DEVELOPMENT OF ISOHYET MAP USING INVERSE DISTANCE WEIGHTING AND ORDINARY KRIGING METHODS FOR KLANG RIVER BASIN

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ABSTRAK

Lembangan Sungai Klang merupakan salah satu lembangan paling penting di negeri Selangor. Ia meliputi Wilayah Persekutuan Kuala Lumpur, Hulu Langat, Gombak, Petaling dan Klang. Lembangan ini mengalami perkembangan ekonomi yang pesat di Malaysia. Oleh itu, pengetahuan mengenai taburan hujan di lembangan ini sangat berguna untuk pengurusan bencana dan pengurusan sumber air. Kaedah interpolasi spatial sering digunakan untuk mencari nilai anggaran parameter meteorologi. Dalam kajian ini, data hujan dibahagikan kepada hujan purat bulanan dan tahunan (sebelum dan selepas 2000). Peta isohyet dihasilkan menggunakan Inverse Distance Weighting (IDW) dan Ordinary Kriging (OK) melalui ArcGIS Geostatistical Analyst. Kaedah-kaedah ini akan dibandingkan dan dinilai menggunakan pengesahan bersilang. Dari analisis ini, Ordinary Kriging (OK) adalah kaedah yang paling bagus untuk lembangan sungai Klang kerana is mempunyai perbezaan nilai anggaran dan ralat yang kecil dan kecenderungan pusat yang lebih besar. Peta isohyet yang dihasilkan oleh Ordinary Kriging (OK) kemudian akan digunakan untuk menganalisis kesan perubahan iklim di lembangan ini. Melalui tahunan peta isohyet, ia dapat diperhatikan bahawa tahunan hujan purata di lembangan ini telah meningkat selepas ke 20 abad. Kawasan yang paling kering didapati di Klang, Selangor yang terletak di bahagian hilir lembangan. Purata hujan turun kurang berbanding sebelum ini disebabkan oleh pemanasan global. Kawasan ini semakin panas dan menyebabkan kemarau lebih teruk. Sementara itu, kawasan paling basah terletak di Kuala Lumpur. Kuala Lumpur terletak di bahagian tengah tangkapan. Nilai purata hujan semakin meningkat di bandar. Ini disebabkan oleh kesan pulau haba bandar yang mengakibatkan suhu yang lebih tinggi di bandar. Akibatnya, kejadian banjir kilat diramal berlaku selepas dua hingga tiga jam hujan lebat di kawasan ini.

ABSTRACT

Klang river basin is one of the most important basins in Selangor. It covers federal territory of Kuala Lumpur, Hulu Langat, Gombak, Petaling and Klang. This basin experiences the highest economic development in Malaysia. Therefore, appropriate knowledge of rainfall distribution in this basin is very useful for disaster management and water resource management. Spatial interpolation method is a frequent common method to find the estimate values of meteorological parameters. In this study, the rainfall data were classified into monthly and annually average rainfall (before and after 2000) in order to assess the rainfall patterns in the river basin. The isohyet maps were produced using Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) through ArcGIS Geostatistical Analyst. These methods are compared and evaluated using cross validation. From the analysis, Ordinary Kriging (OK) is the most optimum interpolation method over Klang river basin because it has less variation of estimate values, smaller error and greater central tendencies. The isohyet maps generated by Ordinary Kriging then are used to analyze the impact of climate change over this basin. It can be observed that annually average rainfall in this basin had been increased after 20 century. The driest area is found in Klang, Selangor which located at the lowest part of the catchment. The average rainfall had been decreased compare to previous due to global warming effect. The study area becoming hotter and make drought more severe. Meanwhile, the wettest area is located in Kuala Lumpur. Kuala Lumpur is in the middle part of the catchment. The average rainfall had been increased intensely in the city. This is because of the urban heat island effect that results in higher temperature in the city. Consequently, flash flood events may occur after two to three hours of heavy rain in this region.

