMP = probable maximum precipitation

Xn = mean of the series of annual maximum daily rainfall.

K = frequency factor

σ = standard deviation of the series of annual maximum daily rainfall

2.2.4.2 Frequency Factor

Hydrologic frequency factor, K, is used to compare and relate results and attach probabilities to several sets of maximum rainfall data. And it is a primarily function of the recurrence interval for a particular probability distribution. It is displayed as an official and unofficial rainfall observation and PMP for 24 hour duration (David, 1981)

Frequency factor is location dependant. In the case of the Pahang river basin the frequency factor of the region has been estimated by different authors. An earlier study has estimated a frequency factor for Malay Peninsula to be 15 (Desa et al, 2001). But with the objective of providing fresh and reliable estimate of PMP in Peninsula Malaysia using historical rainfall data Desa et al (2001) employed the Harshfield method to find out the appropriate frequency factor for the Peninsula Malaysia. For the analysis they used series of annual daily maximum rainfall and come up with a frequency factor value of *K=8.7*.

2.2.4.3 Result

The probable maximum precipitation of 1, 3, and 7 day of rainfall using frequency factor of *K=8.7* is displayed in Table 2-2 and isohytal map of Figure 2-6, Figure 2-7, and Figure 2-8 respectively.

Table 2-2 One, three, and seven day maximum precipitation and Probable Maximum Precipitation for the twelve meteorological stations in lower Pahang basin using a frequency factor of K=8.7

stations	Station number	1 day Max	3 day max	7 day max	1, 3, 7 days PMP K=8.7		
					1 day	3 day	7 day
Rumah Pam	3533102	510	846	1334	1122	1813	2604
Kg. Salong	3429096	171	461	673	382	899	1365
Lubok Paku	3527092	213	525	837	395	1003	1750
Paya Membang	3430097	212	497	702	484	1014	1535
Kg.Serambi	3431099	238	640	874	540	1373	2112
Permatang Pauh	3433105	279	668	1045	684	1565	2311
Kg.Temai Hilir	3532101	274	557	749	650	1317	1914
Kastam Kuala Pahang	3534103	400	951	1464	770	1795	2727
Paya Bungor	3629098	225	482	660	433	907	1379
Ladang Ulu Lepar	3828091	169	475	773	356	889	1517
JKR Mentakab	3423138	165	333	596	334	690	1153
Ldg. Sg. Tekal	3623078	145	284	401	271	481	748

As it is seen in Table 2-2 the PMP of the basin at different locations shows different values. On the southeast coast of the study area and on the highlands, PMP values are higher than the lowlands. For analysis purpose two meteorological stations are taken as a sample which are located at two extreme sides of the study area. One from the east coast, station number

3533102, and other from the extreme west of the study area, station number 3623078. The 1, 3, and 7 day PMP of the station at the extreme east is estimated to be 1122, 1813, and 2604 mm respectively and for the station which is located at the extreme west is 271, 481, and 748mm respectively.

The isohytal maps in Figure 2-6, Figure 2-7, and Figure 2-8 show that the southeast coast of the basin has higher PMP values than the inland. This is due to the influence of northeast monsoon winds. On the other hand the inland portion of the basin has lower values because obstruction of mountains from northeast monsoon wind.

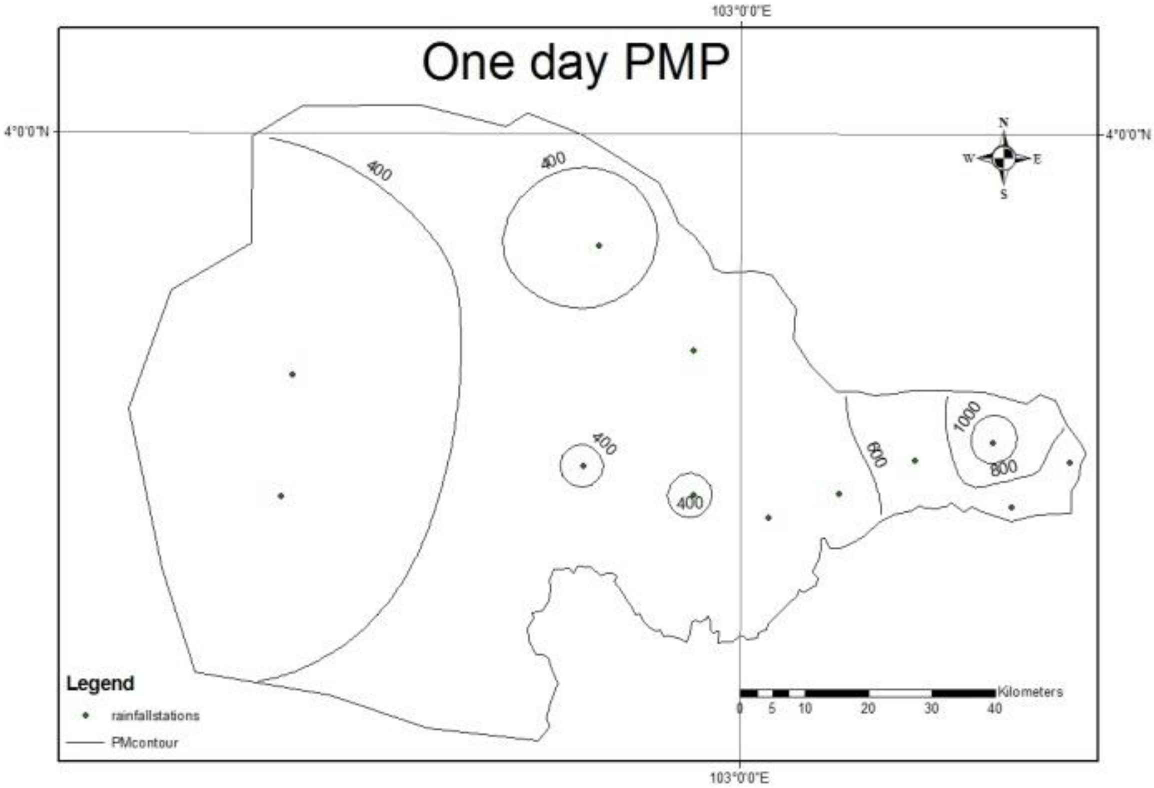


Figure 2-6 Probable Maximum Precipitation of one day rainfall

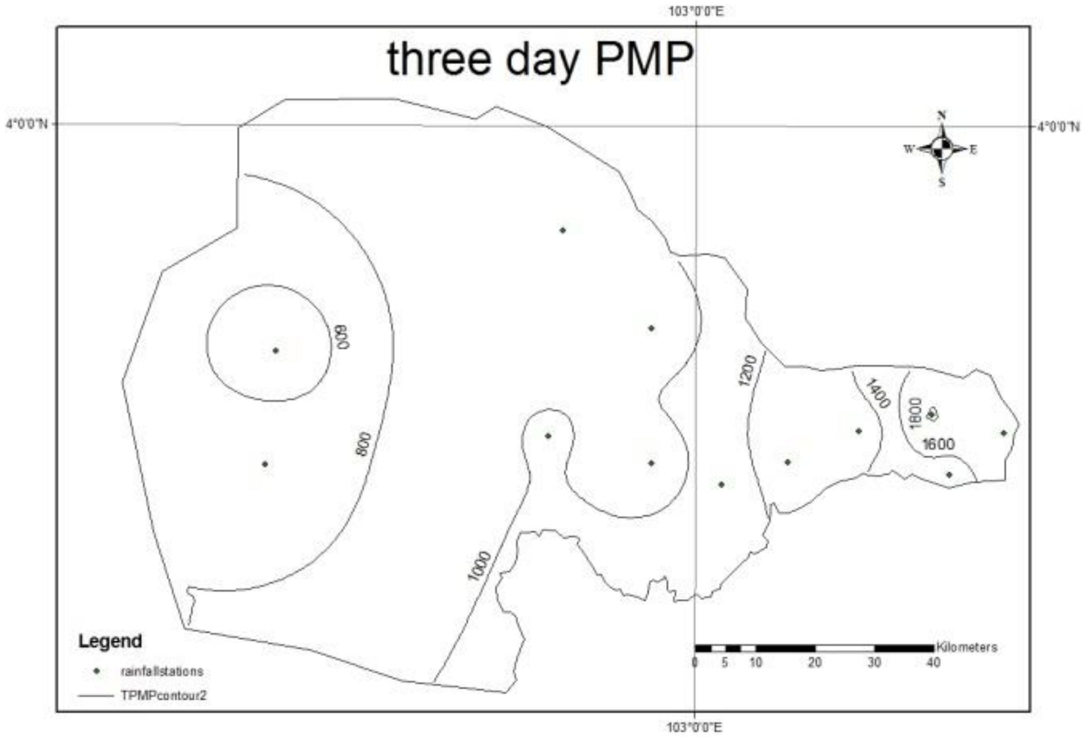


Figure 2-7 Probable Maximum Precipitation of three day rainfall

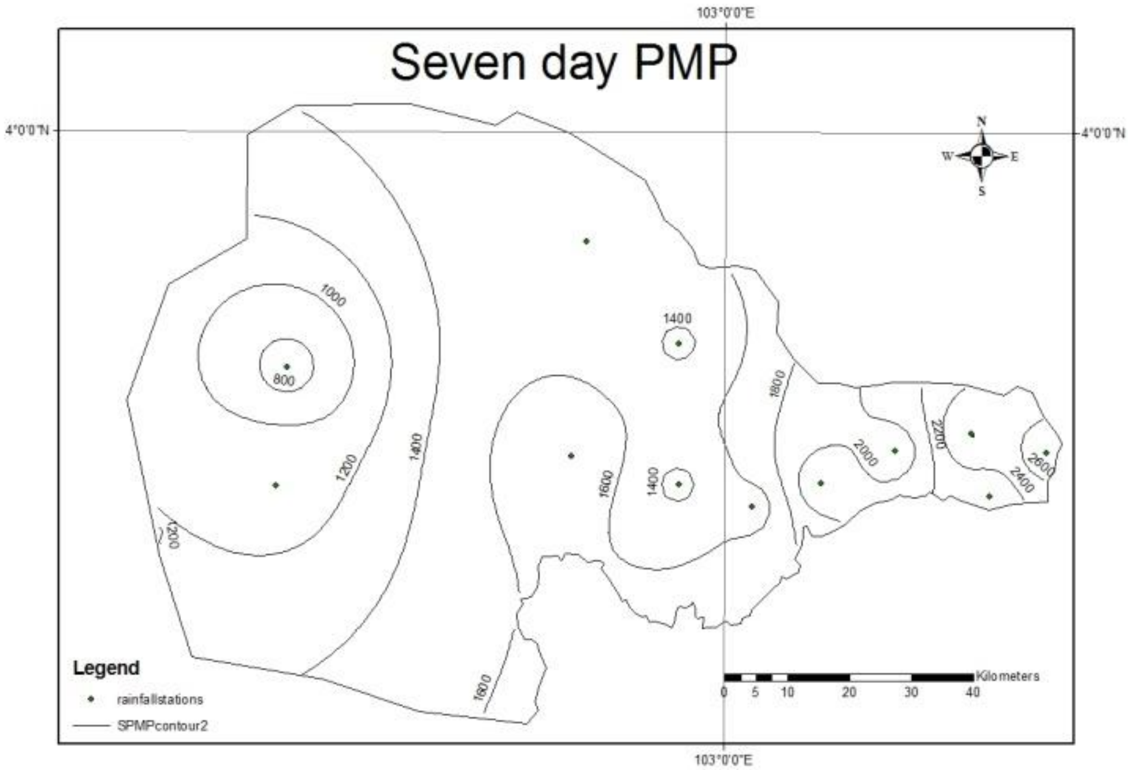


Figure 2-8 Probable maximum precipitation of Seven day Rainfall

2.2.5 Intensity Duration Frequency Curve (IDF)

In many hydrological design projects the first step is to determine the maximum rainfall event. This event is hypothetical, and is usually said to be the design storm event. The most common method of determining the design storm event is using IDF curves which relate rainfall intensity, duration, and frequency (or return period). It also provides a summary of the site's rainfall characteristics by relating storm duration and exceedence probability to rainfall intensity which is assumed to be constant over the duration (time of concentration).

This approach depends on the information required and the data available. It is advisable to use instantaneous rainfall data and time of concentration in minute but due to lack of data, the daily average rainfall is used with time of concentration in day . In this report, the duration of rainfall is one, three, seven, and fourteen day for 1, 2, 5, 10, 20, 40, 100 and 200 years of reoccurrence interval. The IDF curve of the meteorological station which is found at the southeast coast, station number 3533102 is shown in the Figure 2-9 and the IDF curve of other meteorological station can be available in Appendix c

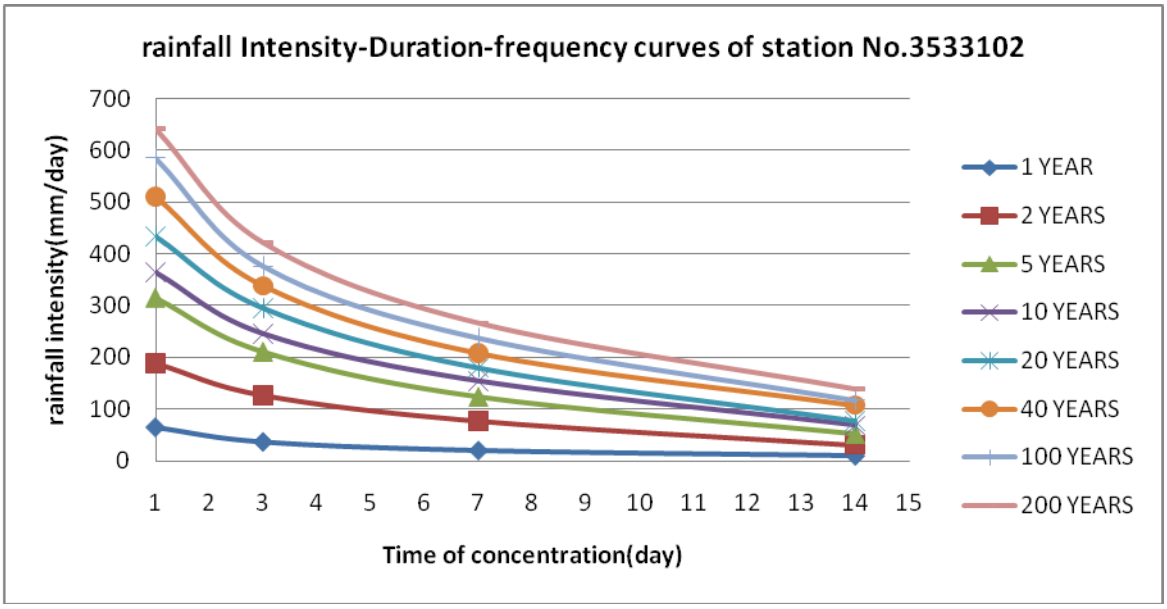


Figure 2-9 Intensity Duration Frequency curve at station No. 3533102, IDF curves for the other stations can be found in Appendix c.

2.3 Principal Component Analysis (PCA)

2.3.1 General Introduction

Principal component analysis (PCA) is a mathematical procedure that transforms a large number of correlated variables into a small number of uncorrelated variables called principal components (modes) and used to simplify the analysis and visualization of multidimensional datasets (Daniel. 2006).

2.3.2 Rotation

Rotation is a method used to further analyze the initial Principal Components and make them more clearer and pronounced (Brown, 2009). There are several rotation methods under the category of Orthogonal (varimax) and Oblique . The result of Principal Component Analysis were rotated using the varimax rotation procedure, since this is the most commonly used rotation procedure (Uvo and Berndtsson, 1996; e.g., Bonell and Summer, 1992).

2.3.3 Motivation for Principal Component Analysis

The topographic complexity of the Pahang river basin and its exposure to the two monsoon winds justify detailed studies concerning spatial rainfall variability. As a result different rainfall regimes coexist in relatively small area. In the context of meteorological data analysis the constraints and interdependency of spatial and temporal data can be identified and redundancy can be eliminated by the use of PCA.

In this study the Principal Component Analysis based on a network including 12 meteorological stations and their 12 mean monthly amounts of rainfall is attempted in order to describe the main patterns governing rainfall in basin. The procedure is applied to a 12×12 intermonth covariance matrix; the unrotated components and two additional solutions deduced after varimax rotation are presented. In case of component scores are computed and their spatial distribution is discussed. Three regionalization of the study area are then obtained and compared in terms of group homogeneity basin on the first two principal components.

2.3.4 The Result of Principal Components Analysis

The first Principal Components which represent 69 % of the total variance having positive value throughout the study area. But as it can be noticed from the Table 2-3 and Figure 2-10 that the area of large first principal component (PC1) values are concentrated over the east of the study area including meteorological station; 3533102, 3431099, 3433105, 3532101, 3534103). On the other hand the areas to the west including meteorological station; 3429096 , 3527092 , 3430097, 3629098 , 3828091, 3423138, 3623078, have lower (PC1) values compared to the east. The second Principal Component which represents 29% of the total variance in Table 2-3 and Figure 2-11 have large value for the meteorological stations to the west than to the east coast. Generally the application of the Principal Component Analysis in the mean monthly values of observed rainfall in the lower Pahang River Basin during the period of 1970-2008, shows that the first two Principal components which represent 98% of the total variance can be used to determine the spatial rainfall variability of the region. The first Principal Component PC1 represents the northeast monsoon rainfall which has high influence on the east coast and high altitude regions around and the second Principal Component PC2 represents low rainfall region.

Table 2-3 The first two Principal Components of mean monthly rainfall value, representing 98% of the variance. Values in bold correspond to the largest principal component for each station.

Meteorological Station	Station Numbers	PCA1	PCA2
Rumah Pam	3533102	**0,823**	0,156
Kg. Salong	3429096	0,334	**0,631**
Lubok Paku	3527092	0,365	**0,627**
Paya Membang	3430097	0,472	**0,496**
Kg.Serambi	3431099	**0,691**	0,302
Permatang Pauh	3433105	**0,818**	0,176
Kg.Temai Hilir	3532101	**0,811**	0,171
Kastam Kuala Pahang	3534103	**0,798**	0,185
Paya Bungor	3629098	0,350	**0,615**
Ladang Ulu Lepar	3828091	0,400	**0,587**
JKR Mentakab	3423138	0,145	**0,667**
Ldg. Sg. Tekal	3623078	0,071	**0,866**

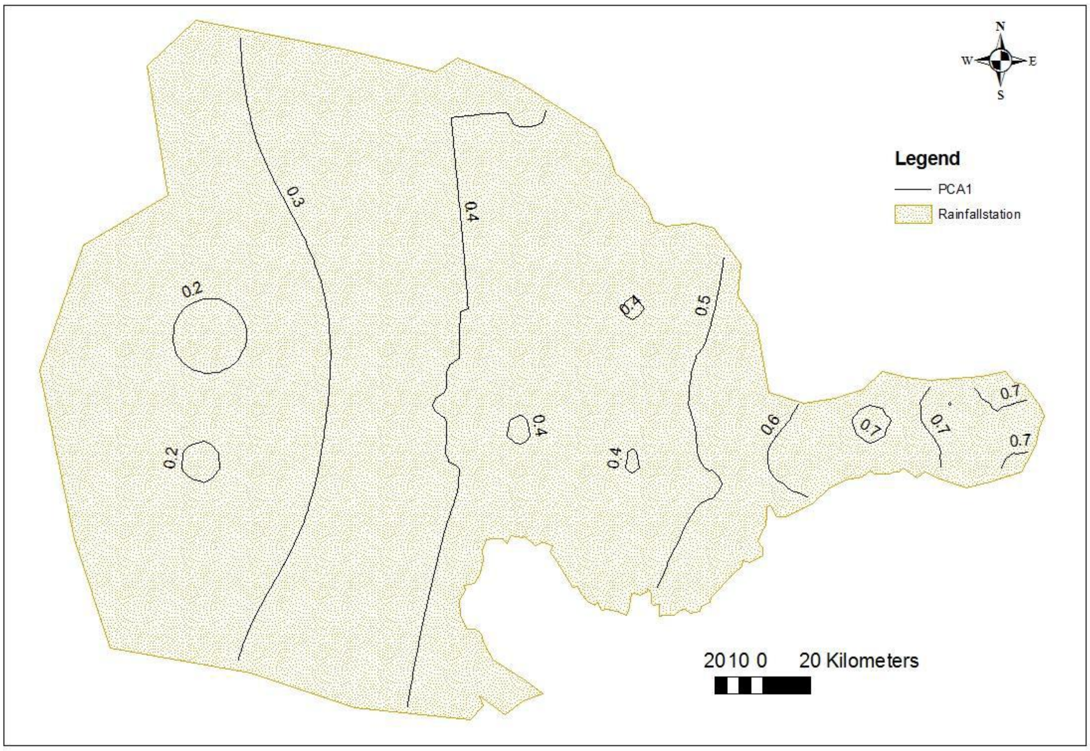


Figure 2-10 The First Principal component, which represents 69% of the total variance.