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LIST OF SYMBOLS

°C	Celsius
Km^2	Kilometre Square
mm	Millimetre
x	Station
Px	Missing Annual Precipitation
m	Missing Station
Nx	Normal Annual Precipitation
P_m	Annual Precipitation Value
n	Number of Stations
$_i$	Index Station
$_n$	Number of Index Station
$\hat{Z}(s_0)$	Prediction Value for Location s_0
$\hat{Z}(s_i)$	Observed Value for Location s_i
N	Total Measured Sample Point Numbers
λ_i	Weight
d_{i0}	Distance Between Prediction and Measured Location
n	Number of Rain Events
Z_i	Observed Value from Position i
$\hat{Z}_i$	Predicted Value from Position i
$\bar{Z}$	Mean Observed Rainfall
A	Area
$\overline{P}$	Average Precipitation

LIST OF ABBREVIATIONS

MMD	Malaysian Meteorological Department
DID	Department of Irrigation and Drainage
IPCC	Intergovernmental Panel on Climate Change
GIS	Geographical Information System
DJF	December January February
JJA	June July August
MAM	March April May
SON	September October November
IDW	Inverse Distance Weighting
OK	Ordinary Kriging
UK	Universal Kriging
S	Spline
TR	Topo to Raster
RHI	Range Height Indicator
WMO	World Meteorological Department
MAE	Mean Absolute Error
RMSE	Root Mean Square Error
SRMSE	Standardized Root Mean Squared Error
G	Goodness of Prediction Measure
ESRI	Environmental Systems Research Institute
LP	Local Polynomial
GP	Global Polynomial
TRMM	Tropical Rainfall Measuring Mission
PBIAS	Percent of Bias

CHAPTER 1

INTRODUCTION

1.1 General

Climate of Malaysia is considered as hot and humid throughout the year due to it located near to the equatorial doldrum area. The average rainfall for Malaysia is around 2500 millimetres a year and its average temperature is 27°C (Mohamed *et al.*, 2014). According to Malaysian Meteorological Department (MMD), consistent periodic changes in the wind flow patterns have distinguished Malaysia climate into four monsoons namely northeast monsoon, southwest monsoon and two shorter periods inter-monsoon seasons. Northeast monsoon started from November until March whereas southwest monsoon usually commences in May or June but ended in September. Inter-monsoon began in March to May and October to mid-November (Fakaruddin *et al.*, 2015).

Climate change has become the hottest debate issue around the world. Malaysia is situated between Pacific Ocean and Indian Ocean. Its climate is influenced by variation of the natural climate associated with both oceans. The knowledge of how natural climate variability to a particular region is significant. This is to understand assess and impact of climate change to a particular region (Fredolin *et al.*, 2012). Flooding is one of the impacts of climate change that can lead a tremendous impact to the financial, environmental or human losses. Department of Irrigation and Drainage (DID) has classified flood in Malaysia into two categorizes which are monsoon flood and flash flood. Recently, Malaysia has encountered several extreme weather events due to the change of climate. These changes can bring serious effects on economic, social, physical or ecological (Hashib *et al.*, 2011). The worst flood event occurred in Malaysia was in the 2014 where more than 200,000 people have been affected and 21 people were killed due to the flood event (Akasah, 2015). Thus, it is critical to understand the characteristic of rainfall in order to presume the effect of rainfall in the evapotranspiration, infiltration and runoff process (Knight *et al.*, 2005).

Klang river basin encompasses some districts in Selangor and also includes federal territory of Kuala Lumpur. This basin has the densest population and is situated in the most developed region in Malaysia. According to Sidek (2016), it is likely to experience the highest economic development in the country with the prediction over 3.6 million of population and with an approximately 5% growth rate per year. Flash flood is the most common geohazard in Kuala Lumpur. After two or three hours of heavy rain, the water level of river in the Kuala Lumpur region could reach its peak discharge. It is a result of unplanned rapid development and major changes of land use at Kuala Lumpur have narrowed certain stretches of the river. It is assumed that during monsoon season 5700 hectares of populated area on the Klang river and its tributaries will be flooded (Gert de Roo, 2004).