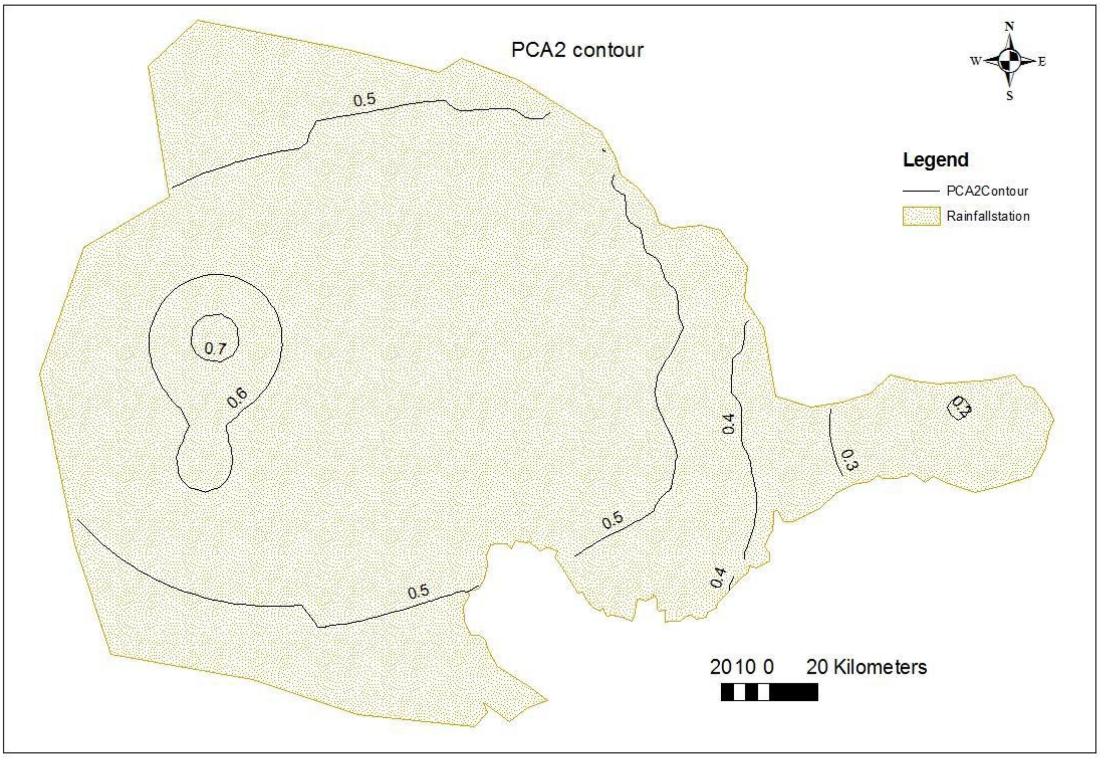


Figure 2-11 The second Principal component, which represents 29% of the total variance.

2.3.5 Homogenous Rainfall Sectors

The objective of interpolation and mapping the first and second Principal Component is in order to determine the homogeneous rainfall regions. Homogenizing the meteorological stations in the study area has been done by using Geographical Information System (GIS) together with the PC values. The result in Figure 2-12 and Figure 2-13 shows that the areas are clustered into three different precipitation groups. The homogenization done using the second Principal Component has revealed more reliable information relating topography with the Northeast monsoons than the first principal component with regard to the conventional rainfall in lowlands.

The first Group A in the Figure 2-13 represents the meteorological stations which are located at the southeast coast of the basin (3533102, 3431099, 3433105, 3532101, 3534103). The average annual precipitation in this area is estimated to be 2500mm. These areas get highest annual rainfall compared with others and categorized to highest rainfall region.

The second Group B in the Figure 2-13 which includes; 3430097, and the mountain regions surrounding the study area. is categorized as medium rainfall region, with average annual rainfall of 2100mm. The third Group C in Figure 2-13 which includes; 3623078, 3423138, 3828091, 3629098, 3527092, 3429096, is categorized as low precipitation region compared with the other two rainfall region. The average annual precipitation in this region is estimated to be 1900mm.

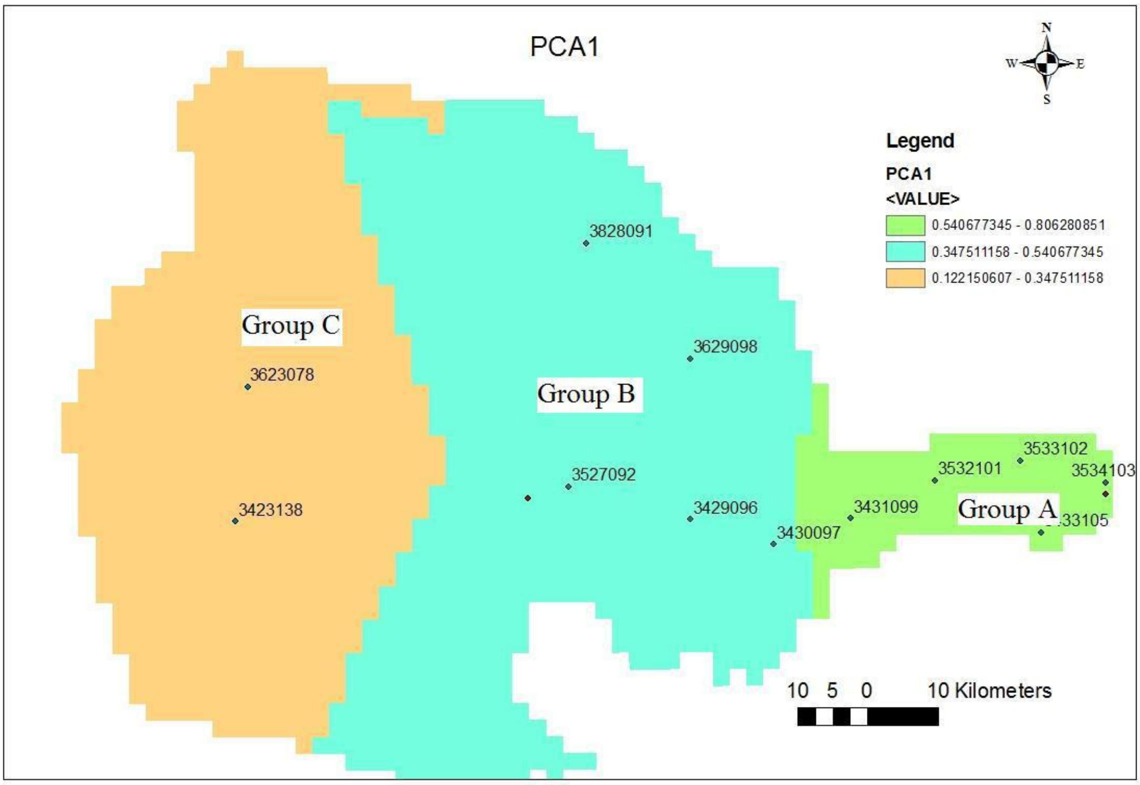


Figure 2-12 Divided homogenous sections using first Principal Components (PC1).

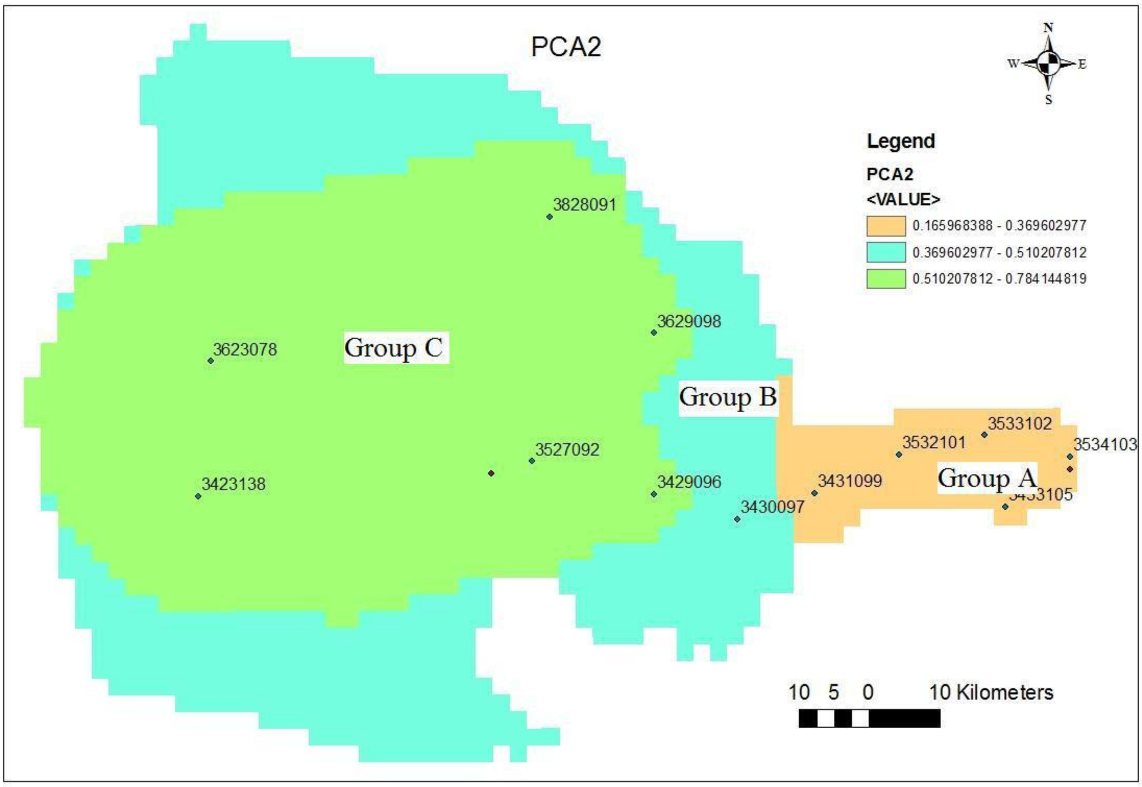


Figure 2-13 Divided homogenous sections using the second Principal Component (PC2)

3. River Discharge data Analysis

3.1 River discharge Analysis

River discharge is the volume of water moving past a cross-section of stream over a set period of time. It is usually measured in cubic meter per second (m^3/s). River discharge is affected by the amount of water within a watershed, it increases with rainfall or snowmelt, and decreases during dry periods (IGOS, 2004).

River discharge is an important component to define the shape, size and course of the river. In a natural river channel, the property of the river flow can be affected by topography of the watershed, soil type, slope of channel, vegetation cover and the like. The quality and quantity of flow can also be affected by human interventions, by altering the landscape cause faster runoff from storm and increased peak flows, due to increased areas of impervious surface which do not let the water to infiltrate into the ground (IGOS 2004).

The catastrophes related to flooding are poorly understood due to the fact that events are a response to the complex hydrological, hydro geological, and topological system that involves the atmosphere, surface, subsurface and the dynamic changes caused by continuous human interventions to nature's processes (Atikah, 2009)

Variation of runoff with time is often studied using flow values for fixed time steps (days, weeks, months, years) rather than for runoff events of non-uniform duration. In the case of major continental rivers, where the passage of flood peaks through the system takes several months, weekly flow values are usually suitable. But for a river basin like Pahang which responds rapidly to precipitation, using the hydrograph of daily values may be appropriate.

In this study, the monthly and annual variation of river flow, the frequency of occurrence of extreme flow events, and yearly flow duration relations will be seen, using 37 years (1972-2008) daily river flow data from five river gauging stations. Three of the gauging stations are on the main bank of the river and two of them are on the two Tributaries Rivers from north and south see Figure 3-1.

Studying the change in river discharge with respect to time helps to understand the impact of change of climate or ground surface on the discharge of the river through time. Unplanned land use and rapid urbanization these days have shown a great impact on change in discharge by altering the rainfall-runoff relationship.

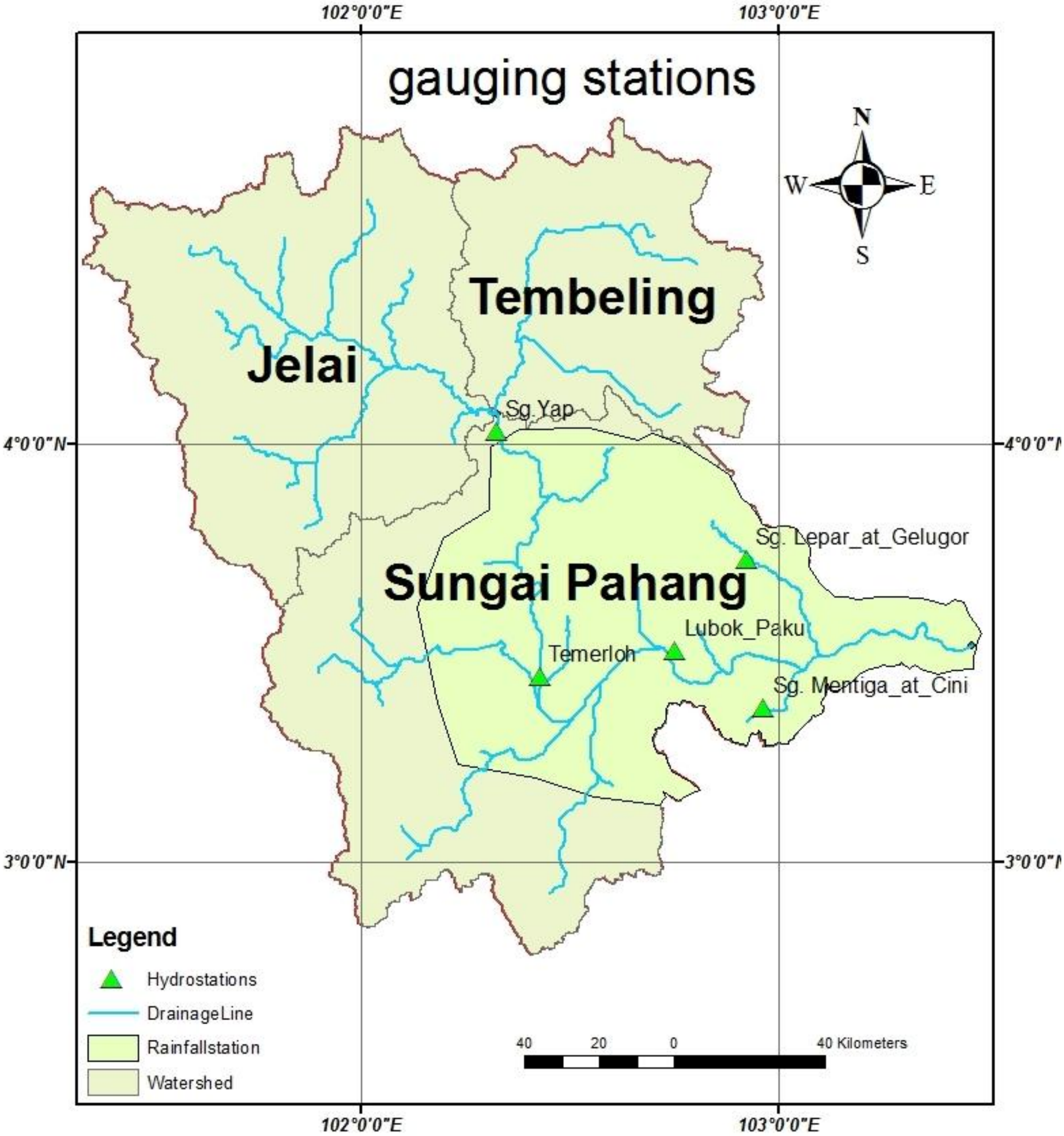


Figure 3-1 The three main watersheds of the Pahang River and locations of gauging stations.

3.2 Mean Monthly River Discharge

Figure 3-2 is the plot of the mean monthly discharge of River Pahang at Lubuk-Paku gauging station for the whole period of recorded. As it can be seen on the figure; October, November, December and January are the months with the highest river discharge records. In the contrary June, July, and August are the months when the river flow is the lowest.

As the Figure 3-2 also reveal that the flow variation of River Pahang mainly depends on the monsoon seasons. Percentage representation of the river flow in a year shows that the discharge of the river during the northeast monsoon season contributes more than half of the annual river flow.

Month	Mean	%
Jan	685.4875	10%
Feb	479.4364	7%
Mar	422.6351	6%
Apr	459.7744	7%
May	551.6391	8%
Jun	416.7762	6%
Jul	330.1505	5%
Aug	317.8353	5%
Sep	412.6042	6%
Oct	639.7014	9%
Nov	950.5995	14%
Dec	1204.388	18%

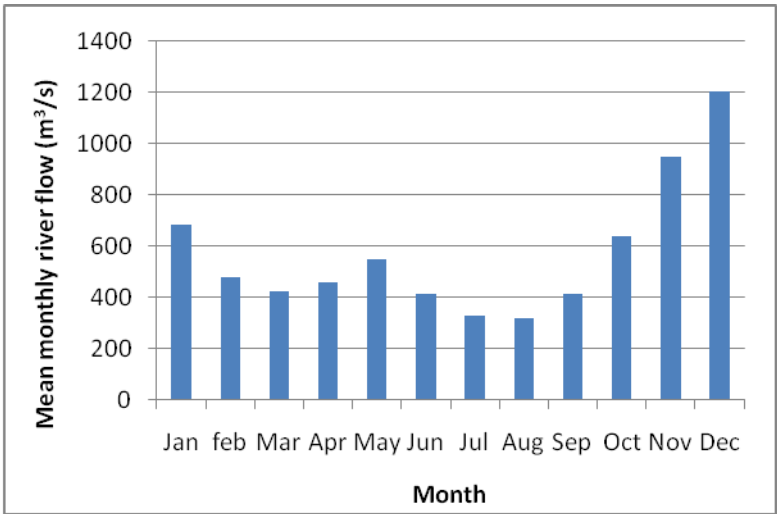


Figure 3-2 The graphs of average monthly flow of River Pahang at Lubuk-Paku gauging station. The graph for the remaining four gauging stations can be seen in Appendix D

3.3 Annual River Discharge Analysis

Mean annual discharge of a river is the average discharge of the river for a number of periods of record. By definition river regimes and expression of seasonal conditions are averaged over many years. Since similar seasonal patterns tend to occur in both wet and dry years, regime graphs may imply a stability of long-term runoff which is misleading (Franchini, 1999). The variability of annual runoff values not only reflects closely the variability of precipitation but is also approximately inversely related to the annual total river discharge (Franchini,199).

Climate change associated with human intervention to nature could result in a potential acceleration of the hydrologic cycle leading to greater frequent increase in extreme events like floods. In addition since monsoon regions are climatically sensitive to seasonal precipitation patterns, annual discharge of the River Pahang and its most extensive tributaries is often related to the monsoon season winds and the ongoing human intervention to the nature.

The mean annual river discharge and the anomalies mean annual flow around the mean discharge of River Pahang for a record period of (1972-2008) at Lubuk-Paku gauging station is presented on Figure 3-3 and Figure 3-4 respectively. The anomalies of mean annual discharge around the mean annual discharge show that there has been consecutive decrease in the river discharge from the mean value for record year of 1976-1983 the Figure 3-4.

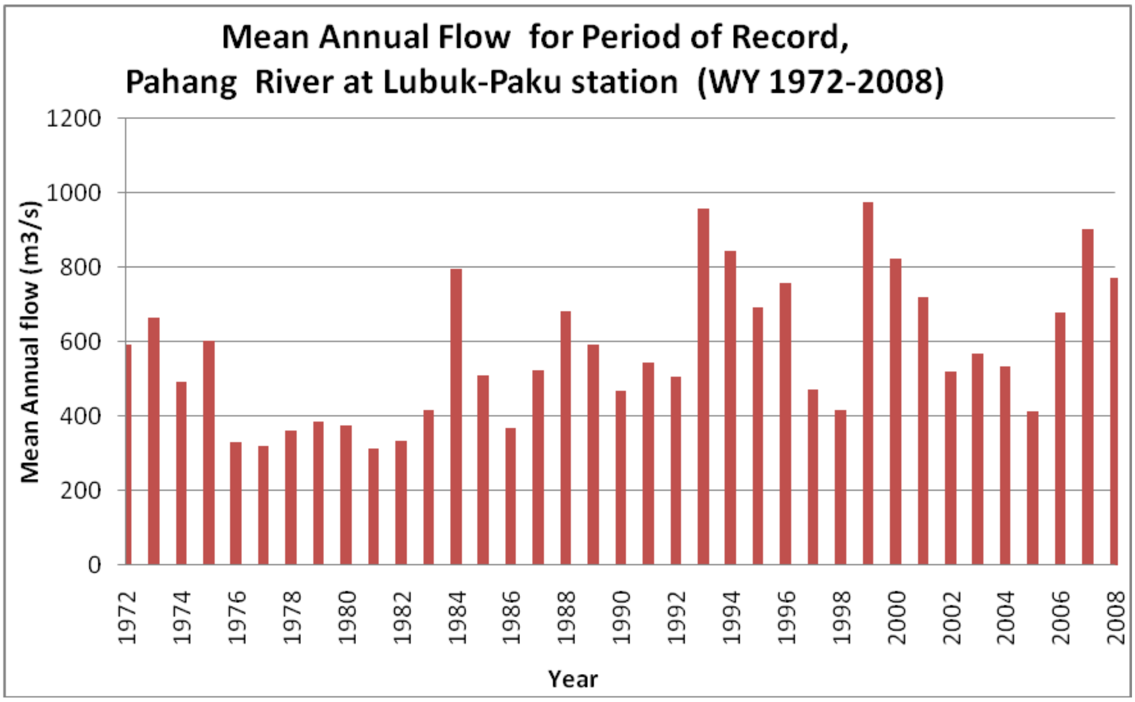


Figure 3-3 Mean Annual Flow of River Pahang at Lubuk-Paku gauging station

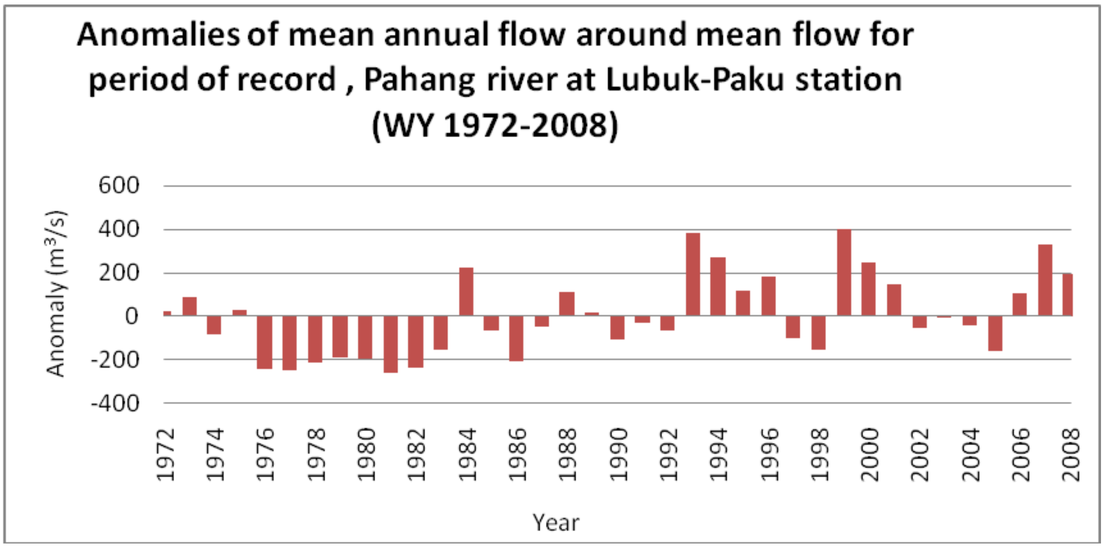


Figure 3-4 Anomalies of mean annual discharge around mean discharge for period of record on Pahang River at Lubuk-Paku gauging station

3.4 Flood Frequency Analysis

It is common to perform a flood frequency analysis for hydrological engineering projects in planning, design and management of structures, which requires detail knowledge of flood characteristics, such as flood peak, flood volume, duration and frequency of occurrences. However flood frequency analysis often focuses on flood peak values and hence provides a limited assessment of flood events.

Flood frequency analyses are used to predict design floods for sites along a river using observed annual peak flow to calculate statistical information. It tells the likely values of discharge to expect in the river at various recurrence intervals based on the available record. It is also helpful when designing structures in or near the river that may be affected by flood.

The flood frequency curve which was fitted mathematically using daily maximum historical data can be used to estimate the probability of exceedence of the runoff events in the future. It is a valuable tool to extrapolate how often a flood of a given discharge will occur. It can be constructed by plotting a graph of discharge versus reoccurrence interval.

Flood frequency distribution can take on many forms according to the equations used to carry out the statistical analysis such as: normal distribution, Log-normal distribution, Gumbel distribution, and Log-Pearson type III distribution. Each distribution can be used to predict design flood; however, there are advantages and disadvantages of each methods. For the flood frequency analysis of River Pahang, in this report Log-Pearson type III method has been used. The Log-Pearson Type III frequency distribution is to fit to the logarithm of annual peak flows and the parameters are estimated by the logarithmic of mean, standard deviation, and skewness coefficient. The advantage of this method is that extrapolation can be made of the values for events with return periods well beyond the observed flood events. The probabilities of floods of various sizes can be extracted from the curve.

The chance of a given discharge being exceeded once in any given year is expressed as probability(Garcia, 1997). Recurrence intervals, or return periods is the average intervals of time, expressed in years, within which the given flood will equaled or exceeded once at a particular location.

Table 3-1 Flood frequency curve calculations using Log-Pearson Analysis type III method for Lubuk-Paku gauging Station.

Flood Frequency Calculations using log-Pearson Analysis III		
(period of record1972-2008)		
Return Period	Skew Coefficient	Discharge
(years)	K(-0.44)	Q(m3/sec)
2	0.004166278	2564.83
5	0.842980301	4036.85
10	1.279059098	5110.35
25	1.742422368	6565.46
50	2.04076594	7714.85
100	2.307864436	8913.57
200	2.552962932	10176.77

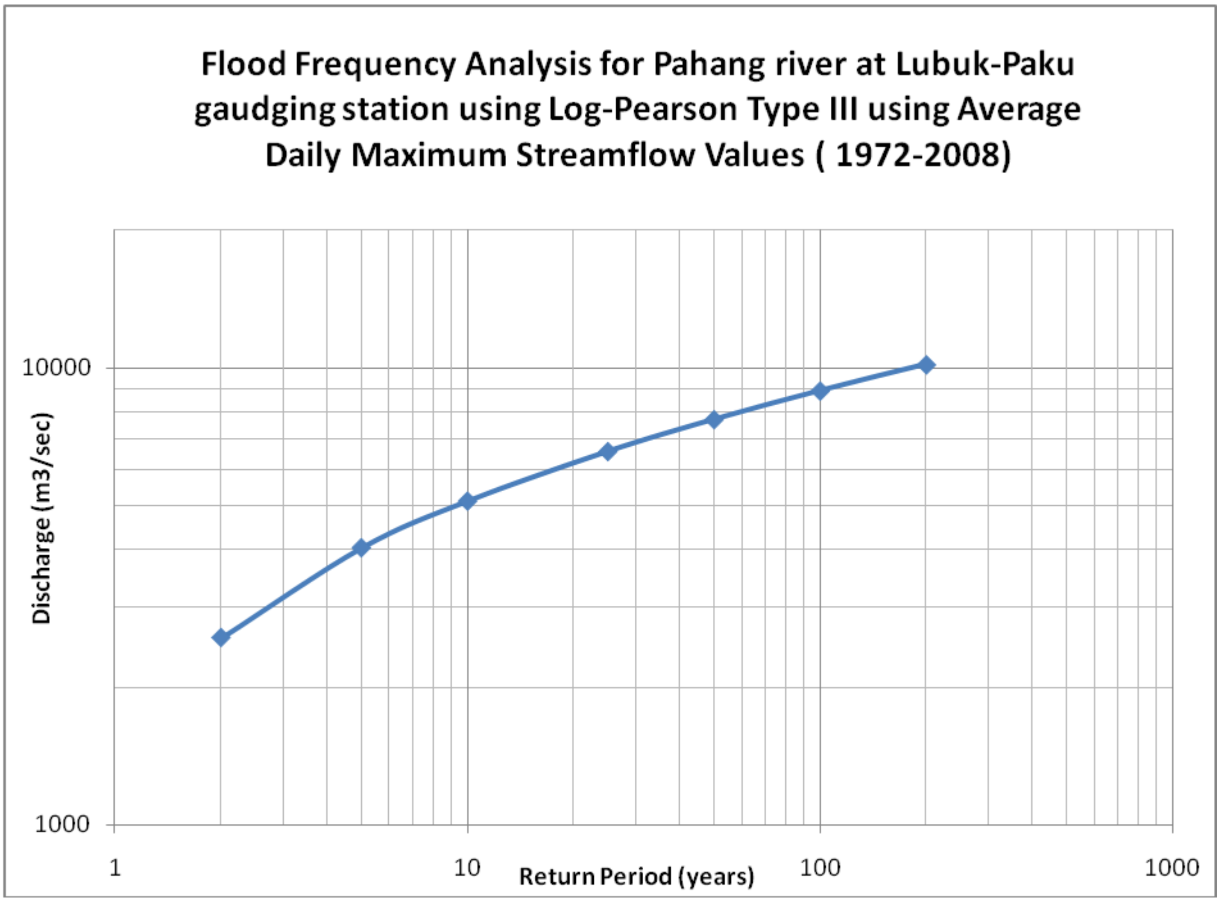


Figure 3-5 The Flood frequency curve of River Pahang at Lubuk-Paku gauging station using log-Pearson type III Appendix F.

Flood frequency values may change either up or down as more data is collected and the method flood frequency is calculated. The greater number of data points is important in assessing the reliability of the flood frequency for those events.

Figure 3-5 and Table 3-1 is the resultant of flood frequency curve for Pahang river at Lubuk-Paku gauging station, which provide "Q" representing the river discharge for the return periods of 2, 5, 10, 25, 50, 100, and 200 years with annual-Exceedence probabilities of 50%, 20%, 10%, 4%, 2%, 1% and 0.5%, for each return periods respectively. For example, flood having a return period of 50 years has a one chance in 50 years or 2% probability of happening in a given 50 years. For River Pahang discharge of 50 years return period at Lubuk-Paku gauging station is 7714m3/s and it has 2% probability to happen in 50 years time, but this does not mean that a discharge of this magnitude will happen only once every 50 years or the occurrence of a flood of a given return period does not affect the probability of such a discharge occurring again.

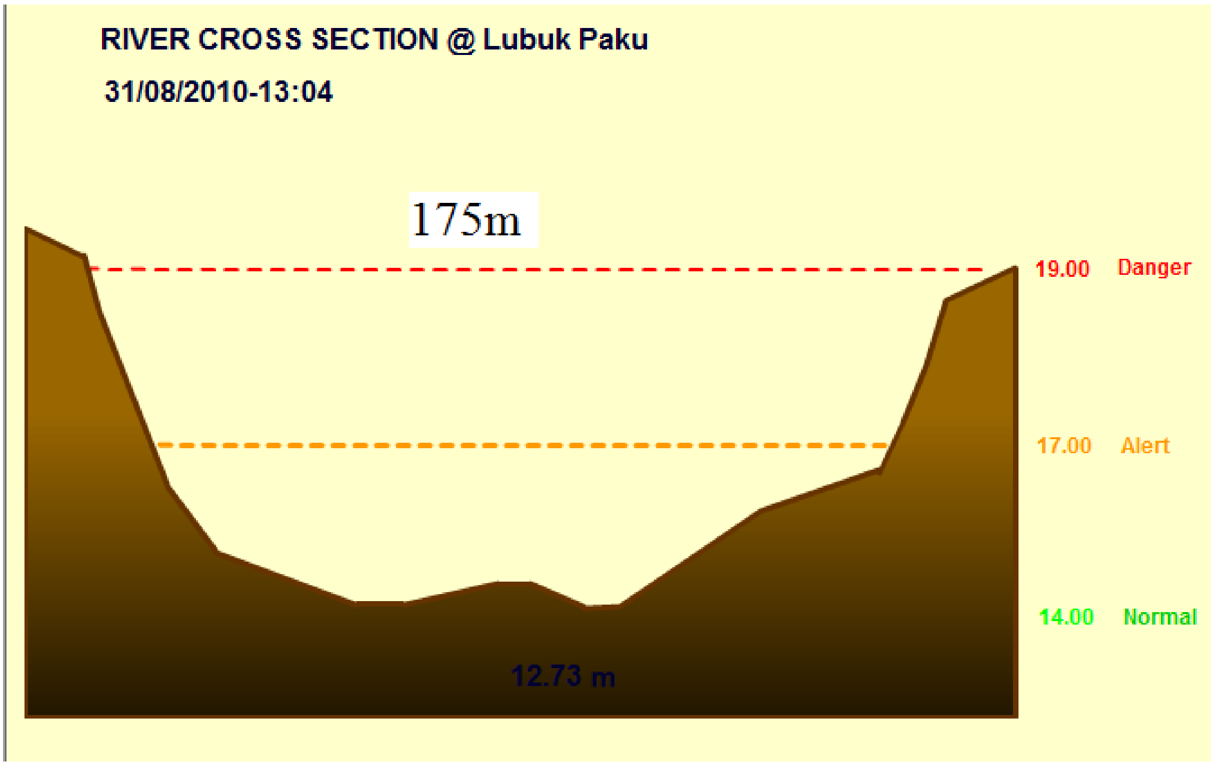


Figure 3-6 The cross section on the river at Lubuk-Paku gauging station (Malaysian Meteorological Department station Id,3527410)

Analyzing the 37 years river discharge data which used for this study with Figure 3-6 the discharge of the river at danger level (19m, Above mean Sea Level), is 4032m3/s. which means the river bank can only pass 4032m3/s. The maximum cross section area of the river at this particular location, Lubuk-Paku, is 860m2. The velocity of water can be calculated by dividing the river discharge for the cross section area and is approximately 5m/s.

Since the probability of the river discharge to exceed 4036m3/s is 20% which means the water level in the river to be more the danger water level is in the figure is 20% (see Figure 3-6). The return period corresponding to this discharge in the Figure 3-5 and Table 3-1 is 5 years therefore is there is a risk of having flood once every 5 years.

The magnitude impact of flooding of course depend on the magnitudes of exceeded discharge. If the magnitude of the river discharge is high the impact will be high too.

3.5 Flow Duration Curve

The flow duration curve provides information about the percentage of time or days that a particular stream flow was exceeded over some historical period. It has long been used as a way of summarizing catchments hydrologic responses, but more recently these curves have been used to validate the output of hydrologic models and compare the observed and modeled hydrologic responses (David, 2004).

In the flow duration curve the shape at the upper and lower regions are the most important parts in evaluating the characteristics of a river. The upper-flow region indicates the type of flow regime that the basin is likely to have flooded, whereas, the lower-flow region characterizes the ability of the basin to sustain low flows during dry seasons.

As it is shown on the flow duration curve for Pahang River plotted in Figure 3-7, the two extreme ends have steep slope bending upward in the case of upper-flow region and bending downward in case of lower-flow region.

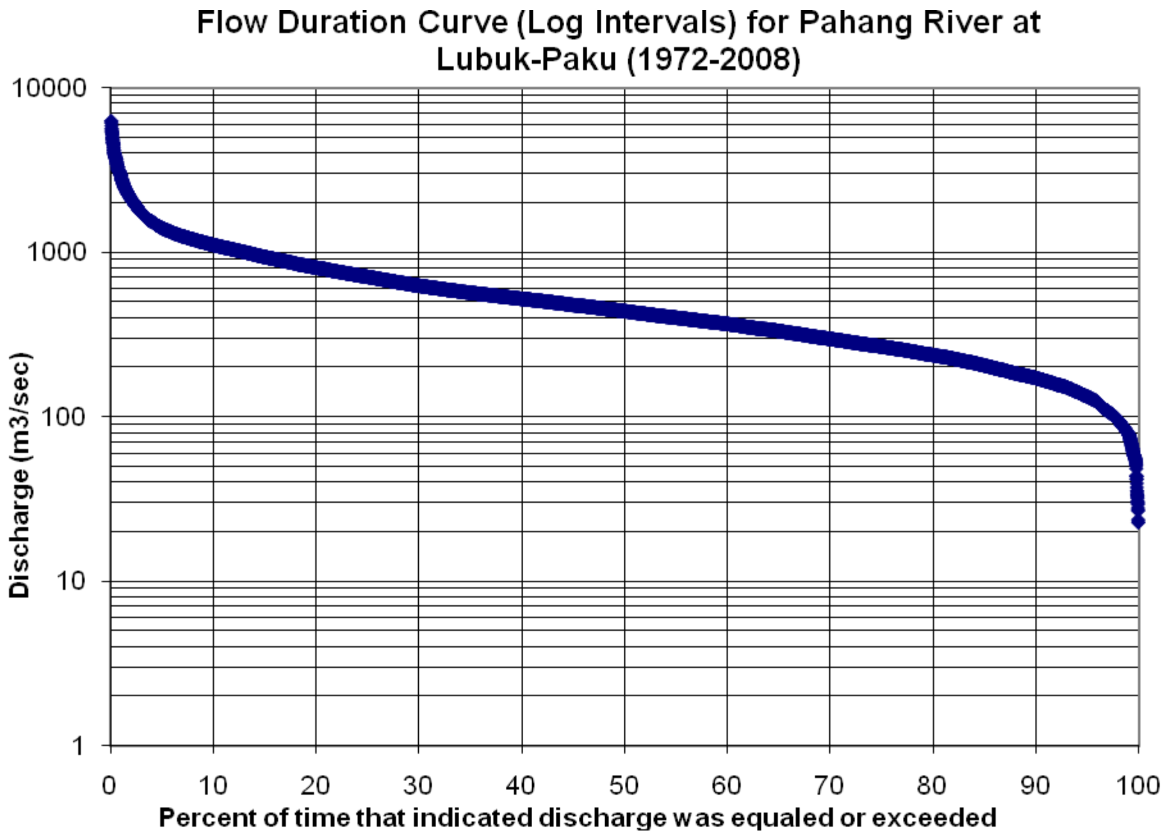


Figure 3-7 Flow duration curve of river Pahang at Lubuk-Paku gauging station and flow duration curve of the other four gauging stations can be seen in Appendix E

Considering the central portion of the graph, by dividing it into two equal parts, taking median-flows (Q50) which is equal to 50% of time as a center, will help to identify the base-flow contribution of the river. At Lubuk-Paku gauging station the median flow is equal to 436m^3/s. Thus part of the curve with flow below the median (Q50%) represents low-flow condition. Base flow is interpreted to be significant, if this part of the curve has low slope, as this reflects continuous discharge to the stream. A steep slope for these base-flows suggests relatively small contributions from natural storage like groundwater and these streams may cease to flow for relatively long periods. In this way the shape of the flood Duration Curve can even indicate the hydro geological characteristics of a watershed (Smakhtin, 2001)

3.6 The Rational Methods to Estimate the Runoff Generated from Ungauged Catchments

Among the existing computation methods and mathematical models for rainfall-runoff modeling, the most widely used method is the Rational Method. This method is relatively simple and applicable to small areas. The rational method uses an empirical linear equation to compute the peak runoff rate for a selected period of uniform rainfall intensity.

In this the study, the main motivation of using Rational Method is used to calculate the runoff that would be generated from the sub-watersheds located at the downstream of the Lubuk-Paku gauging station.

3.6.1 The Rational Method Formula

The rational method with its general assumptions estimates the peak rate of runoff at any location in a catchment as a function of drainage area, runoff coefficient, and rainfall intensity for duration equals to the time of concentration(American Society of Civil Engineering, 1998).

$$Q = CIA \qquad 3-1$$

Where

Q = the peak rate of runoff m^3/s

C = the runoff coefficient, an empirical coefficient representing the relation between the rainfall and runoff.

I = the average intensity of rainfall in (mm/day) for the storm duration equals to time of concentration.

A= drainage area

3.6.1.1 The Intensity of the Rainfall

The intensity (I) is the average rainfall rate in millimeter per minute for the period of maximum rainfall of a given frequency with duration equals to the time of concentration. Time of concentration is the time required for the rainfall water to flow from the most remote point of catchment to the location being analyzed. After time of concentration if has been determined , the rainfall intensity should be obtained. For the Rational Method, the design rainfall intensity averaging should be that occurs for the design year storm with duration equals the time of concentration (Iowa Storm water management manual, 2008).

Usually for Rational Method, the intensity of the rainfall need to be obtained from the intensity Duration Frequency (IDF) Curve, but the IDf curve that was Drawn in subtitle 2.2.5, in this report are using the time of concentration as day. Since the time of concentration cannot be one day for such a small area, empirical formulas have been used to calculate the time of concentration and then intensity of the rainfall. These empirical formulas relate manning's equation with the daily rainfall values.

For overland flow over irregular surfaces the friction factor (manning's value) is an effective roughness coefficient that includes the effects of raindrop impact; channelization of flow into rills; obstacles such as little crop ridges, and rocks, frictional drag over the surface; and erosion and transport of sediment. Although only limited data exist for these factors, enough are available to relate the surface conditions to an unpaved surfaces, these friction factors are significantly different from those traditionally used for channel flow. By relating this manning friction factors with runoff Kerby (1959) found a formula for Time of Concentration :

$$t_c = 0.83\left(\frac{nl}{\sqrt{S}}\right)^{0.47} \qquad (3-2)$$

Where

t_c = Time of concentration (minutes)

n= friction factor (manning's n)

L = middle distance from the top of the catchment to the bottom (ft).

S = slope of the catchment

L is measured straight-line distance from the most distant point to the outlet and is measured parallel to the slope to the point where a well-defined channel is reached.

Table 3-2 The length of reach in meter and feet, the slope catchment, and calculated value of time of concentration.

Stations	Length (m)	Length(ft)	S	tc (min)
Rumah Pam	2219	7281	0.01	28.27
Kg. Salong	13143	43123	0.02	55.42
Lubok Paku	14143	46404	0.02	57.36
Paya Membang	17191	56404	0.02	62.87
Kg.Serambi	2219	7281	0.01	28.27
Permatang Pauh	2219	7281	0.01	28.27
Kg.Temai Hilir	2219	7281	0.01	28.27
Kastam Kuala Pahang	2219	7281	0.01	28.27
Paya Bungor	23239	76246	0.03	65.86

The base of rational method is that a storm has constant intensity of rainfall during a period which is considered to be its time of concentration chosen to determine the runoff (Bengtsson and Niemczynowicz, 1998). Accordingly the intensity of rainfall can be calculated using the time of Concentration.

$$P = 3 * (t_c)^{-0.7} \qquad 3-3$$

Where

P = rainfall intensity (mm/min)

The calculated value of rainfall intensity for each meteorological station will be found in Table 3-4

3.6.1.2 Area of the Catchment

The area of polygon corresponding to each meteorological station can be found from polygon processing in sub-chapter 2.1.4 and Appendix A. The meteorological stations which are located at the southeast coast of the basin, (Kastam-Kuala-Pahang, Ruman-Pam, Kg.Temai-Hilir, Kg.Serambi, and Permatang-Pauh) are situated in one polygon.

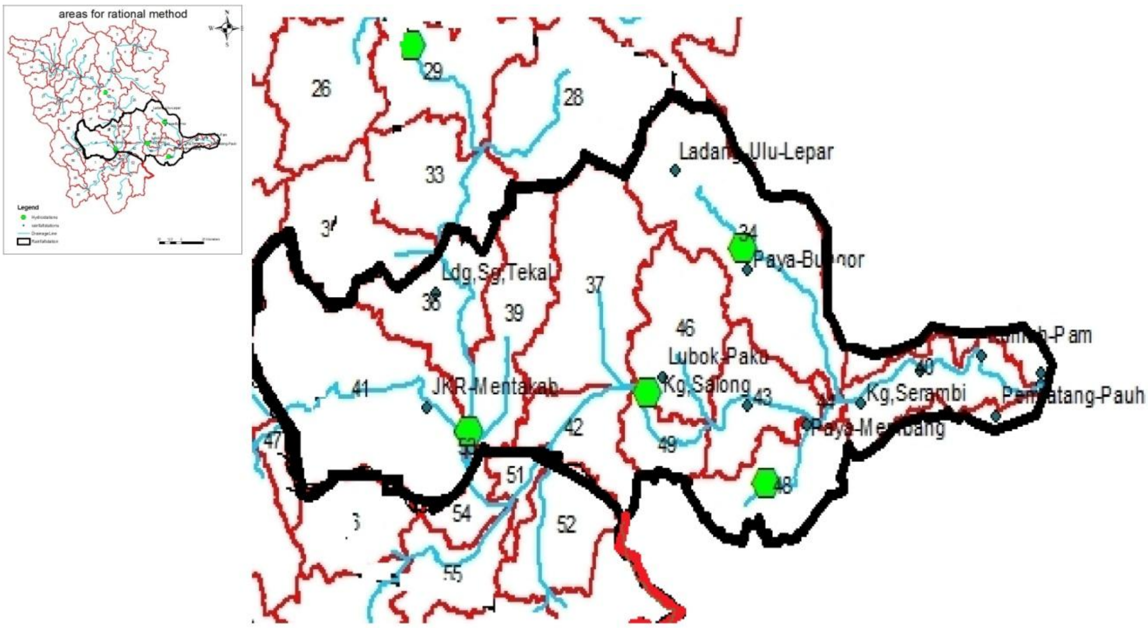


Figure 3-8 The Meteorological stations which are considered in the rational method with their corresponding polygons.

3.6.1.3 The Runoff coefficient

The runoff coefficient represents how large parts of certain surfaces that contribute to the runoff. Higher value of the runoff coefficient C converts more rainfall into runoff. A designer must use judgment to select the appropriate runoff coefficient value within the range for the appropriate land use. Generally, larger area with high permeable soils, flat slopes, and dense vegetation should have low runoff coefficient values and small areas with low permeable soils, steep slopes, and sparse vegetation cover should be assigned the highest runoff coefficient values (American Society of Civil Engineering, 1986). Table 3-3 shows coefficient of runoff values recommended by the American Society of Civil Engineering and Water Pollution Control.