The important element in hydrological cycle is precipitation. It controlled water disasters and water supplies (Taesombat and Sriwongsitanon, 2009). Rainfall data is needed by the hydrologist in hydrological modelling process and to estimate terrific precipitation events caused by the global climate change like droughts and floods (Wagner *et al.*, 2012; Jamaludin and Suhaimi, 2013). This is because acquired precise rainfall data is crucial in order to predict the spatial behaviour of the rainfall intensity and its pattern. Due to the topographic variability, rainfall will never distribute evenly through the catchment areas. However, it is impossible to install many rainfall station gauges in the area of study (Jamaludin and Suhaimi, 2013; Taesombat and Sriwongsitanon, 2009). Good interpolation method is required to find the missing values of meteorological parameter (Wijemannage *et al.*, 2016). Several spatial interpolation methods have been introduced in order to estimate the rainfall data in the unsampled locations (Sarann *et al.*, 1997). Estimated actual rainfall over the basin is very useful for prediction of the possibility of flood event happen due to climate change so that flood mitigation and prevention can be carried out as soon as possible (Hao and Chang, 2013; Wijemannage *et al.*, 2016). The rainfall information also helps engineer to design suitable drainage system in the area of study.

1.2 Problem Statement

Climate change has been arisen as one of the major global challenges for whole world. According to The Star Online on 11 June 2017, the temperature different between the region in Kuala Lumpur and its neighbouring rural areas is about 10°C. The hotter temperature caused heavy rainfall happened in urban area that lead to several flash floods whereas less rainfall in suburban area. The effect of urban heat island in the city is due to the rapid development. Flash flood always occurs in Klang Valley after heavy rain. It is the result of rapid urbanisation in the river catchment area which deteriorated the capacity of river. As a result of heavy development, large concentration of runoff flow into the river which exceed the capacity of the river. For instance, flash flood happened in Jalan Bangsar, Jalan Pantai Baharu, Jalan Pudu and Jalan Semantan had caused more than 100 vehicles trapped in Klang Valley on 12 May 2016.

Figure 1.1 Flash flood in Jalan Tuanku Abdul Halim
Source: The Star Online (2016)

Accurate and effective rainfall data is vital for hydrologist with regard to create a reliable isohyet map that describes the spatial behaviour of rainfall intensity and its pattern. The maps are developed via Geographical Information System (GIS) software with precise data of annual rainfall and seasonal rainfall. Acquired precise isohyet map can help to detect the location of floodplain. It would aid Malaysian Meteorological Department (MMD) to made early preparation for flood disaster planning such as issues early warning to the local residents. It also assisted hydrologist in hydrological analysis and water resources management. Several spatial interpolation methods are used to analysis the spatial of rainfall data. These methods aided to estimate rainfall value at ungauged location and to find the mean areal rainfall over the entire catchment area of study.

1.3 Objectives

The objectives of this study are:

i. To produce isohyet maps for Klang river basin using Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) methods.

ii. To evaluate and identify the most optimum spatial interpolation method for rainfall distribution in Klang river basin.

iii. To analyse monthly and annual rainfall pattern maps that developed from the optimum spatial interpolation method for the impact of climate change over Klang river basin.

1.4 Scope of Study

The study involved analysis of monthly and annually rainfall data and its pattern in Klang river basin in order to understand the climate change over the basin. The rainfall data were collected from the Department of Irrigation and Drainage (DID). Precise annually rainfall information is significant to produce a spatial behaviour of rainfall intensity and rainfall pattern map. The isohyet map is developed via Arcgis 10.2 software by using spatial interpolation technique. Spatial interpolation method is used to interpolate rainfall data obtained from the rain gauge station. In this study, one deterministic interpolation method (Inverse Distance Weighted) and one geostatistical interpolation method (Ordinary Kriging) will be assessed and compared using cross validation techniques. It intends is to identify which method will produce more accurate and reliable rainfall value. Based on Wijemannage et al (2016), Ordinary Kriging (OK) and Universal kriging (UK) methods are the optimum interpolate rainfall techniques for low rainfall situation compare to Inverse Distance Weighting (IDW), Spline (S) and Topo to Raster (TR) methods. The effect of climate change over Klang river basin also can be detected through the rainfall patterns that generated by ArcGIS 10.2.