Table 3-3 Runoff coefficient of different type of catchment (AMC, 2010)

Character of surface	**Runoff Coefficient C**
Pavement	
Asphaltic and concrete	0.70-0.95
Brick	0.70-0.85
Roofs	0.75-0.95
Lawns, sandy soil	
Flat, 2 percent	0.05-0.10
Average, 2-7 percent	0.10-0.15
Steep, 7 percent	0.15-0.20
Lawns, heavy soil	
Flat, 2 percent	0.13-0.17
Average, 2-7 percent	0.18-0.22
Steep, 7 percent	0.25-0.35

Table 3-4 The rainfall intensity, the area of polygons corresponding to the stations, the runoff coefficient of each meteorological station used for the computation of rational method and the calculated value of runoff.

Stations	Time of concentration	intensity (mm/min)	coefficient of runoff	areas of polygon(m2)	the runoff (m3/s)
Rumah Pam	28.27	0.289	0.12	75098935	43.435
Kg. Salong	55.42	0.143	0.1	335781702	80.42
Lubok Paku	57.36	0.176	0.12	465683853	164.13
Paya Membang	62.87	0.165	0.12	400625078	132.41
Kg.Serambi	28.27	0.289	0.2	75098935	72.39
Permatang Pauh	28.27	0.289	0.12	75098935	43.43
Kg.Temai Hilir	28.27	0.289	0.15	75098935	54.29
Kastam Kuala Pahang	28.27	0.289	0.13	75098935	47.05
Paya Bungor	65.86	0.160	0.2	509572678	271.74
Total					909.34

4. Flood Routing

4.1 Background

As defined by Mujumdar (2001), flood routing is a mathematical method for predicting the changing magnitude and celerity of a flood wave as it propagates down rivers. Computation of the movement of flood wave along a channel with time and space is called flood routing (Mujumdar, 2001). It takes into account the effects of storage and flow resistance on the flood wave hydrograph shape. The definition sketch Figure 4-1 shows the major change of a discharge hydrograph as a flood wave moves down in a stream.

The stage and discharge curve represent the passage of flood waves of stream depth and discharge respectively. As this wave moves down, the shape of the hydrograph gets modified due to channel storage, resistance of flow in the channel, lateral addition or withdrawal of flows and so on. At the same time, the peak flow will be lowered and the time base is also enlarged. The peak of the outflow hydrograph is reduced due to storage effects and called attenuation and delayed compared to the inflow peak. The time difference between the peak of the inflow and outflow is known as the lag time (travel time).

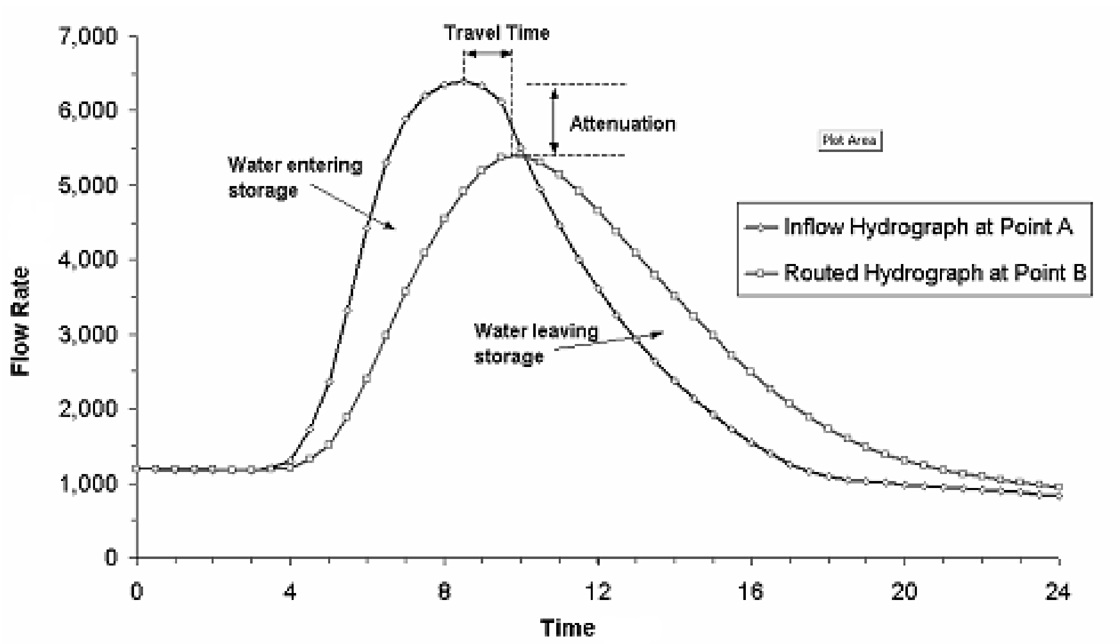


Figure 4-1 Translation and storage processes in stream channel routing (Ponce, 1983)

4.2 Motivation for River Routing Application

Since river discharge data is not available further downstream from the Lubuk-Paku gauging station and since river passes through different physical factors that can affect the magnitude and characteristics of the flow, river routing is needed to estimate the river discharge at any distance downstream of Lubuk-Paku.

The two tributary rivers which join the main river at the downstream of Lubuk-Paku station and the runoff that would be generated from areas along the river will be considered as lateral flow. The runoff generated from areas located in between the Lubuk-Paku and the Pekan were calculated using the rational method in the previous sub-chapter 3.6. In order to take the lateral flow into consideration, a two steps routing has been performed:

1. The first step routing includes estimation of the peak flow from Lubuk-Paku to the points where River Gelugor joins River Pahang. The length of the river channel between the two points is estimated to be 85km.

2. The second step routing performed after adding up the two tributary rivers, (River Gelugor and River Chini), and the runoff generated from the areas in between to the outflow of the first step routing. The length of the reach is estimated to be 71km.

Figure 4-2 The river reach where the two step routing processes have taken place. The red line indicates the first step routing and brown line shows the second step routing

4.3 Routing Method

Flood routing methods are usually classified as either Hydrological Routing or Hydraulic Routing based on the simplifying assumptions used to develop the equations (Brunner, 1989). Brunner (1989) also stated that hydrologic routing methods employ essentially the equation of continuity, on the other hand hydraulic methods of routing use continuity equation along with equation of motion of unsteady flow.

Considering the physical factors that can affect the flow of the river such as morphology of the river, topography of the region, the intensity of rainfall, and vegetation coverage, an appropriate river routing technique has been applied for River Pahang. The most appropriate method for river routing is Muskingum-Cunge Method.

4.3.1 Muskingum-Cunge Method

Muskingum-Cunge method is a physically based and efficient technique often applied to solve flood routing problems in a river. The Muskingum-Cunge method is useful for simulating a large stream network since it can successively calculate the flow rates at all stream-network nodes at a single time without being disturbed by the time differences of flow wave arrivals at each junction of streams. This method attempts to take into account the diffusion of flood wave in channel due to flow resistance and characteristics of the river channel (Brunner, 1989).

The derivation of Muskingum-Cunge method includes the diffusion form of the momentum in addition to the continuity equation.

$$\frac{\partial Q}{\partial t} + \frac{\partial Q}{\partial x} = \mu \frac{\partial^2 Q}{\partial x^2} + Cqlat \qquad (4-1)$$

Where

Q = discharge of the river

t = time

x = distance along the channel

$qlat$ = lateral inflow

C = wave celerity

μ = hydraulic diffusivity

The hydraulic diffusivity is found to be:

$$\mu = \frac{Q}{2S_o} \qquad (4-2)$$

The wave celerity c in the direction of flow:

$$c = \frac{dQ}{dA} \qquad (4-3)$$

$$v_g = \frac{c\Delta x}{2} \qquad (4-4)$$

Equation (4-4) is Grid diffusivity.

The cell Reynolds number is defined as the ratio of hydraulic diffusivity equation (4-2) to grid diffusivity (equation (4-4)).

$$D = \frac{q_o}{S_o\, c\, \Delta x} \qquad (4-5)$$

D = Cell Reynolds number.

Estimating K and X is more physical based and should reflect changes in the models. Equation (4-5) confirms that K is in fact the flood wave travel time, i.e., the time it takes a give discharge to travel the reach length Δx with the Kinematic wave celerity *c*.

$$K = \frac{\Delta x}{c} \qquad (4-6)$$

$$X = \frac{1}{2}\left(1 - \frac{Q}{BS_o c\Delta x}\right) \qquad (4-7)$$

$$X = \left(\frac{1}{2}\right)(1 - D) \qquad (4-8)$$

Where

X = the routing Parameter

Δx = the reach length

q_o = reference discharge per unit width

c = kinetic wave celerity and

S_o = Bottom slope

Equation (4-6) and (4-7) imply that for very small values of Δx, D may be greater than 1, which leads to negative values of X (Ponce, V. M., 1989).

The solution of the Muskingum-Cunge method is accomplished by discretization of the equations on a distance and time plane.

$$O_2 = C_o I_2 + C_1 I_1 + C_2 O_1 \qquad (4-9)$$

$$C_0 = \frac{-1+C+D}{1+C+D} \qquad (4-10)$$

$$C_1 = \frac{1+C-D}{1+C+D} \qquad (4-11)$$

$$C_2 = \frac{1-C+D}{1+C+D} \qquad (4-12)$$

$$C = c\left(\frac{\Delta t}{\Delta x}\right) \qquad (4-13)$$

C is the Courant number equation (4-13), restricted to values less than or equal to 1 for numerical stability reasons. It is the ratio of physical wave celerity βV to grid celerity $\frac{\Delta x}{\Delta t}$ (Ponce, V. M., 1989).

4.3.2 The Input Values for the two Step Routing

Since the main interest for the river routing is to estimate the peak discharge at Pekan, the inflow values for both step routing are different depending on the distance to the downstream.

The inflow for the first step 85km long channel routing is found by summing the peak river discharge from Lubuk-Paku station with the runoff generated from the areas between the Lubuk-Paku station and junction of River Gelugor to River Pahang. The inflow for the second step is the sum of outflow value from the first step routing, runoff generated from the areas along, and discharge of the two tributary rivers.

Table 4-1 The input values for the first and second step routings

description	For the first step routing	For the second step routing
The peak discharge	6400 m^3/s	6506m^3/s
The peak area of flow	2100m^2	2300m^2
The peak with	230m	234m
The time interval	5 hours	5 hours
Length of the reach	85km	71km
Celerity ratio	1.67	1.67
The river bed slope	.0005	.0005

The peak area and peak width are the area and top width of the cross section of the river when the river discharge is at its peak level. The peak areas, the peak width, length of the reach and the river bed slope are measured using Google Earth, and Geographical Information System (GIS).

4.4 Results

The result routing of the second step flood routing shows the inflow hydrograph has attenuated from 6507m3/s to 6388m3/s at Pekan. This change in peak discharge from the inflow hydrograph to the outflow is due to the routing process of river channel. The peak outflow hydrograph lagged one day after the peak of inflow hydrograph see Figure 4-3 and Figure 4-4.

Finally the peak discharge at the river end can be found by summing the outflow of the second routing value 6388m^3/s together with the runoff value that would be generated from the areas near the river calculated by rational method which is estimated to be 6757m^3/s.

Table 4-2The result of the first and second steps routings

	For the first step routing	For the second step routing
The average velocity $V = Q_p/A_p$	3.05m/s.	2.8m/s.
The wave celerity $c = \beta V$	5.1m/s.	4.7m/s.
The flow per unit width $q_o = \frac{Q_p}{A_p}$	$6.4\,\frac{m^2}{s}$	$5.3\,\frac{m^2}{s}$
The courant number is (C)	0.97	0.95
cell Reynolds number D routing coefficients $C_0,\ C_1, and\ C_2$	0.49 0.2, 0.59, and 0.21	0.49 0.2, 0.6, and 0.2

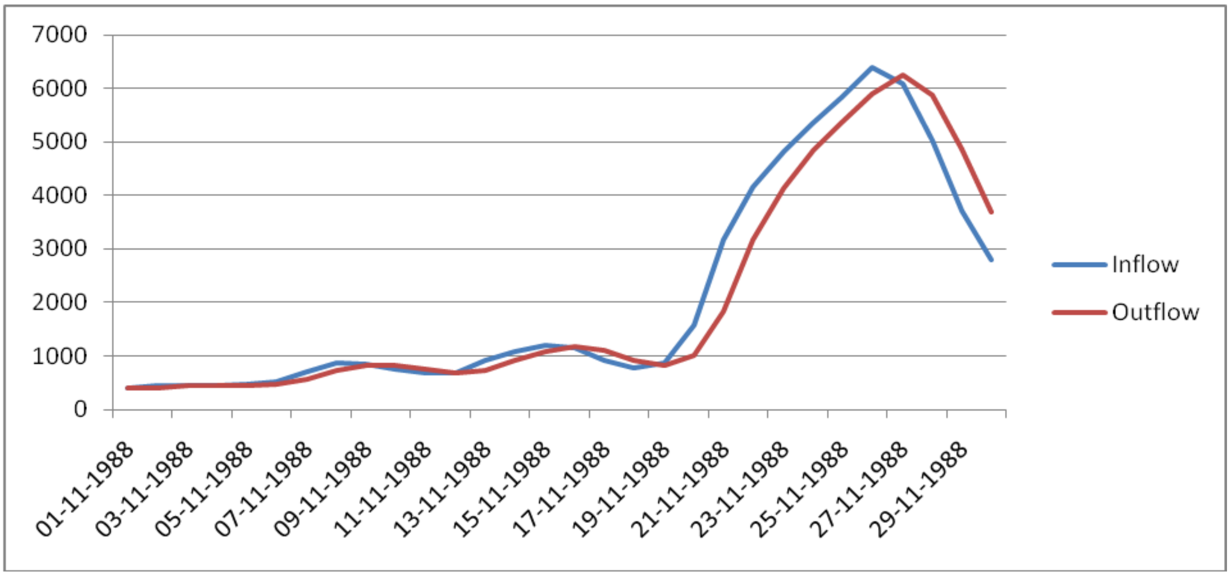


Figure 4-3 The result of flood wave routing in the Pahang River reach from Lubuk-Paku gauging station to the junction River Gelugor of the main river.

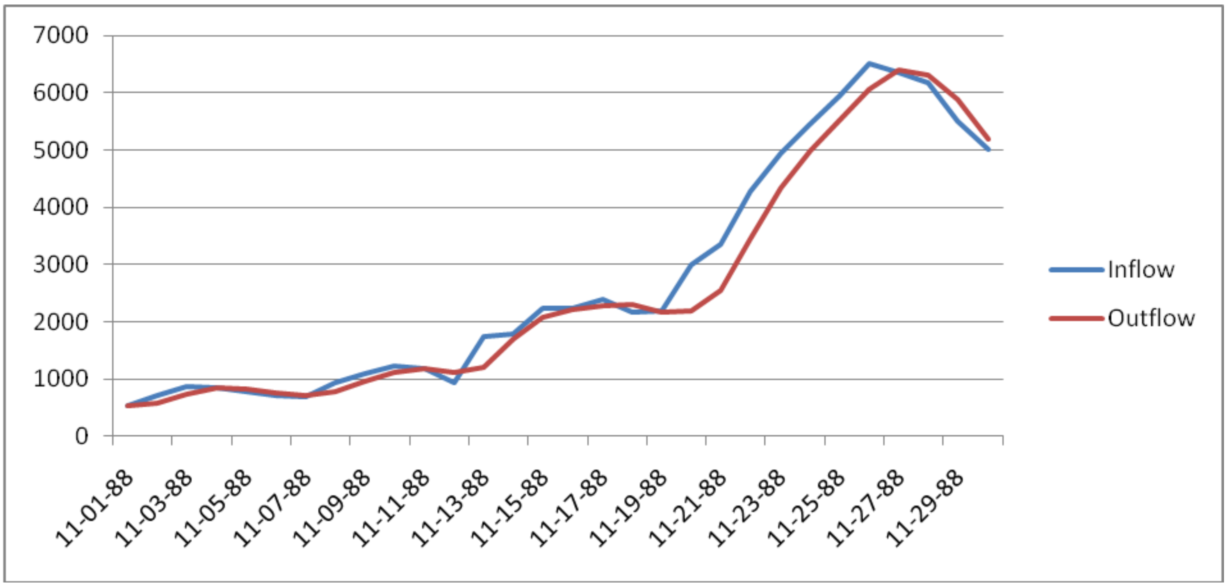


Figure 4-4 The result of flood wave routing in the Pahang River reach from the junction of River Gelugor to Pekan. The distance between thus two points is 71km.

5. Hydrodynamic Effect of wave from South China Sea

In this chapter the wave height data at the river entrance will be analyzed using the appropriate method to calculate the increase in water depth due to the wave setup. The increase in water level at the outer bank when the flood wave passes through the curve channel will be included too. As it is shown in Figure 5-5 the royal town Pekan is located at the place where the river passes curved channel.

5.1 Data collection

The scarcity of sea surface data has been a severe limitation for coastal and ocean engineering activities. Wave data collected over long span of time will provide a more reliable climatology for efficient off-shore studies (Patrick, C., 2005).

Hourly wave height data has been downloaded from the Joint Archive of Sea Level (JASL) website (available at: http://uhslc.soest.hawaii.edu/uhslc/htmld/d0322A.html). JASL continued to acquire quality control, manage, and distribute sea level data as initiated by the Tropical Ocean Global Atmosphere (TOGA) program. The station is located quite close to the river Mouth of Pahang at Kuantan, at 3058.5'N latitude and 103025.8'E Longitude. The wave height is referred to the Zero point assigned to the tide gauge.

Since the data source does not indicate the direction of the wave, it was estimated based on the characteristics of wind direction during the monsoon seasons. Due to the geographical location, northeast monsoon has substantial influence on the southeast coast of the basin. Northeast monsoons have a dominant westward component (Lihan et al., 2010) so the direction of wave is assumed to be westward towards the land mass.

Figure 5-1 shows the average monthly wave height at the station located close to the river mouth. It shows that the wave in the sea is influenced by the northeast monsoon wind, which lasts from October to February. During northeast monsoon season the wave height is usually higher compared to other months.

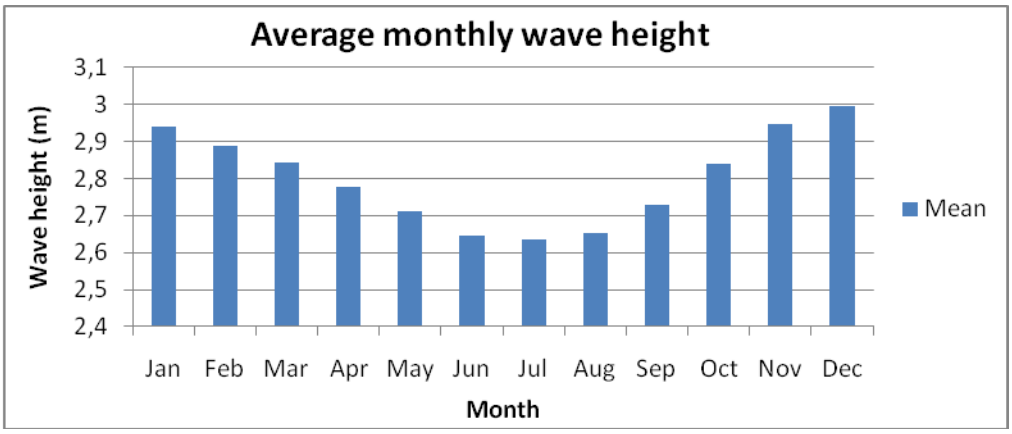


Figure 5-1 Average monthly wave height (Data collected from JASL)

5.2 Wave Setup at the River Entrance

Wave setup is the additional water level that within the surf zone due to the transfer of wave-related momentum to the water column during wave-breaking (Robert and Todd, 2003). Upon breaking, the wave energy is dissipated by the flow of the river, as is evident from the turbulence generated; however, momentum is never dissipated but rather is transferred to the water column resulting in change of a slope of the water surface to balance the onshore component of the flux of momentum (Robert and Todd, 2003). Wave setup is the height of Mean Water Level (MWL) above Still Water Level (SWL) (Robert and Todd, 2003). Still water level (SWL) is defined as the water level in the absence of wave effects. Whereas wave setup will cause a departure from the still water level and this water level including the effects of the waves is called the Mean Water Level (MWL) (Xuan,and Hisao, 2007). At the upper right in the Figure 5-2 shows the wave setup at the river mouth of River Pahang.

This deals with the wave setup at the entrance of River Pahang into South China Sea and presents preliminary recommendations for design. Calculating the wave setup helps to understand the increase in water level at the entrance of the river into the sea due to the transfer of wave-related momentum to the river water column during wave-breaking. But the effect of increase in the river water level at the river entrance will propagate back to the upstream until the water level equals its normal water level, which will be discussed under the next sub-topic gradually varied flow.

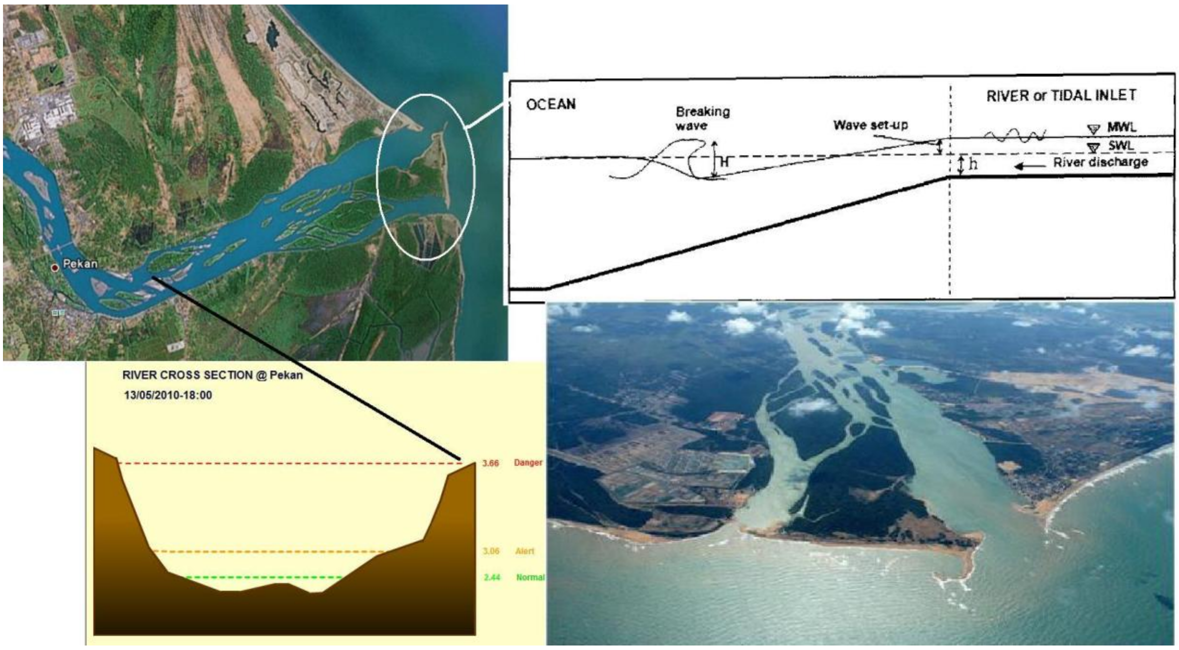


Figure 5-2 Definition sketch of the wave setup at a river mouth and river cross section (Google earth, Hitoshi, T., and Nguyen, X. T., 2008)

5.2.1 Data Collection

In order to investigate the wave setup the requirement data sets are wave height in deep water, tidal level and river water at the upstream, and discharge of the river at the time of typhoon.

Because of complex hydrodynamic conditions in front of the river mouth, thus the water depth was temporal and spatial changed. The latest cross-section for the river Pahang estimated to be 3.66m. As of the data recorded by (JASL) , the maximum wave height for South China Sea was 5.72m. The maximum river discharge at the river mouth after considering the routed outflow value together with the lateral flow the runoff generated from the areas along the river is 6757m3/s.

5.2.2 The Wave Setup Calculation

Xuan and Todd (2003) in their study of wave setup concluded that wave setup rise at river entrance not only dependent on the offshore depth, but also on river discharge and the morphology of the river mouth. They also estimated the wave setup value for a river with water levels between 1 to 6m to be 10 to 14 percent of the maximum wave height. Accordingly the wave setup at the entrance of River Pahang to the South China Sea can be calculated by taking the maximum wave height value from the data recorded by JASL which is 5.72m and multiply it by 0.14.

Accordingly the maximum wave setup at the entrance of River Pahang to the South China Sea can be calculated by taking the wave height value of 5.72m and multiply it by 0.14.

$$H_w = 5.72m$$

$$Wave\ setup = 14\%\ of\ 5.72 = 0.8m$$

The river water level at the river mouth will increase by a maximum of 0.8m due to the wave setup, and the maximum water level at the river mouth will be the sum of wave setup and the maximum river level which will be 4.5m.

In calculating the wave setup sea wave it would be important to global mean sea level rise take into consideration, since recent studies show that global mean sea level has been rising and there is high expectation that the rate of rise has increased. In the recent year the average rate of rise 3.1mm ± 0.7mm for 1993 to 2003 (Church and White, 2006).

5.3 Gradually Varied Flow Equations

Gradually varied unsteady flow occurs when the flow variables such as the flow depth and velocity do not change rapidly in time and space. Such flows are common in rivers during floods (Murty, 2001). The flow is classified as gradually varied flow when the change of the fluid depth along the channel dy/dx much less than one.

In this study the propagation of increase in water level to the upstream in the river due to wave setup at the river entrance has been calculated using Gradually varied flow equation.

Gradually varied flow equation involves expenditure of energy where the potential energy of the water due to position and force of gravity is converted into kinetic energy of motion. The energy equation expresses the relationship between the elevation head, velocity head and energy dissipation required to move water. Energy equation and Manning equation were used to calculate the water surface profiles and average velocity of flow.

Applying energy equation over a small distance in the control volume ΔX

The total energy is the summation of the water depth *y* and the velocity head $\frac{v^2}{2g}$

$$E = y + \frac{v^2}{2\,g} \qquad (5-1)$$

By differentiating the total energy for a small distance gives the difference of the bed slope S_o to frictional slope S_f

$$\frac{dE}{dx} = S_o - S_f \qquad (5-2)$$

$$\frac{d\left(y+\frac{v^2}{2g}\right)}{dx} = S_o - S_f \qquad (5-3)$$

The head loss for a specified reach is equal to the head loss in the reach for uniform flow having the same hydraulic radius and average velocity or in terms of manning equation.

$$S_f = \frac{n^2 v^2}{\emptyset^2 R^{\frac{4}{3}}} \qquad (5-4)$$

Change in energy for small section ΔX is

$$\Delta\left(y + \frac{v^2}{2g}\right) = (S_o - S_f)\Delta X \qquad (5-5)$$

$$\Delta X = \frac{\Delta\left(y+\frac{v^2}{2g}\right)}{S_O - \left(\frac{n^2 v^2}{R^{\frac{4}{3}}}\right)} \qquad (5-6)$$

$$\Delta X = \frac{\left(y_2+\frac{{v_2}^2}{2g}\right)-\left(y_1+\frac{{v_1}^2}{2g}\right)}{S_O - \left(\frac{n^2 v^2}{R^{\frac{4}{3}}}\right)} \qquad (5-7)$$

Where

ΔX = is a change in distance of a small section

$y_1 + \frac{v_1^2}{2g}$ = the total head at the upstream

$y_2 + \frac{v_2^2}{2g}$ = the total head at the river mouth

S_o = the bed slope of the channel

E = is the total head

n = is the manning constant of the river channel

R = is the hydraulic radius of the channel

S_f = head loss

Table 5-1 The input values for gradually varied flow.

Descriptions	Values
The Maximum river discharge Qmax	6757 m^3/s
The bottom width	800m
The Manning's Coefficient "n"	0.025
The side slope of channel	0.1
The river bed slope	.0005
The river depth at the upstream "Y1"	2.58m
The specified flow depth at the downstream boundary "Y2"	3.66+0.8= 4.5m
The number of computation interval	100

5.3.1 Result of gradually varied flow

In working with gradually varied flow, the first step is to determine the general characteristics of the water surface and what type of backwater curve would exist. The second step is to perform the numerical computations to determine the elevation of the water surface or depth of flow. In case of this study the type of backwater curve is M_1 Profile, since the actual depth of water is greater than the normal depth and the critical depth. The normal depth is calculated based on the geometric and hydraulic input data, Newton's iteration is used to solve the non-linear equation.

The calculated gradually varied flow values shows the water level at the upstream will increase approximately by 0.5m due to wave setup at the river entrance. Y2 which is the river depth at the river mouth is 4.5m and which is the sum of the river depth at the river mouth and the wave setup. The step by step increase in water level due to the wave setup is can be seen in Appendix G.

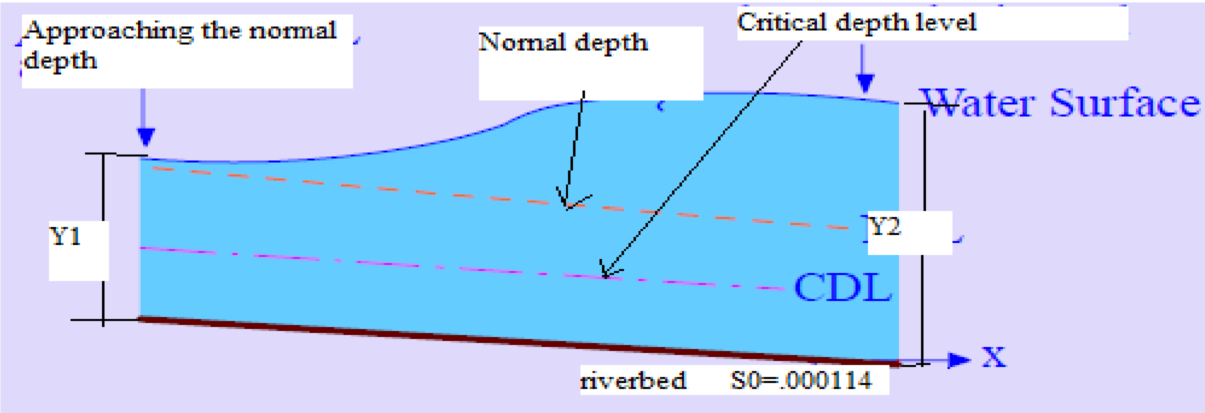


Figure 5-3 Sketch of M1 profile, due to the wave blocking the river water from discharging (Murty, 2001)

The computation depth interval Δy = .0057m

The normal depth Yn= 3.85m and Normal-depth Froude number Fn= 0.356

The mean flow depth increases with distance X on the upstream side until Y approaches the normal depth. The sketch of an M_1profile is shown in Figure 5-3.

As the result of gradually varied flow demonstrates that the water level in the river will exceeds the dangerous water level of 3.66m amsl, which is indicated on Figure 5-4 by 0.5m. Which means the water above the dangerous water level will all spill out to the areas around and cause flooding.

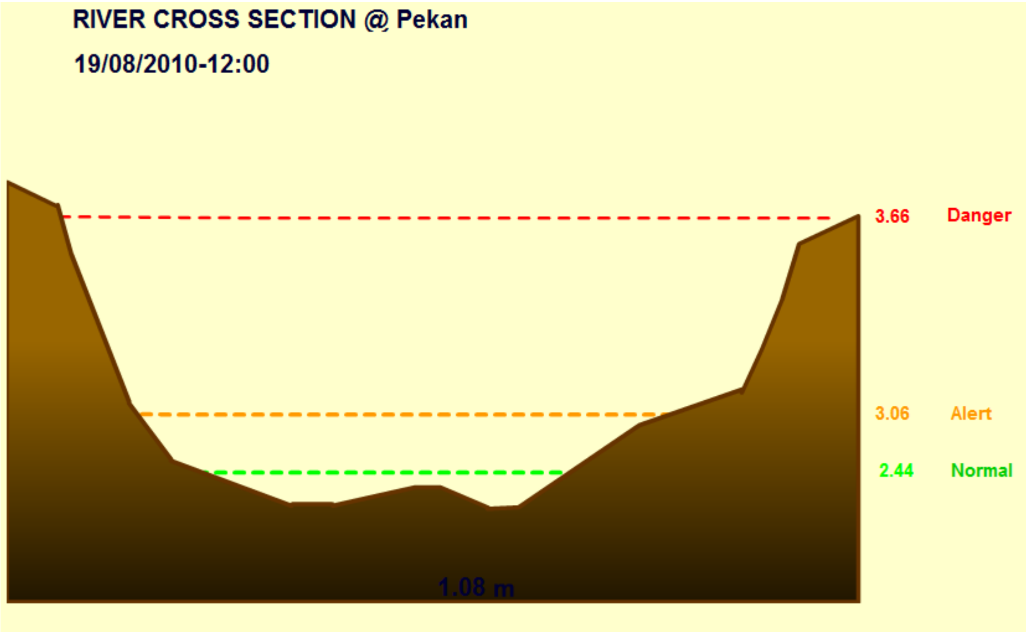


Figure 5-4 the normal, alert , and dangerous water level of the river Pahang at Pekan(malaysian Meteorological Department).

Since the effects of vegetation have been shown to result to reduce the propagation of wave into the river column, planting tree in the river bank will reduce the effect of wave. For linear waves, vegetation protruded in the river bank through the water surface experiences a net drag force which is quadratic related to velocity of flow on the vegetation in the direction of wave propagation. And of course, there must be an equal and opposing force exerted on the water column. This opposing force acting on the water column partially counteracts the force due to momentum transfer and thus reduces the sea wave from propagating to the upstream.

5.4 The River Flow at the Curved Channel

When a river flows through a curved channel, a rise in the water surface occurs at the outer bank with a corresponding lowering of the water surface at inner bank. Centrifugal motion forces fluid to super elevate on the outside bank of the river. In the design of a channel, it is important that this difference in water levels are estimated (French. R, 1985). At the curve shown in the Figure 5-5 a stable design of cross section width, depth, and slope based on analytical equations of flow resistance and assuming flow continuity is indeterminate.

The meander form and related geometry is generated and maintained by a spiral motion of the river water through the bends. At a curved channel the velocity of flow at the outer bank is faster than the velocity of flow at the inner bank. From this general relation and Reynolds's number which depends on the flow speed, it can be projected that erosion from the outer bank and deposition at the inner bank due to the spiral motion of the river water through the bends.

During high flow period it is apparent that the velocity of the flow will be higher than normal time. And the flow velocity at the outer bank is faster than the inner bank which increases the momentum of the water and simultaneously increases the water level at the outer bank more than at the inner bank.

Figure 5-5 The flow of River Pahang at the curve nearby Pekan (Google earth)

If all the flow is assumed to move around the curve at the subcritical average velocity$V$, then

$$\Delta h = \frac{V^2 b}{gR} \qquad (5-8)$$

$\Delta h =$ Change in water surface elevation across channel

$b =$ Channel width

R = distance from center of curve to centerline of channel

If Newton's second law of motion is applied to each streamline of the flow as it passes around the curve, then it is possible to demonstrate that the transverse water surface profile is a logarithmic curve of the form

$$\Delta h = 2.3\frac{V^2}{g}\, log\frac{R_o}{R_i} \qquad (5-9)$$

Where R_o and R_i are the outer and inner radii of curve. Assumed the velocity of flow is zero at the river banks and maximum at the center line of the curving channel. Between the sides and the center, the velocity varied according to a parabolic curve.

In case of Pahang river, as the water passes through the curve which is seen on the Figure 5-5 at a particular location during flooding the rise of water level at the outer bank need to be taken into consideration.

Flood wave velocity during extreme peak

$V = 3.56m/sec$

$R_o = 3000m.$

$R_i = 2000m.$

$$\Delta h = 2.3\frac{3.557^2}{9.81}\, log\frac{3000}{2000} \qquad (5-10)$$

$\Delta h = 0.523m.$

The depth of the river at the outer bank will increase by approximately 0.5m.

6. Discussion , Conclusion , and Recommendation

6.1 Discussion

Due to the topographic complexity together with the two monsoon seasons the spatial and temporal variability of rainfall is difficult to estimate the in Pahang river basin. The result of principal component analysis indicated that the first principal Component (PC1) is more related to the northeast monsoon season. The south-east coast of the basin and the highlands surrounding the whole basin receive large amount of rainfall than the lowlands. These highland areas also have more potential to convert rainfall into runoff because of their steep slope.

Analysis of river discharge records for the River Pahang at the three gauging station which is situated in the main bank of the river also indicated that the increase in discharge of the river is mainly associated with the rainfall on the highlands than the lowlands. The probability of the river discharge the exceed the maximum discharge that the river bank can pass safely 20%. Which means the area might be flooded once in 5 years.

The wave breaking at the entrance of the river increases the water level of the river. The increase in water level in the river column also propagates back to the upstream and increase the depth of river gradually up to distance back. As of the analysis result the water level in the river will increase by 0.5m up to 9km back to the upstream beyond the dangerous water level, 3.66m above mean sea level, which is shown in Figure 5-4. Which means the water above this level will spill out of the bank and can cause flooding in the areas along.

As it can be seen on Figure 5-5, Pekan city is located along the river, and the river channel at that particular location is curved which makes the city vulnerable to flooding. It was estimated in this work that the water level at the outer bank will rise by approximately 0.5m.

6.2 Conclusion

More meteorological and river gauging stations are needed to be established and more studies need to be done concerning rainfall-runoff relationships on the highlands to identify the areas which contribute highest runoff and increase the river discharge.

As of the flood frequency analysis, there is 20% probability of the river to exceed its the maximum river discharge that the river bank can pass safely (4032m^3/s) at Lubuk-Paku Gauging station, the areas downstream of this station are at risk of being flooded once in 5 years time. The government or river Authorities in the basin need to inform the stockholder or community in order to create awareness and work on flood control projects and assessment of flood characteristics of basins corresponding to best management practices such as flood protection and early warning process. n flood control projects and assessment of flood characteristics of basins corresponding to best management practices such as flood protection and early warning process.

Due to the sea wave from South China Sea the water level in the river is going to rise by 0.5m above the dangerous water level at the southeast coast of the basin. To protect the water above the dangerous water level from spilling out of the bank protection structures like dikes need to be constructed at low elevated site along the river.

Since mean monthly rainfall, mean monthly river discharge, and mean monthly wave height, have higher value during the northeast monsoon season (November, December, and January), the probability for the three sources of flooding to be maximum at once is high. For that reason any kind structure intended to be constructed in the basin particularly at the southeast coast need to take these factors into consideration in the study and design process.

As Pekan and the Southeast coast of the basin are situated at flood prone area, flood protection structure need to be constructed to protect the areas from flooding.

6.3 Recommendations

Due to the topographic complexity together with the two monsoon winds from different direction, the spatial and temporal variability of precipitation is difficult to estimate the basin. The meteorological stations which were used in this study are not enough to have reliable information about the rainfall distribution. The southeast coast of the basin is supposed to have higher rainfall than the rest of the basin because it is exposure to the northeast monsoon. The main mountain range (Benjaran Titiwangsa) is also the place where high rainfall is expected to fall. Based on these facts the Author would like to recommend to have more meteorological stations at the mountain.

Since the saline sea water can gets to the river column because of sea wave but is hardly flow back to the sea. This will cause salt water intrusion in the landmass. Since Extraction of groundwater at the southeast coast for Eel farm would aggravate the contamination of the groundwater with salt the government or river authority need to work with Eel farmer to make them aware of the problems and to find solution.

Since vegetation in the river bank have the capacity to reduce the propagation of sea wave to increase water level in the river column because of the drag force on them, planting trees on the river bank must be initiated, by the government or river authorities out there.

Because erosion and deposition at curved channel is expected to be high due to the centrifugal force of flowing water, as a counteractive measure need to be taken to protect the Pekan from being eroded by limiting urban development activities which may lead to deforestation. The government and local population need to work together to restore the forest back.

References

Atikah, S. (2009), a case study on floods of 2006 and 2007 in Johor, Malaysia Page 13. Available at: http://www.engr.colostate.edu/~pierre/ce_old/resume/Theses%20and%20Dissertations/Atikah%20Shafie%20Johor_final_121009.pdf

Bates, B.C. (2008), Climate Change and Water, Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, pp: 210. Available at: http://www.ipcc.ch/meetings/session28/doc13.pdf.

Bengtsson, L and J. N (1998), Using the Rational Method for design in complex Urban Basins, Nordic Hydrology, 29 (2), 1998, pp. 73-84.

Brown D. J (2009), Choosing the Right Type of Rotation in PCA and EFA, JALT Testing & Evaluation SIG Newsletter. 13 (3) November 2009 (p. 20 - 25)

Brunner, G.W. (1989). Muskingum-Cunge Channel Routing (Lecture L-1277). Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

Church, J.A., White, N. J. (2006), 20th century acceleration in global sea-level rise, Geophysical Research Letters, 33, L01602

Craig B. P.E., Boroughs. (2003), Daily flow routing with the Muskingum-Cunge method in the River Pecos River ware model Project, Hydraulic Engineer, Tetra Tech, Inc., Breckenridge, CO

Daniel, S. Wilks (2006), Statistical Methods in the Atmospheric Sciences,

David, M. (1981), the magnitude of hydrological frequency factor in maximum rainfall estimation, hydrological sciences-Bulletin-des sciences Hydrologiques, 26, 2, 6/1981 Pp 171

David, A. P. (2004) a new method for estimating flow duration curves: an application to the Burdkin River Catchment North Queensland, Australia, page 1. Available at: www.iemss.org/iemss2004/pdf/ungauged/postanew.pdf

Desa M.M.N., Noriah A.B. and Rakhecha, P.R. (2001). Probable Maximum Precipitation for 24 hrs Duration Over Southeast Asian Monsoon Region - Selangor, Malaysia, Atmospheric Research J., vol. 58, 2001, pg. 41-54.

DWNP. (1987), Department of wild life and National parks. Taman Negara Master Plan Peninsula Malaysia, Kuala Lumpur, Malaysia.

Franchini, M., Lamberti, P., and Di Giammarco, P (1999).: Rating curve estimation using local stages, upstram discharge data and a simplified hydraulic model, Hydrol. Earth Syst. Sci., 3, 541–548, 1999, http://www.hydrol-earth-syst-sci.net/3/541/1999/

French, R.H. (1994), Open-channel Hydraulics. In: McGraw-Hill, New York (1994), pp. 247–278.

Garcia K.T., 1997, January 1997 flooding in northern Nevada—Was this a “100-year” flood?: U.S. Geological Survey Fact Sheet FS-077-97, 4 p.

Hiew, K. L. (1996). Flood Mitigation and Flood Risk Management in Malaysia. International Risk floodplain Management, pp. 205-216, 1996-11. Available at: http://www.ceprode.org.sv/staticpages/pdf/eng/doc10139/doc10139-contenido.pdf.

Hitoshi, T. & N. Hisao. (2004), Wave setup at different river entrance morphologies; Pp 1-11

Høybye, J. H. (2009), Pekan Coastal Flooding assessment impact, page 2.

IGOS (Integrated Global Observing Strategy) (2004), Water Cycle Theme report, IGWCO (The Integrated Global Water Cycle Observations Theme)

Iowa Storm water management manual, (2008), rational method, Available at : http://www.ctre.iastate.edu/pubs/stormwater/documents/2C-4RationalMethod.pdf

Kerby, W. S. (1959). Time of concentration for overland flow. Civil Engineering 29 (3), 60.

Lihan T., Nurain, S. Z., Amizam, M. A. J., Sahibin, A. R., Mustapha, A. M (2010), Determination of Spatial and Temporal Variability of Pahang River Plume Using Remote Sensing image, Connection Government and Citizen though Ubiquitous GIS. Available at: http://www.mapasia.org/2010/proceeding/pdf/tukimat.pdf

Malaysian Wetland Working Group, (1988). The value of Malaysian wetlands and their role in national development. Special Report to the Minister of Science, Technology and Environment, Malaysia. Malaysian Wetland Working Group, Kuala Lumpur.