1.5 Significant of Study

This study is conducted to present spatial rainfall data analysis using two spatial interpolation methods and choose the best performance method for Klang river basin region. Unfortunately, limited number of rain gauges were installed at the selected points in the study area due to the budget constraint, complex construction procedure of rain gauge station and topography of the site (Jamaludin and Suhaimi, 2013). The rainfall data at the unsampled location can be easily obtained through spatial interpolation method. Spatial interpolation is a method that used to estimate the rainfall value at ungauged place by using existing rainfall data.

Accurate rainfall data in the entire area of study is necessary in order to produce an effective isohyet map. The isohyet maps produced via Geographical Information System (GIS) can help to determine the minimum and maximum rainfall amount for monthly and annually in Klang river basin. It can assist to understand the rainfall pattern and its intensity in order to assess and evaluate the climate change in this basin. The wettest and driest region can be detected through the isohyet maps. The distribution and intensity of rainfall also can help to identify the floodplain zone within Klang river basin. This is important for the better preparation for flood event in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Rainfall plays a vital role in water cycle. It contributes fresh water supply that are essential for human, animal, agriculture and industrial development. Fresh water is produced when water is evaporated from ocean or earth surface. Earth is called as "blue planet" because 72 percent of its surface is covered with water. Although earth has abundant water but only 3 percent of those water that is suitable and safe usage by humans. The most common water sources that consume by human are come from river and stream. This is because surface water is easy to reach and collect compare to the groundwater. The other 97 percent is salty ocean water. It is possible to separate possible to separate the salt from the ocean water through a process called desalinization. However, this process is very expensive. Hence, without rainfall life could be in another manner.

Precipitation also controls the natural hazards such as floods and droughts. Based on Chen et al. (2013), rainfall is used as an indicator of climate change. Rainfall volume and its distribution are the important elements for a climate research. Australian Department of the Environment and Energy stated that global hydrological cycle is strengthen with a warming climate. This means wet areas will get wetter whereas dry areas will be drier due to climate change. Every degree centigrade of warning will increase 7 percent of global water vapour. Warmer surrounding will hold more moisture compare to cold surrounding. Change of the rainfall patterns is one of the main factors that contributed by climate changes. Changes in rainfall patterns consequence the prediction for rainfall become more and more tough (Clark, 2011).

2.2 Hydrological Cycle

Hydrologic cycle also known as water cycle. It depicts how water exchanges between ocean, atmosphere, soil, groundwater system and land surfaces. It is a vital element for engineers and hydrologists to understand and describe the hydrological system. Water on Earth always move constantly and changing states. This cycle is an endless recycling process and water can exist in three different phases called solid, liquid or gas. The principle sources of hydrologic cycle are the water that comes from rivers and oceans. Water cycle begin with water evaporate from surface water due to the heat energy from the sun. This is the process where the liquid form of water changed into water vapour take place. Then, the rising air currents lifted the water vapour along with water from evapotranspiration from plants and soil into the air. Cooler temperature in the air condenses the water vapour and form clouds. As the cloud particle grows dense and become unstable, it precipitates in rain, snow, sleet or hail form. Most of the precipitation falls back to oceans or onto land as surface runoff. A portion of surface runoff enters back into the river via valley. Some runoffs infiltrate into the ground and become groundwater. Loaiciga (1995) said the key factor for climate's evaluation as greenhouse gases to continuous develop in the atmosphere is hydrological cycle. It helps to maintain the heat balance for Earth's surface atmosphere system.

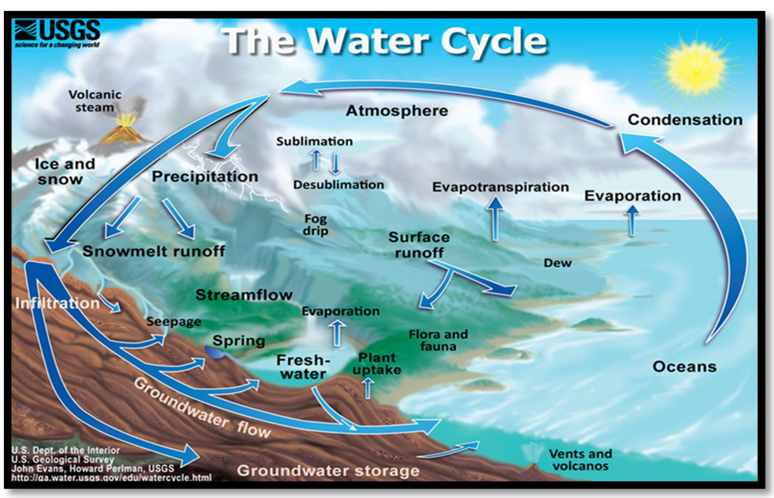

Figure 2.1 Hydrologic cycle

Source: U.S. Geological Survey (2004)

2.2.1 Evaporation

Evaporation is a process of convert liquid water into gas or vapour. 90 percent of the water in the atmospheric come from evaporation, while the remaining 10 percent is contributes from plant transpiration. Evaporation process need heat energy to break down the bonds that hold the water molecules together. This explains why water evaporates faster at boiling point compare to at freezing point. Solar radiation from the Sun is the primary energy source for evaporation. A water molecule spends around 10 days in the air once it evaporated (Pregun *et al.*, 2011).

2.2.2 Evapotranspiration

Evapotranspiration is the water that evaporates from ground surface combine transpires from plant. Transpiration happen when water vapour is released from plant's stomata. It is the result of chemical changes and biological changes of plant when undergoes photosynthesis process to convert carbon dioxide into oxygen. This process is important in water cycle since it subjects 15 percent of the water vapour in the atmosphere. Temperature, wind speed, soil type and type of plant are the factors that can affect evapotranspiration rate (Pregun *et al.*, 2011).

2.2.3 Condensation

Condensation is the reverse of evaporation. In this process water vapour changes into liquid water. Critical stage in water cycle because it is in charge of cloud formation. When water vapour rises up, they mix up with tiny particular called aerosol in the atmosphere. These tiny particulars are dust, soot and salt in the atmosphere. As the surrounding temperature drop, the water vapour changes into tiny particular of water and ice crystals. Cloud is formed when tiny water particle and aerosol stick together (Pregun *et al.*, 2011).

2.2.4 Infiltration

Infiltration occur when precipitation penetrate the soil surface and move into rocks via pore spaces. Water fall from atmosphere is absorbed by the soil. Infiltrated water can be stored by plant roots and later used for transpiration process. Factors that affect the rate of infiltration are type of soil, amount of precipitation, topography of land and area of vegetation cover (Pregun *et al.*, 2011).

2.3 Precipitation

According to Selase (2015), precipitation is any forms of moisture that falls from the sky onto the Earth surface under the influence of gravity. The precipitate can be in rain, snow, sleet hail, or glaze form. It is the principle source of water supply for Earth. Sufficient water vapour and the ability of rising air to carry the water vapour to higher altitude where it can condense are essential requirement to produce precipitation. It is the result of condensation in the atmosphere. Precipitation is the driving force of hydrological processes, sediment and chemical fluxes, and thus it is a crucial input data needed by the hydrologist to conduct hydrological models (Tuo, 2016). It will never distribute uniformly through the catchment area.

2.4 Types of Precipitation

Types of precipitation are depending upon the method in which the water vapour is lifted to onto the atmospheric and cooled so as to produce precipitation. There are three different kinds of precipitations such as conventional precipitation, orographic precipitation and cyclonic precipitation. Rainfall divide into three types and each one with characteristic features starting from conception stages until the final stages where it fall down to earth as rain (Selase *et al.*, 2015).

2.4.1 Conventional Precipitation

Zafar and Chandrasekar (2014) describes the convective precipitate is an intense short term rainfall with variable height of rain that may be up to more than 13km. Convective rain is more likely covers a small and localised area with limited duration. Convectional precipitation formed when the surface of the earth is heated by the Sun. It warmed the air a few metres above the ground and cause the moisture laden air rise due to its low density. In the atmosphere, the air cool down and condenses on the condensation nuclei. When it rises further it converges and continues to moves upwards steady. Large cumulonimbus clouds formed when condensation point is reached. The heavy and unstable cloud will create intense thunder storm (Selase *et al.*, 2015). Thunder and lighting is caused by the electrical charge due to the unstable conditions.