Muhammad, G. B. (2007), Hydrology and Water Quality Assessment of the Lake Chini’s Feeder Rivers, Pahang, Faculty of Science and Techinology, School of Environment and Natural Resource Science, University of Kebangsaan Malaysia. Available at: www.idosi.org/aejaes/jaes2(1)/6.pdf

Mujumdar, P. P. (2001), flood wave propagation, The Saint Venant Equations, Pp 68. Available at: http://www.ias.ac.in/resonance/May2001/pdf/May2001p66-73.pdf

Murty, B.S. (2001), Classification of Gradually varied flow, Indian Institute of Technology Madras,

NOAA, (2007), Observing Climate Variability and Change. Available at: http://www.oar.noaa.gov/climate/t_observing.html

Patrick, C. (2005), Validity of North Shore, oahu, Hawaiian Islands Surf Observations, Journal of Coastal Research, 21/6. Pp. 1127-1138

Robert, G. D. (2001), Wave setup, department of civil and coastal Engineering University of Florida, Gainesville, FL, USA.

Robert and Todd, (2003), Department of Civil and Coastal Engineering University of Florida, Gainesville, FL, USA

Sharon, S., K. Sandhu, J., Chandran, R., Ananda, L., Jseph Tan, Pushpa.T. (2003), the Asian Reader, Institute of Southeast Asian Studies, Singapore. pp.155-156

Smakhtin, Y., (2001), Low flow hydrology, a review Journal of Hydrology 240:147-186.

Takeuchi, K., A. Jayawardena, and Y. Takahasi,(2007). Catalogue of rivers for Southeast Asia and the Pacific, volume 1. Available at: http://flood.dpri.kyoto-u.ac.jp/ihp_rsc/riverCatalogue/Vol_05/7_Malaysia-5.pdf.

Tan, K.W., M. B. Mokhtar. (2009), An Appropriate Institutional Framework Towards Integrate Water Resources Management in Pahang River Basin, Malaysia. European Journal of scientific Research, ISSN 1450-216X Vol.27 No.4 (2009) pp.536-547. Available at: http://www.eurojournals.com/ejsr_27_4_06.pdf.

The Encyclopedia of earth (2009), Malaysia- FAO's Information System on Water and Agriculture. Available at: http://www.eoearth.org/article/Malaysia-_FAO's_Information_System_on_Water_and_Agriculture

Todd, L.W, Beach and Shores Resource Center Florida state University, Tallahassee, FL, USA, pp. 1-21

Uvo, B. C., R.Berndtsson (1996), Regionalization and Spatial Properties of Ceara State Rainfall in Northeast Brazil, Journal of Geographical Research, Vol 101, No, D2, pp. 4221-4233.

Venkatesh, M. (2005), center for Research in Water Resources, Surface Water hydrology PPT Spring 2005, pp. 1-20

Venkatesh, M. (2009), Watershed and stream network delineation. School of Civil Engineering Purdue University.

World Meteorological Organization WMO (1986), *Manual for Estimation of Probable Maximum Precipitation.* Operational Hydrological Report No 1; second edition; Geneva; pg. 96

Xuan,T., N. Hisao, (2007), Wave Setup at River and Inlet Entrance Due to an Extreme , Geophysical Research Letters, 33, L01602

Reference for the Figures

Craig B. Boroughs P.E., daily flow routing with the Muskingum-Cunge Method in the River Pecos Riverware model Project Hydraulic Engineer, Tetra Tech, Inc., Breckenridge, CO

Malaysian Meteorological Department http://infobanjir.water.gov.my/xsection/PHG10.htm

Malaysian Meteorological Department http://infobanjir.water.gov.my/xsection/PHG22.htm

Ponce,V.M., (1983), Development of Physically Based Coefficients for the Diffusion Method of Flood Routing, Report No. 83110, (SCS contract No. 53-3A75).

Zbigniew, W., Kundzewicz. (1986), Phisical based Hydrological flood routing methods, Hydrological Sciences-Journal- des Sciences Hydrologiques 3

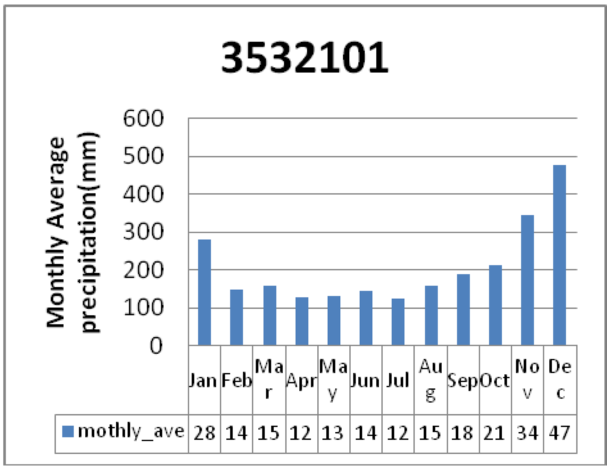
Appendix

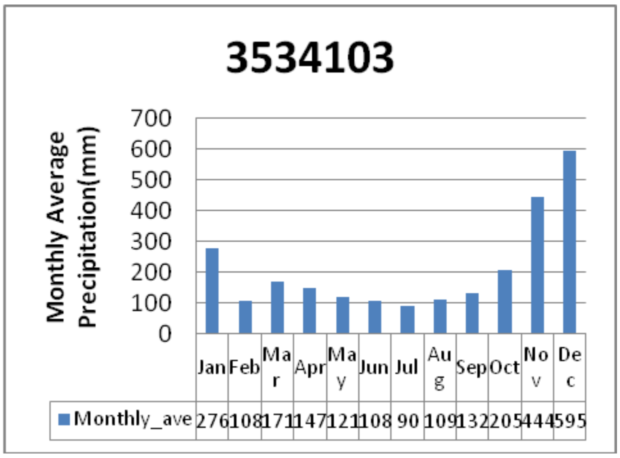
A. Appendix: The area and length of the sub-watersheds in the Pahang river basin

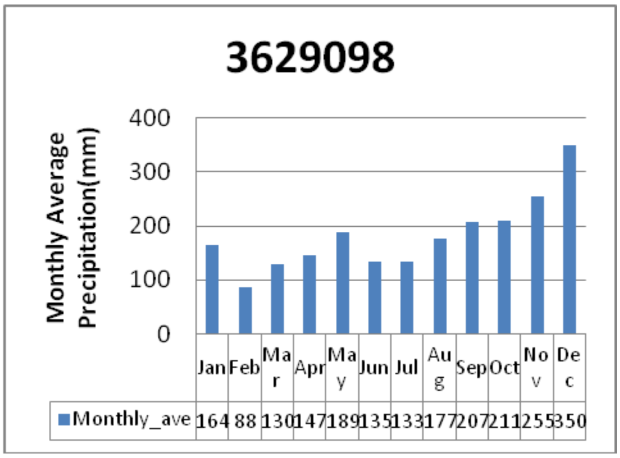
	OID_	Shape_Leng	Shape_Area(m^2)	HydroID	GridID	NextDow-nID
Polygon	1	265465.76	1053899073.49	261.00	1.00	280.00
Polygon	2	129401.19	289114814.70	262.00	2.00	264.00
Polygon	3	92117.26	90122741.64	263.00	3.00	264.00
Polygon	4	141608.06	389550367.18	264.00	4.00	266.00
Polygon	5	108745.24	280422306.06	265.00	5.00	266.00
Polygon	6	233193.90	958103413.78	266.00	6.00	279.00
Polygon	7	123134.99	338950361.07	267.00	7.00	263.00
Polygon	8	201030.21	523204444.86	268.00	8.00	275.00
Polygon	9	121512.87	282101834.68	269.00	9.00	270.00
Polygon	10	152856.07	400907722.31	270.00	10.00	275.00
Polygon	11	137590.19	366560464.42	271.00	11.00	270.00
Polygon	12	228222.51	909843876.28	272.00	12.00	263.00
Polygon	13	203815.80	748585986.68	273.00	13.00	283.00
Polygon	14	127073.91	360204166.87	274.00	14.00	276.00
Polygon	15	62781.24	54373115.62	275.00	15.00	277.00
Polygon	16	130720.50	180293812.11	276.00	16.00	277.00
Polygon	17	126307.86	178899904.58	277.00	17.00	280.00
Polygon	18	127802.08	380701863.33	278.00	18.00	276.00
Polygon	19	153632.43	428425904.93	279.00	19.00	289.00
Polygon	20	194071.99	408160117.95	280.00	20.00	281.00
Polygon	21	20496.74	5516238.26	281.00	21.00	283.00
Polygon	22	375996.56	1214768117.85	282.00	22.00	279.00
Polygon	23	143292.68	398534419.37	283.00	23.00	285.00
Polygon	24	177666.11	544343543.38	284.00	24.00	281.00
Polygon	25	40629.50	39820671.54	285.00	25.00	289.00
Polygon	26	151068.00	488725945.97	286.00	26.00	285.00
Polygon	27	160681.72	587018347.61	287.00	27.00	290.00
Polygon	28	198547.74	776791906.69	288.00	28.00	293.00
Polygon	29	190598.89	462471654.62	289.00	29.00	293.00
Polygon	30	30287.64	23333959.03	290.00	30.00	284.00
Polygon	31	264130.85	722836595.30	291.00	31.00	284.00
Polygon	32	140929.54	360023841.95	292.00	32.00	290.00
Polygon	33	162725.31	461638660.37	293.00	33.00	296.00
Polygon	34	258581.21	1019145356.67	294.00	34.00	300.00
Polygon	35	163473.54	468571798.46	295.00	35.00	296.00
Polygon	36	192611.17	422911468.00	296.00	36.00	313.00

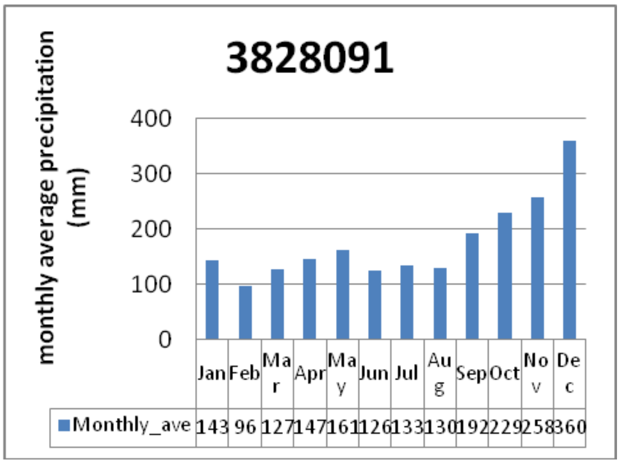
Polygon	37	207271.74	691210774.92	297.00	37.00	309.00
Polygon	38	204650.69	647373867.72	298.00	38.00	301.00
Polygon	39	191866.33	468090518.14	299.00	39.00	313.00
Polygon	40	191409.78	375494676.61	300.00	40.00	-1.00
Polygon	41	262675.08	1155527988.61	301.00	41.00	314.00
Polygon	42	133776.20	300834283.25	302.00	42.00	309.00
Polygon	43	142254.57	335781702.35	303.00	43.00	304.00
Polygon	44	46184.19	30344032.14	304.00	44.00	300.00
Polygon	45	186950.78	671119373.89	305.00	45.00	307.00
Polygon	46	152940.98	465683853.61	306.00	46.00	303.00
Polygon	47	72956.47	87348980.97	307.00	47.00	301.00
Polygon	48	159644.76	400625077.59	308.00	48.00	304.00
Polygon	49	96081.39	184633720.28	309.00	49.00	303.00
Polygon	50	133010.79	379758002.57	310.00	50.00	307.00
Polygon	51	104743.05	110937480.81	311.00	51.00	302.00
Polygon	52	139108.81	359764532.57	312.00	52.00	302.00
Polygon	53	21955.86	5614846.45	313.00	53.00	314.00
Polygon	54	100884.31	131788912.66	314.00	54.00	311.00
Polygon	55	160372.26	300261959.35	315.00	55.00	311.00
Polygon	56	121396.60	323803413.08	316.00	56.00	315.00
Polygon	57	202695.93	660406387.72	317.00	57.00	315.00
Polygon	58	225946.18	1035045264.56	318.00	58.00	312.00
Polygon	59	190088.40	524025499.85	319.00	59.00	312.00
Polygon	60	144288.31	312487910.75	320.00	60.00	317.00
Polygon	61	139692.44	403983392.45	321.00	61.00	317.00
Total A			26980825270.47			

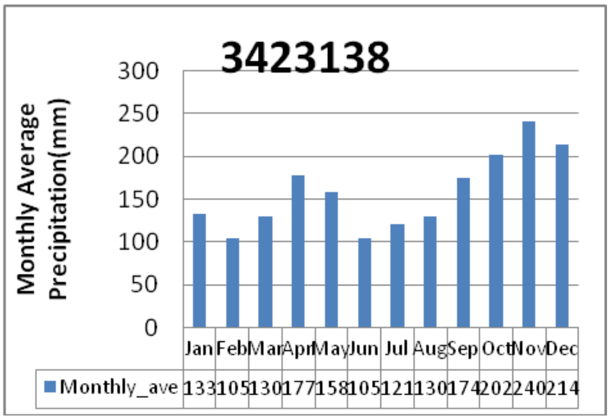
B. Appendix B: The Average monthly Precipitation of each 12 meteorological stations

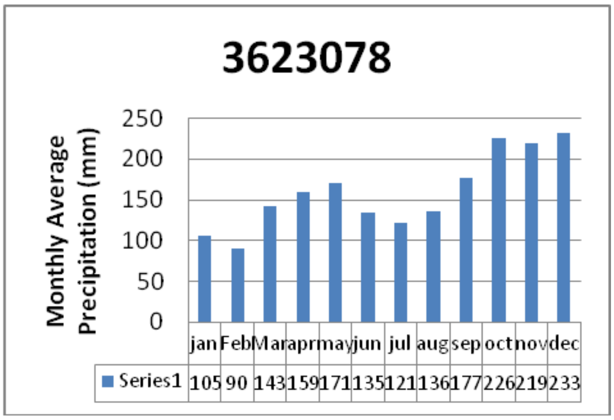


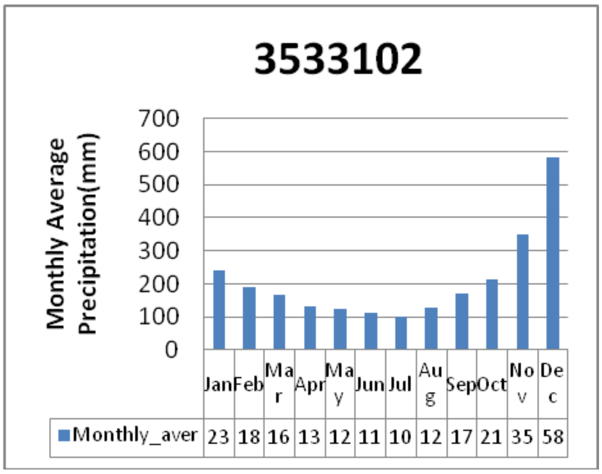


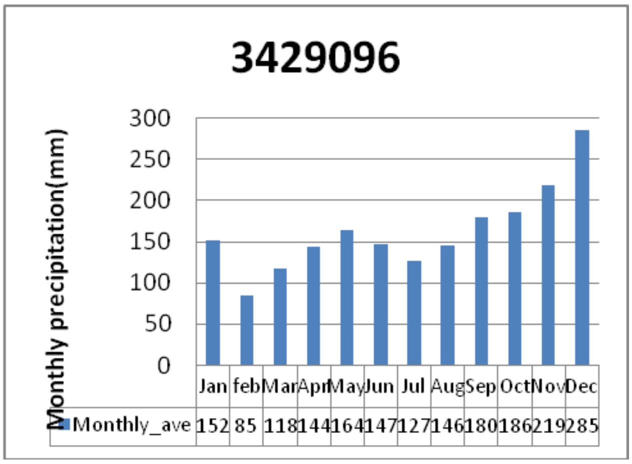


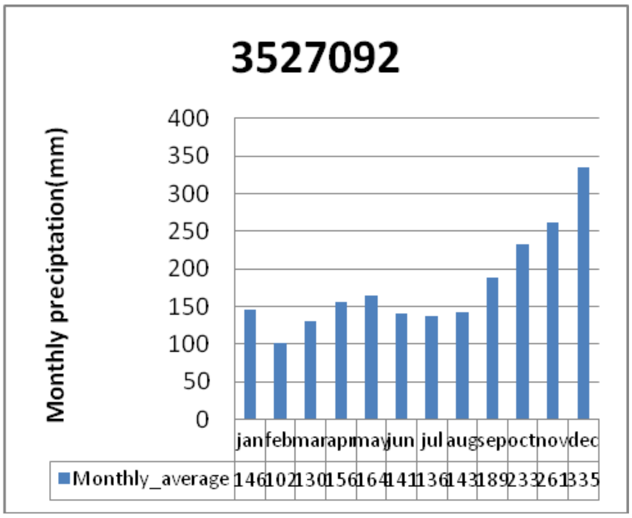


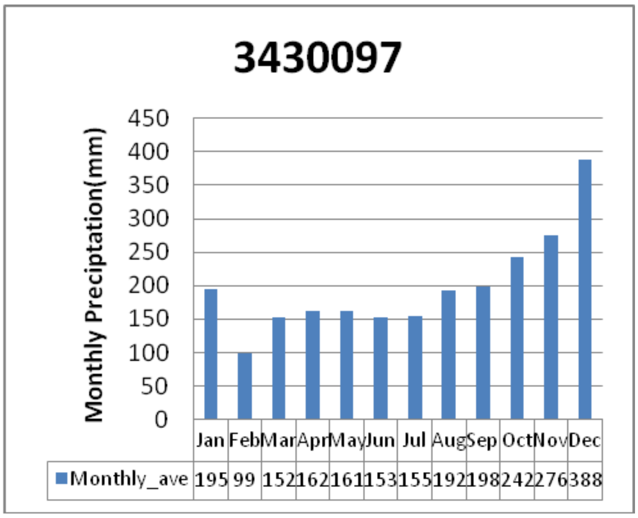


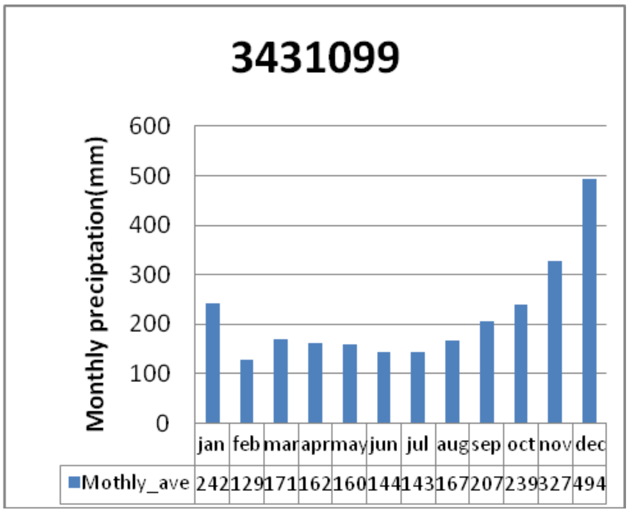


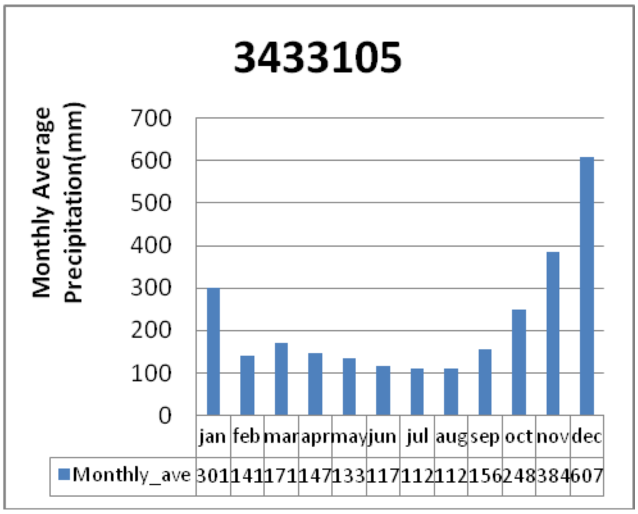

3533102
Monthly Average Precipitation(mm)
700
600
500
400
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Monthly_aver 23 18 16 13 12 11 10 12 17 21 35 58


3429096
Monthly precipitation(mm)
300
250
200
150
100
50
0
Jan feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Monthly_ave 152 85 118 144 164 147 127 146 180 186 219 285

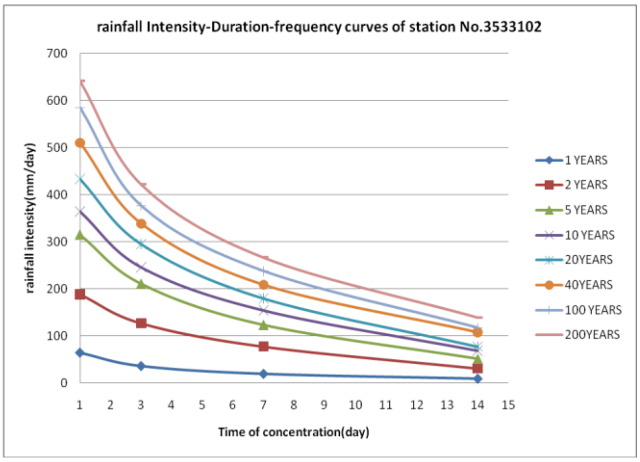

3527092
Monthly preciptation(mm)
400
350
300
250
200
150
100
50
0
jan feb mar apr may jun jul aug sep oct nov dec
Monthly_average 146 102 130 156 164 141 136 143 189 233 261 335

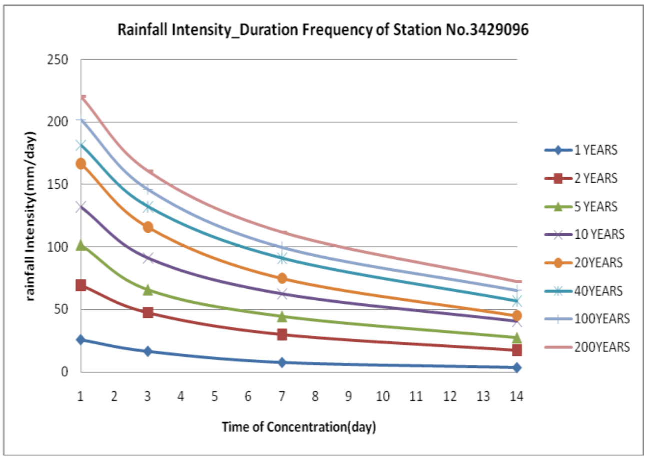

3430097
Monthly Preciptation(mm)
450
400
350
300
250
200
150
100
50
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Monthly_ave 195 99 152 162 161 153 155 192 198 242 276 388