The unequal heating of the earth's surface cause convection. Conventional rain is normally found in the regions which near to equator.

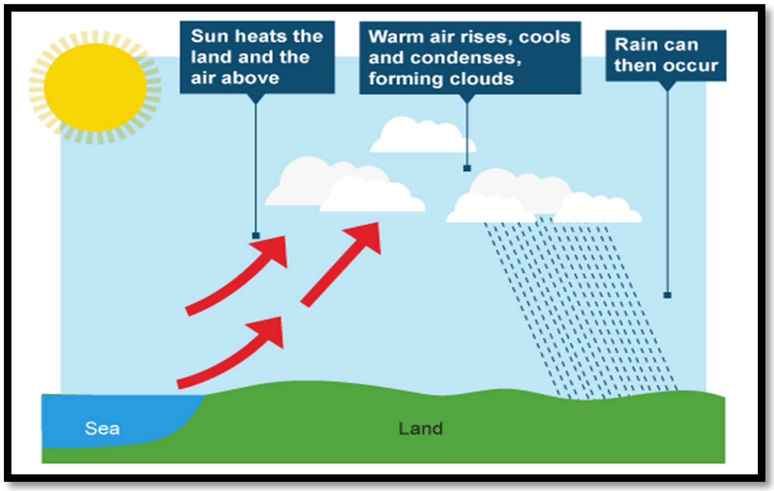

Figure 2.2 Conventional precipitation
Source: BBC (2014)

2.4.2 Orographic Precipitation

Orographic precipitation is formed when moist air is pushed by the wind towards mountainous terrain. As a consequence the moist air is lifted highly into the atmosphere. As the warm air rises, it cools and form orographic clouds. Most of the precipitation falls at the upwind of mountain ridge. While the remaining precipitation falls at the downward of the mountain ridge known as spillover. The opposite side of the mountain or leeward side usually receive low rain or no rain. This leeward side area also called as rain shadow. Basically orographic rainfall typically happens along slopes of slopes or in mountainous areas especially at the windward side where the water vapour is obstructs and forces by wind to rise (Selase *et al.*, 2015). This type of rainfall is common occur in British Columbia.

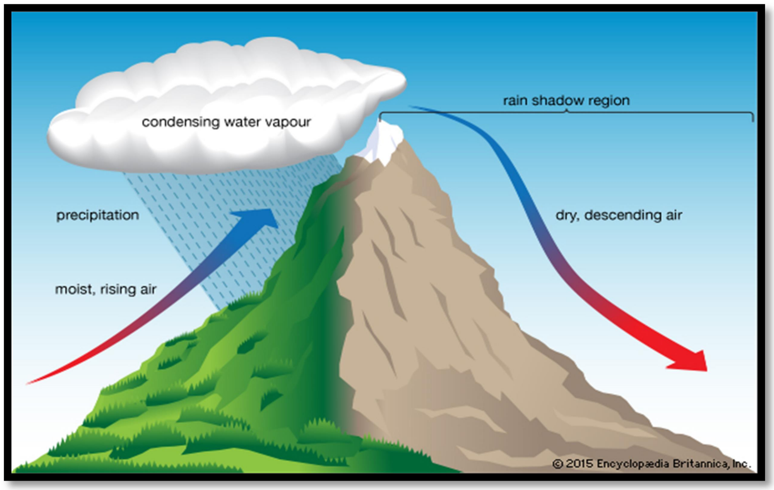

Figure 2.3 Orographic precipitation
Source: Encyclopaedia Britannica. Inc. (2015)

2.4.3 Cyclonic Precipitation

This typical precipitation is occurred by lifting the air mass due to the difference pressure created by the unequal heating on the earth's surface (Raghunath, 2006). Cyclonic precipitation can be derived into frontal precipitation and non-frontal precipitation.