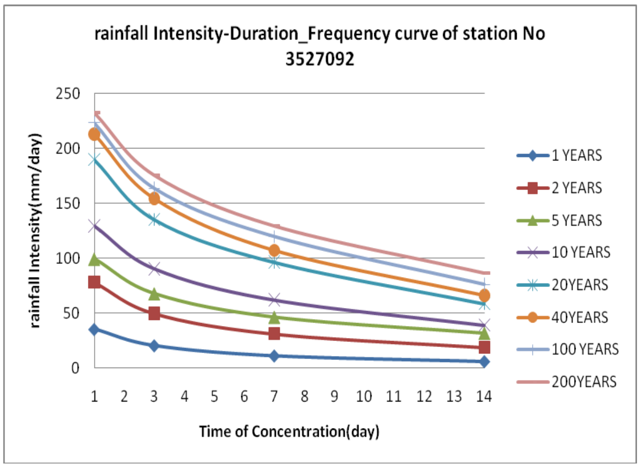

3431099
Monthly preciptation(mm)
600
500
400
300
200
100
0
jan feb mar apr may jun jul aug sep oct nov dec
Mothly_ave 242 129 171 162 160 144 143 167 207 239 327 494

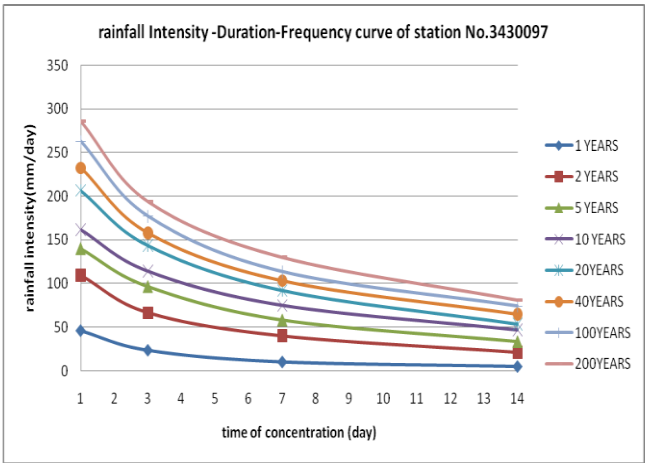

3433105
Monthly Average Precipitation(mm)
700
600
500
400
300
200
100
0
jan feb mar apr may jun jul aug sep oct nov dec
Monthly_ave 301 141 171 147 133 117 112 112 156 248 384 607

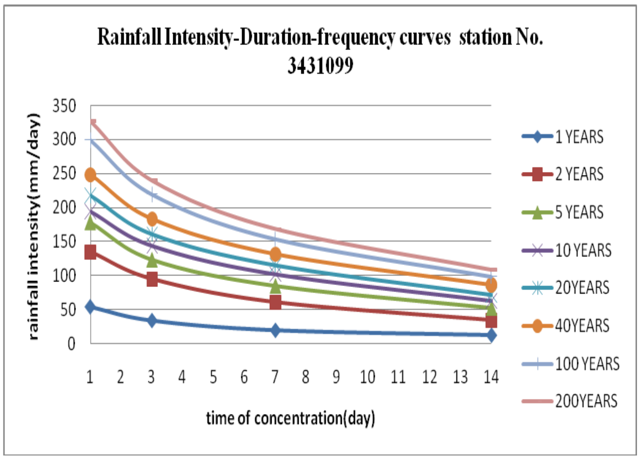
C. Appendix c: *Intensity Duration Curve (IDF)*

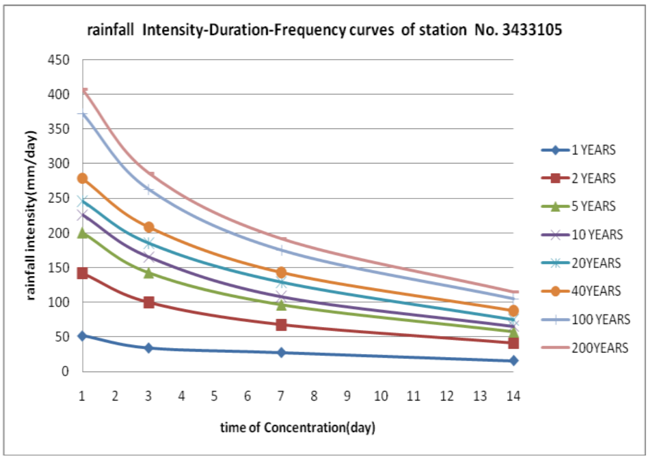


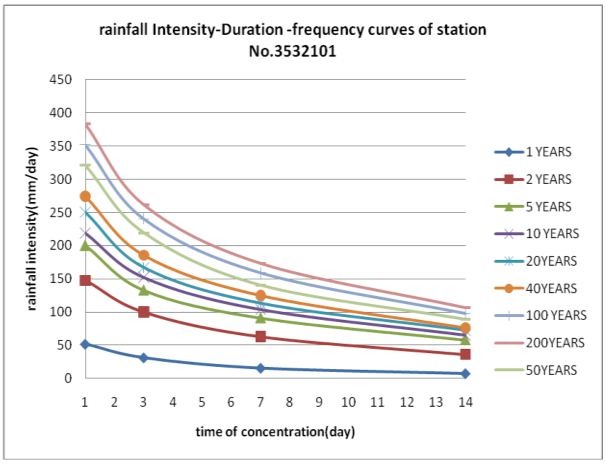


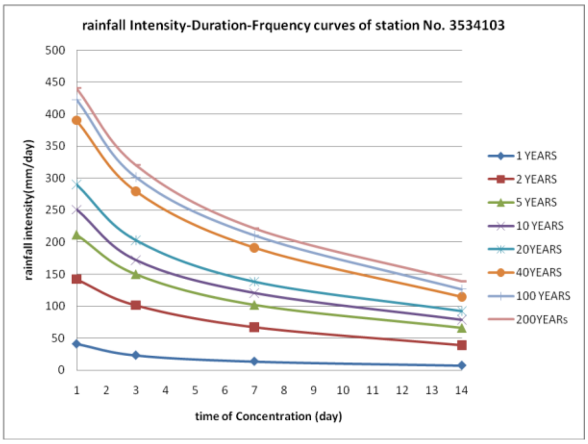


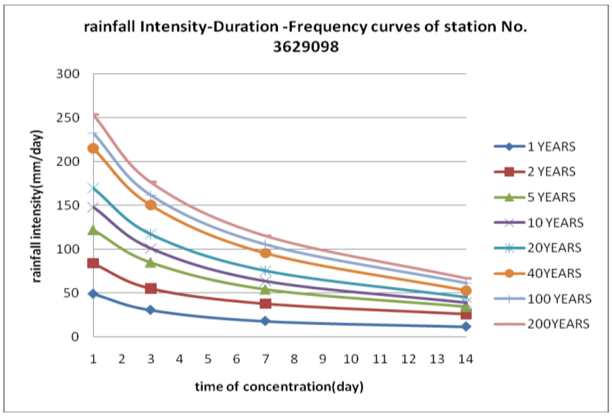


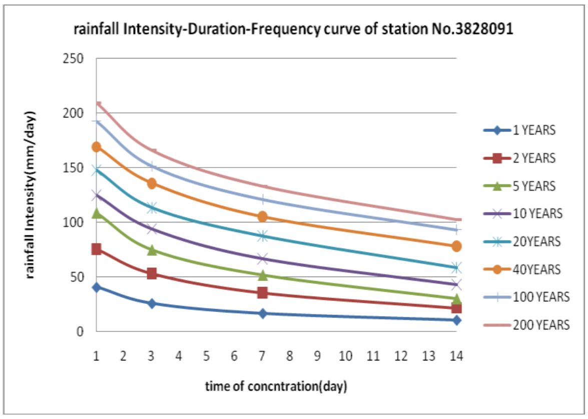


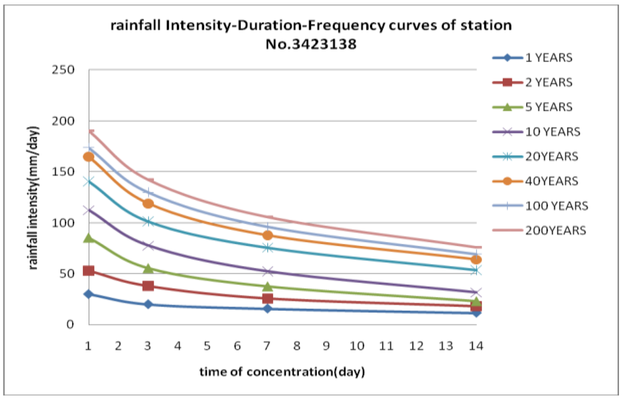


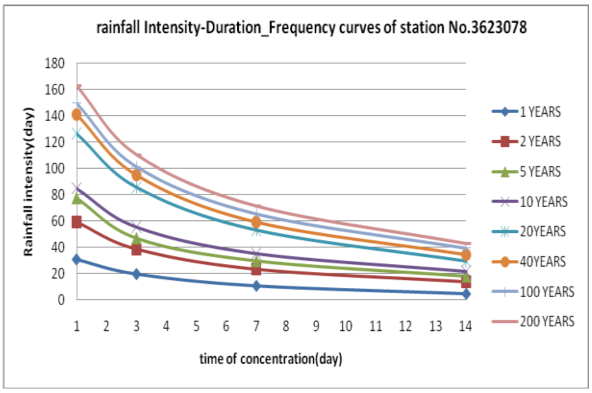

rainfall Intensity-Duration -frequency curves of station No.3532101
rainfall intensity(mm/day)
time of concentration(day)
1 YEARS
2 YEARS
5 YEARS
10 YEARS
20YEARS
40YEARS
100 YEARS
200YEARS
50YEARS


rainfall Intensity-Duration-Frquency curves of station No. 3534103
rainfall intensity(mm/day)
time of Concentration (day)
1 YEARS
2 YEARS
5 YEARS
10 YEARS
20YEARS
40YEARS
100 YEARS
200YEARs

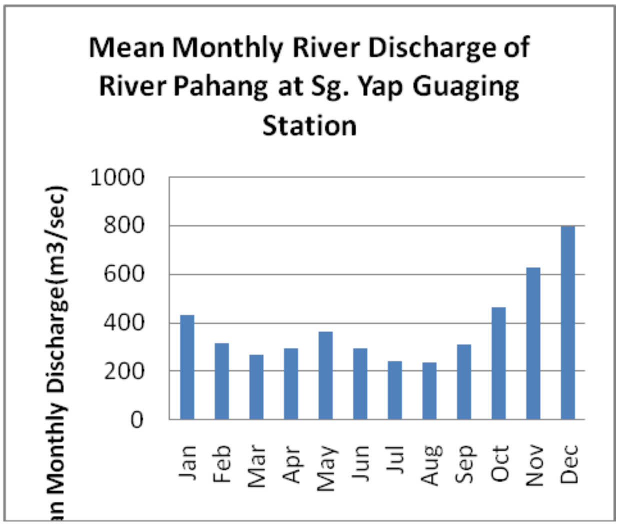

rainfall Intensity-Duration -Frequency curves of station No. 3629098
rainfall intensity(mm/day)
time of concentration(day)
1 YEARS
2 YEARS
5 YEARS
10 YEARS
20YEARS
40YEARS
100 YEARS
200YEARS

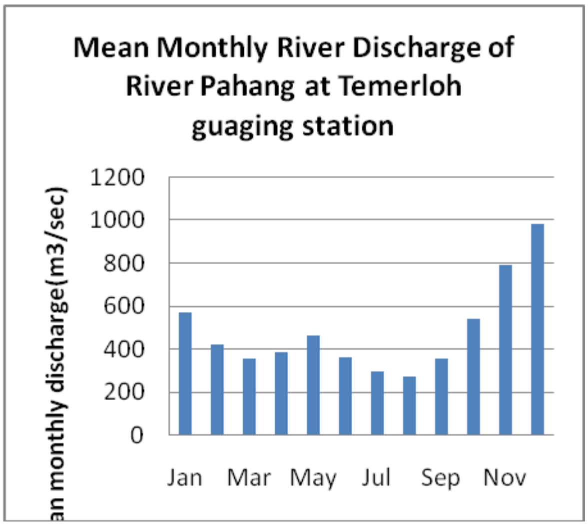

rainfall Intensity-Duration-Frequency curve of station No.3828091
rainfall Intensity(mm/day)
time of concntration(day)
1 YEARS
2 YEARS
5 YEARS
10 YEARS
20YEARS
40YEARS
100 YEARS
200 YEARS

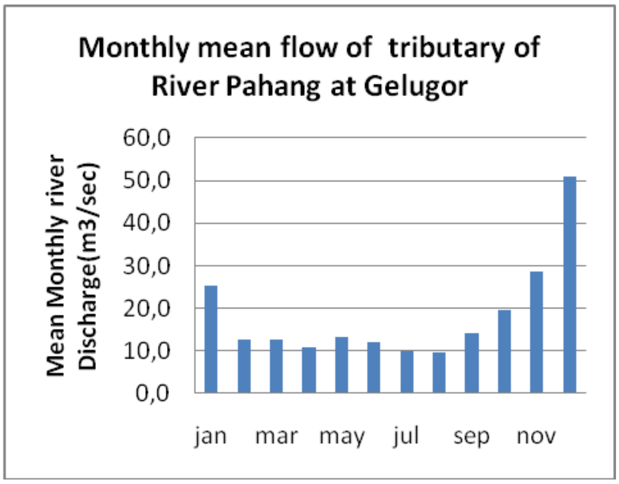

rainfall Intensity-Duration-Frequency curves of station No.3423138
rainfall intensity(mm/day)
time of concentration(day)
1 YEARS
2 YEARS
5 YEARS
10 YEARS
20YEARS
40YEARS
100 YEARS
200YEARS

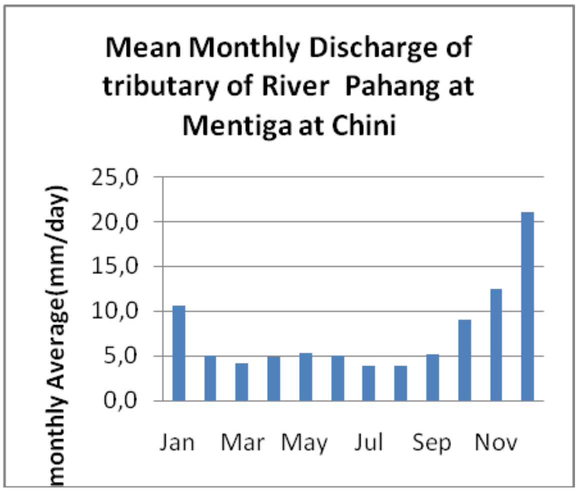

rainfall Intensity-Duration_Frequency curves of station No.3623078
Rainfall intensity(day)
time of concentration(day)
1 YEARS
2 YEARS
5 YEARS
10 YEARS
20YEARS
40YEARS
100 YEARS
200 YEARS

D. Appendix D: Mean Monthly River flow at different gauging stations in Pahang River and tributaries



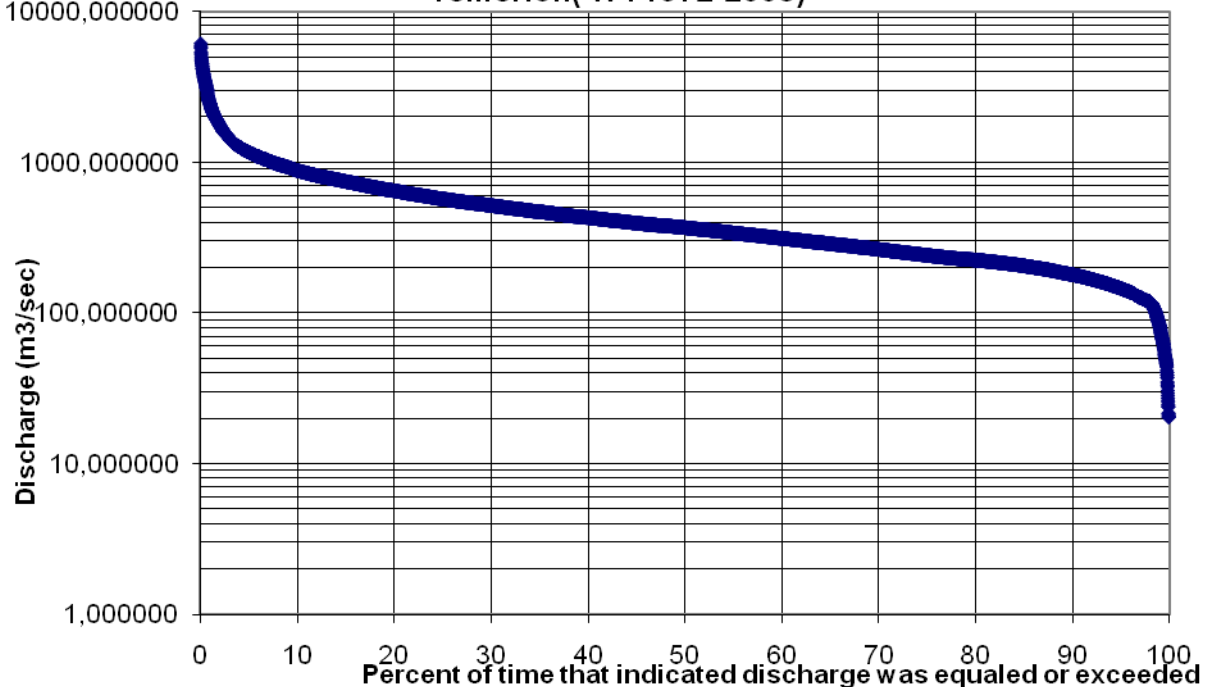




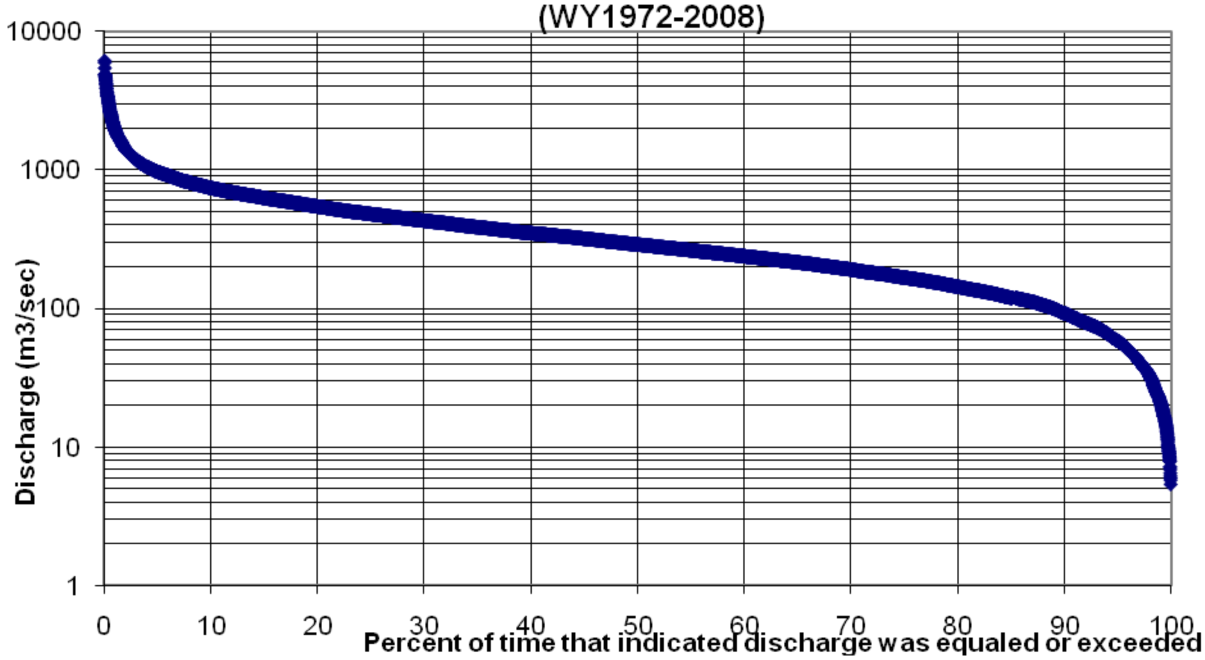


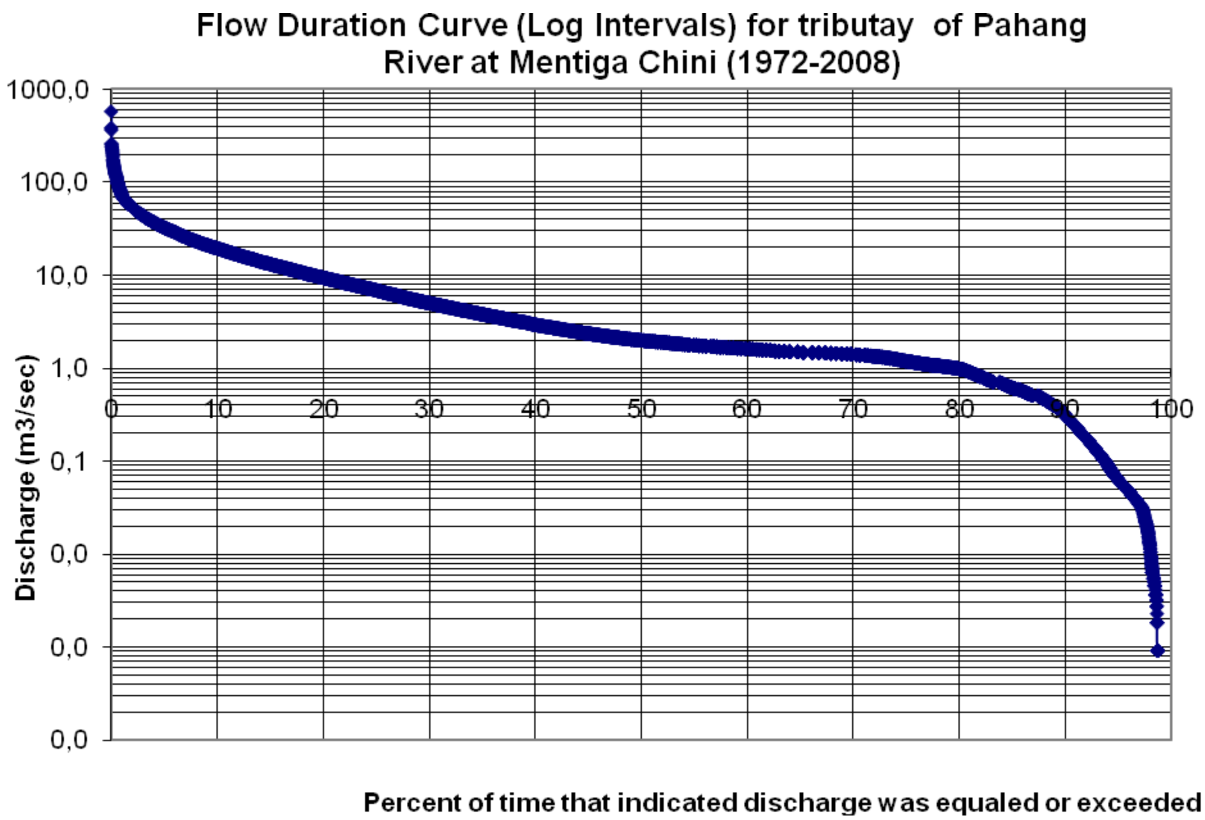
E. Appendix E: Flow Duration Curve

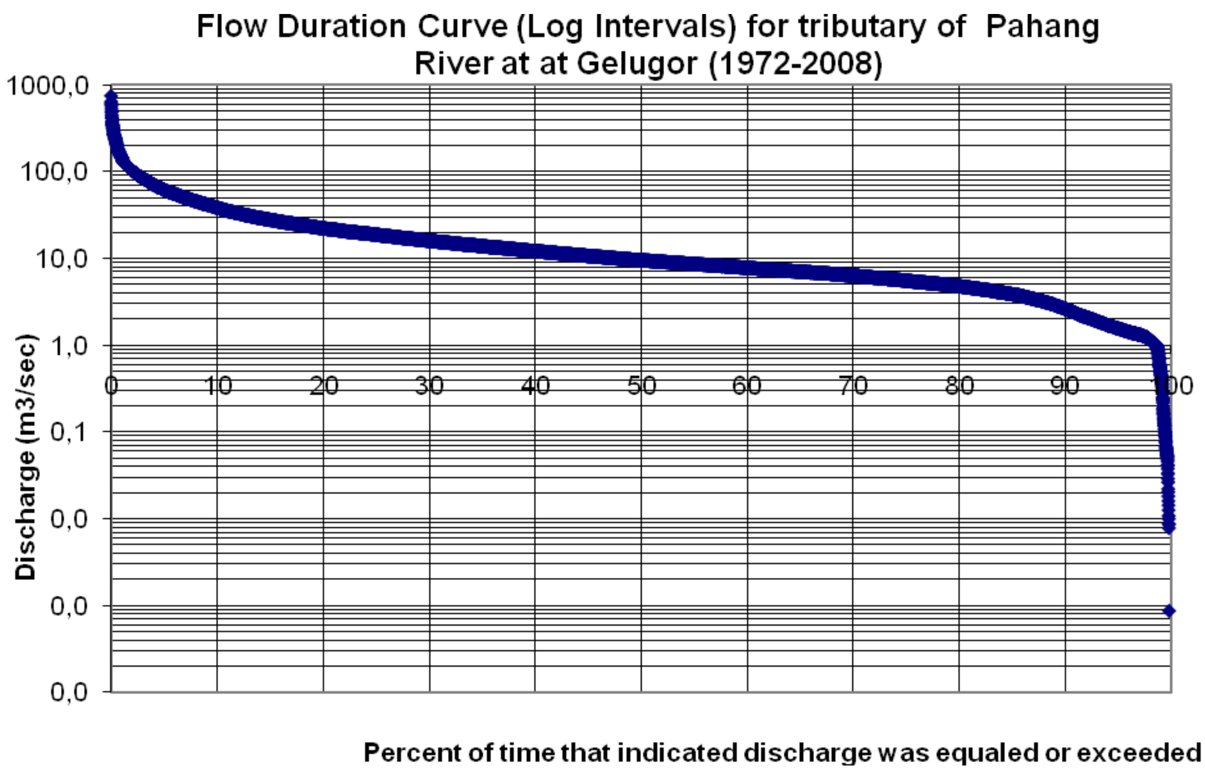
Flow Duration Curve (Log Intervals) for Pahang River at Temerloh(WY1972-2008)



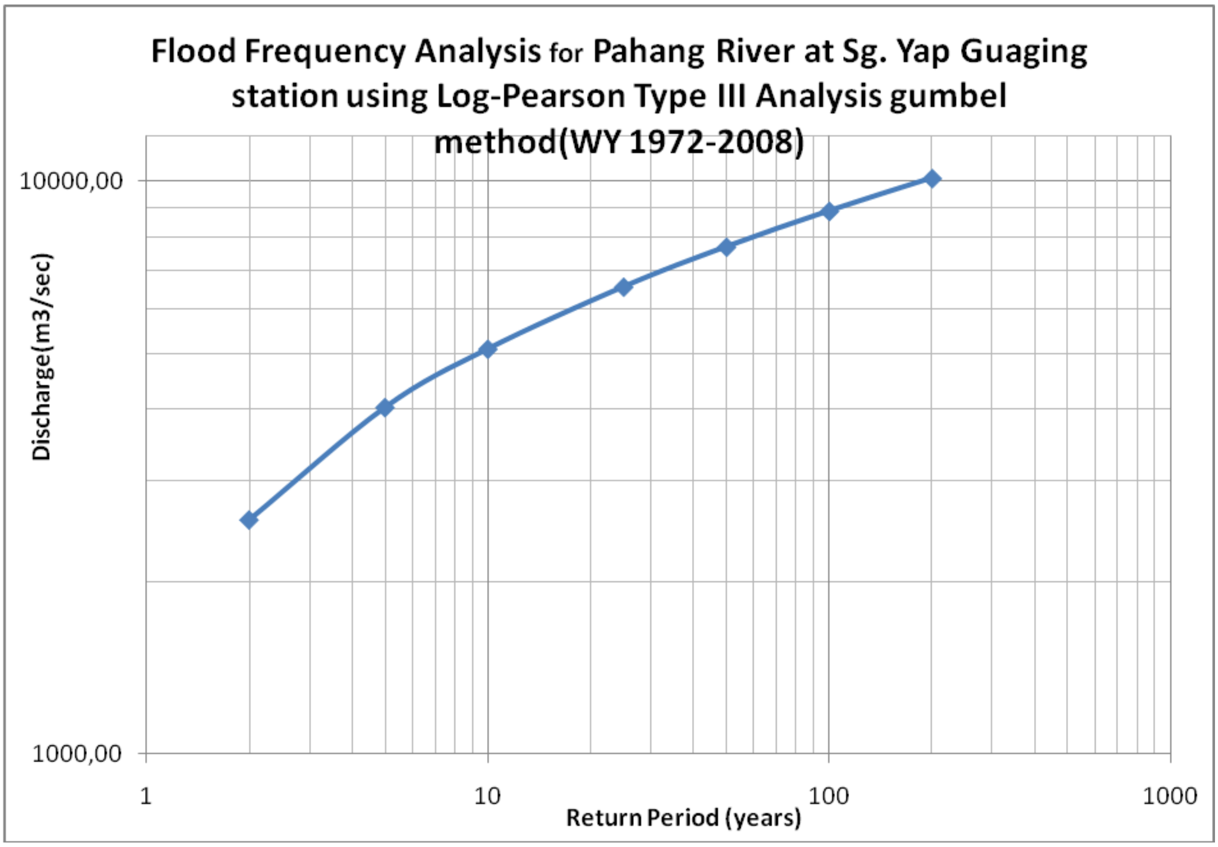
Flow Duration Curve (Log Intervals) for Pahang River at Yap (WY1972-2008)

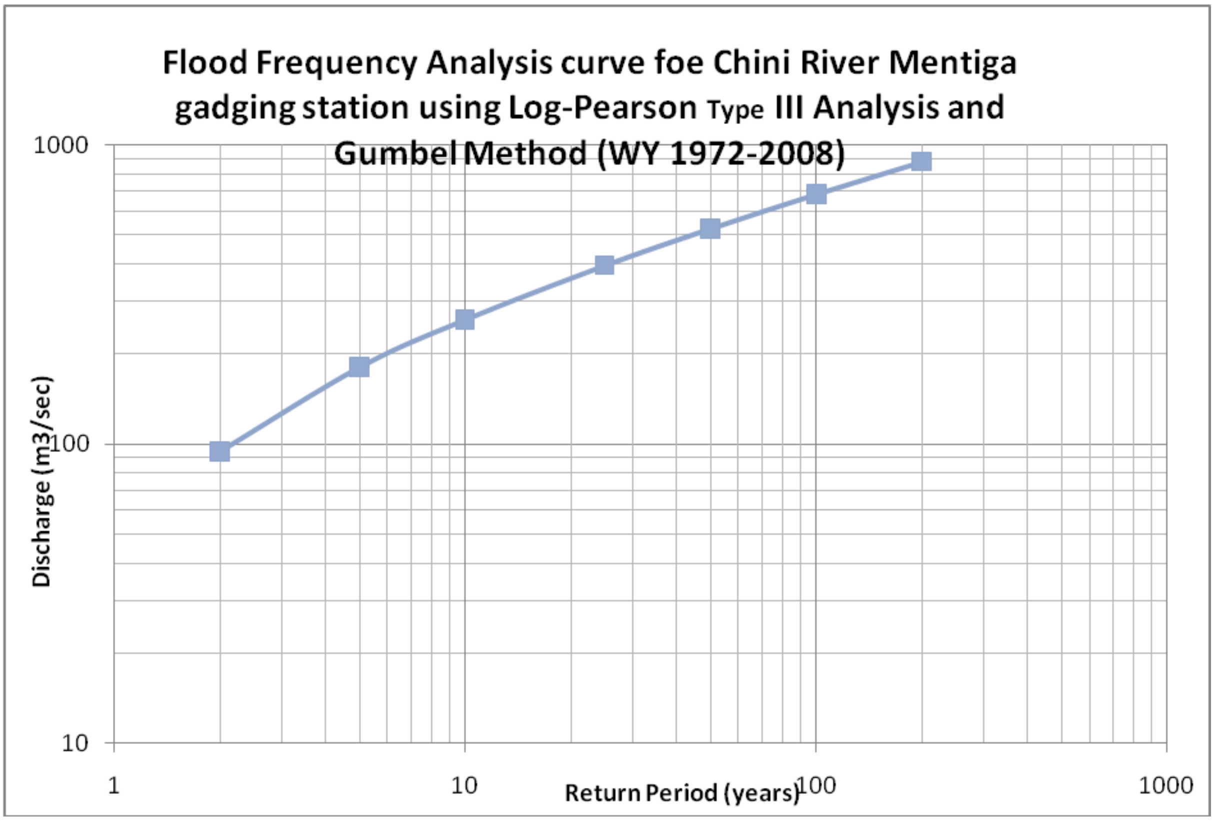


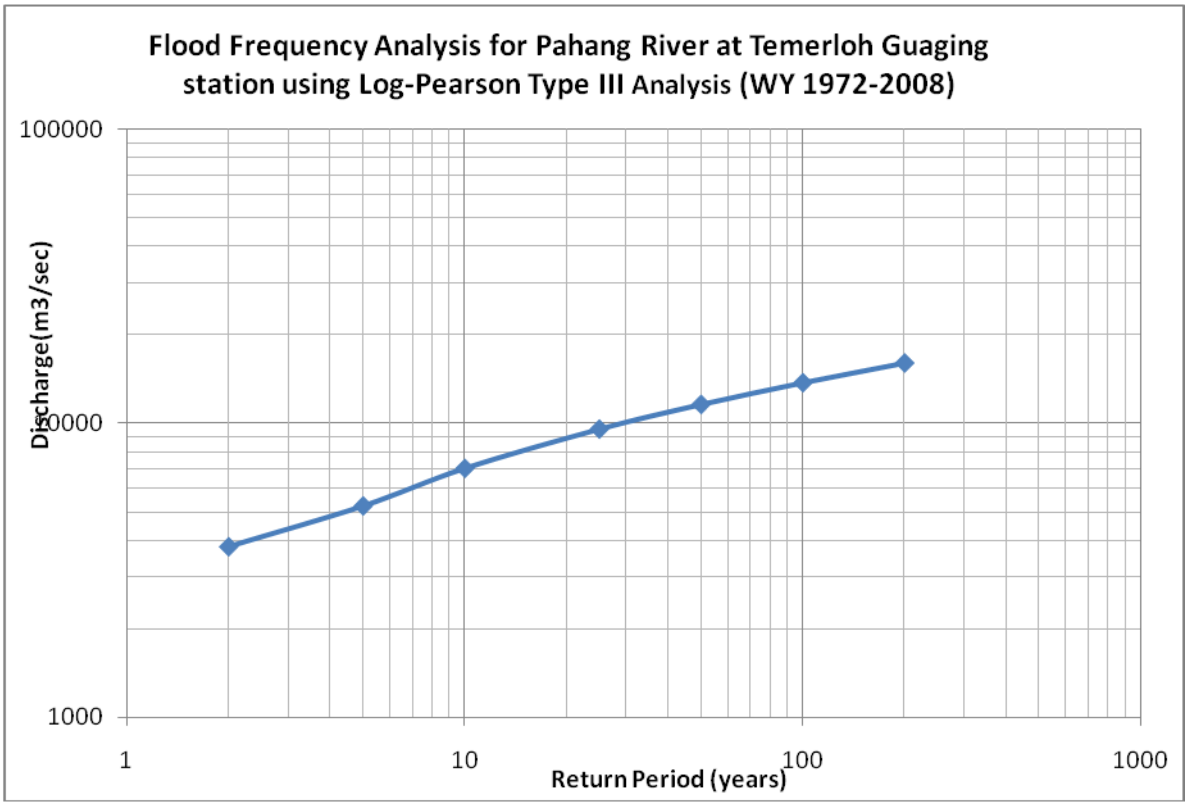

Flow Duration Curve (Log Intervals) for tributay of Pahang River at Mentiga Chini (1972-2008)
1000,0
100,0
10,0
1,0
0,1
0,0
0,0
0,0
Discharge (m3/sec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time that indicated discharge was equaled or exceeded

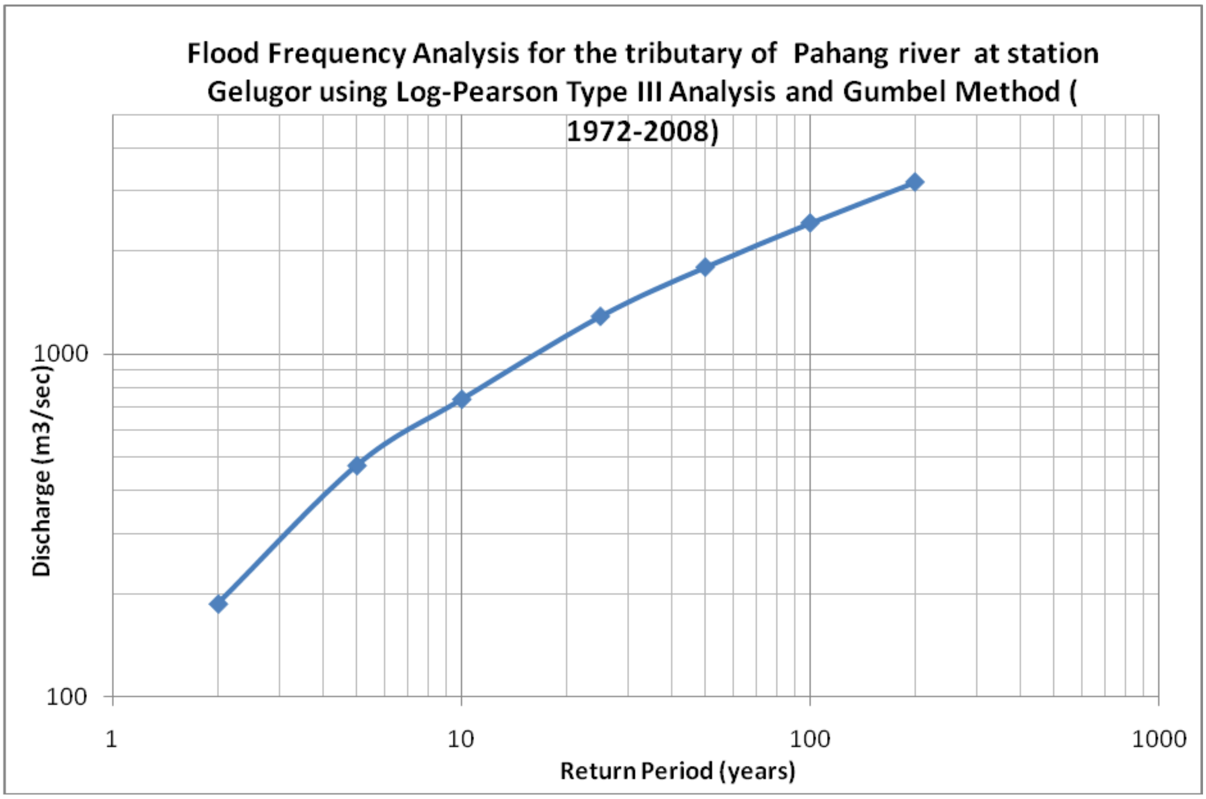

Flow Duration Curve (Log Intervals) for tributary of Pahang River at at Gelugor (1972-2008)
1000,0
100,0
10,0
1,0
0,1
0,0
0,0
0,0
Discharge (m3/sec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time that indicated discharge was equaled or exceeded

F. Appendix F: Flood frequency analysis Curve






Flood Frequency Analysis for Pahang River at Temerloh Guaging station using Log-Pearson Type III Analysis (WY 1972-2008)
100000
10000
1000
Discharge(m3/sec)
1
10
100
1000
Return Period (years)


Flood Frequency Analysis for the tributary of Pahang river at station Gelugor using Log-Pearson Type III Analysis and Gumbel Method (1972-2008)
1000
100
Discharge (m3/sec)
1
10
100
1000
Return Period (years)

G. Appendix G: The result of gradually varied flow

Depth	Area	Velocity	Velocity head	Specific head	Wetted perimeter	Hydraulic radius	Friction slope	Average slope	Specific head difference	Length increment	Total length
(m)	(m^2)	(m/s)	(m)	(m)	(m)	(m)	(m/m)	(m/m)	(m)	(m)	(m)
4,5	3602	1,88	0,179	4,679	809,04	4,45	0,0003	-	-	-	0
4,481	3587	1,88	0,181	4,662	809,01	4,43	0,0003	0,0003	0,003	15	89,4
4,458	3569	1,89	0,183	4,641	808,96	4,41	0,0003	0,0003	0,003	15,4	196,2
4,436	3551	1,9	0,185	4,621	808,92	4,39	0,0003	0,0003	0,003	15,8	305,8
4,417	3535	1,91	0,186	4,603	808,88	4,37	0,0003	0,0003	0,003	16,2	402,1
4,394	3517	1,92	0,188	4,582	808,83	4,35	0,0003	0,0003	0,003	16,7	517,4
4,372	3499	1,93	0,19	4,562	808,79	4,33	0,0003	0,0003	0,003	17,2	636,3
4,353	3484	1,94	0,192	4,544	808,75	4,31	0,0003	0,0003	0,003	17,7	741,2
4,33	3466	1,95	0,194	4,524	808,7	4,29	0,0003	0,0003	0,003	18,3	867,5
4,308	3448	1,96	0,196	4,504	808,66	4,26	0,0003	0,0003	0,003	19	998,4
4,289	3433	1,97	0,197	4,486	808,62	4,25	0,0004	0,0004	0,003	19,6	1114,5
4,266	3415	1,98	0,2	4,466	808,58	4,22	0,0004	0,0004	0,003	20,4	1255,1
4,244	3397	1,99	0,202	4,446	808,53	4,2	0,0004	0,0004	0,003	21,4	1401,8
4,225	3381	2	0,204	4,428	808,49	4,18	0,0004	0,0004	0,003	22,2	1533,1
4,202	3364	2,01	0,206	4,408	808,45	4,16	0,0004	0,0004	0,003	23,4	1693,2
4,18	3346	2,02	0,208	4,388	808,4	4,14	0,0004	0,0004	0,003	24,7	1862
4,161	3330	2,03	0,21	4,37	808,36	4,12	0,0004	0,0004	0,003	26	2014,6
4,138	3312	2,04	0,212	4,35	808,32	4,1	0,0004	0,0004	0,003	27,7	2203,1
4,116	3294	2,05	0,214	4,33	808,27	4,08	0,0004	0,0004	0,003	29,7	2404,6
4,097	3279	2,06	0,216	4,313	808,23	4,06	0,0004	0,0004	0,003	31,7	2589,7
4,074	3261	2,07	0,219	4,293	808,19	4,03	0,0004	0,0004	0,003	34,5	2822,6
4,052	3243	2,08	0,221	4,273	808,14	4,01	0,0004	0,0004	0,003	38	3077,8
4,032	3228	2,09	0,223	4,256	808,11	3,99	0,0004	0,0004	0,003	41,7	3318,3
4,01	3210	2,11	0,226	4,236	808,06	3,97	0,0004	0,0004	0,003	47,2	3631,1
3,988	3192	2,12	0,228	4,216	808,02	3,95	0,0004	0,0004	0,003	54,5	3989,5
3,968	3176	2,13	0,231	4,199	807,98	3,93	0,0005	0,0005	0,003	63,3	4345,8
3,946	3158	2,14	0,233	4,179	807,93	3,91	0,0005	0,0005	0,003	78,2	4844,6
3,924	3140	2,15	0,236	4,16	807,89	3,89	0,0005	0,0005	0,003	103,4	5484,5
3,904	3125	2,16	0,238	4,143	807,85	3,87	0,0005	0,0005	0,003	144,4	6234,6
3,882	3107	2,17	0,241	4,123	807,8	3,85	0,0005	0,0005	0,003	275	7671,1
3,86	3089	2,19	0,244	4,103	807,76	3,82	0,0005	0,0005	0,003	4068,9	15645