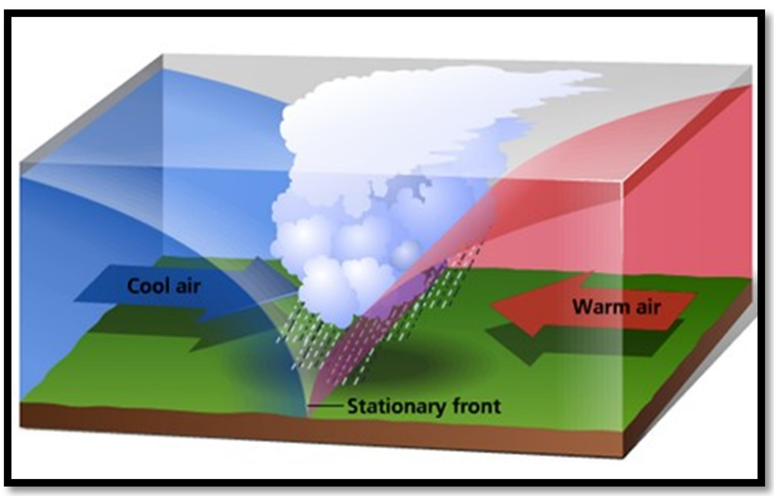

Figure 2.4 Cyclonic precipitation
Source: PMF IAS (2016)

Frontal precipitation is produced when two difference temperatures and densities air masses clash with each other. Front or frontal surface is an abrupt zone or boundary for cold air mass and warm moist air mass. A front can be either warm front or cold front. It depends on whether the warm air mass over cold and dense air mass is active or passive accent. The frontal precipitation happens due to the warm moist air is blocked by the stationary cold air mass. As a result, the warm air rises up due to its lighter weight compare to the cold air mass. This situation called as warm front. Similar result occurs when moving cold air mass meet stationary warm air mass. The stationary warm air mass is forced to move upward by the cold air mass. This scenario is known as cold front. At high altitude the lifted warm air mass cools down and form cumulonimbus clouds. The process will carry on until the whole warm air mass is passes over the cold air mass (Raghunath, 2006). Heavy rain happens along the front.

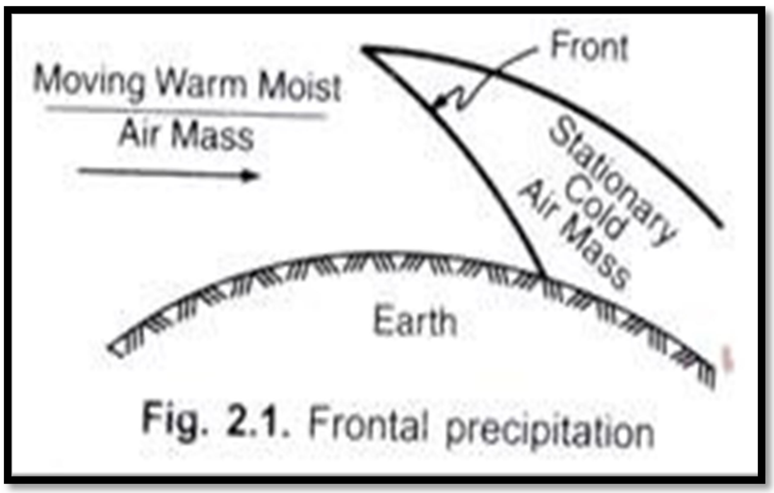

Figure 2.5 Frontal precipitation

Source: http://www.yourarticlelibrary.com

Non-frontal precipitation is resulted from the cold air mass moving toward to the stationary warm moist air mass. The front developed is known as stationary front. The cold air mass forced the warm air mass to rise. The warm moist air mass lifted because its mass is lighter than cold air mass. Lifted warm air mass cools down at the high altitude. Condensation occurs and it falls down to the ground as precipitation. Movement of cold front is faster than warm front and usually overtake warm front. Cold front will cause higher intensity rainfall on comparatively small area (Raghunath, 2006).

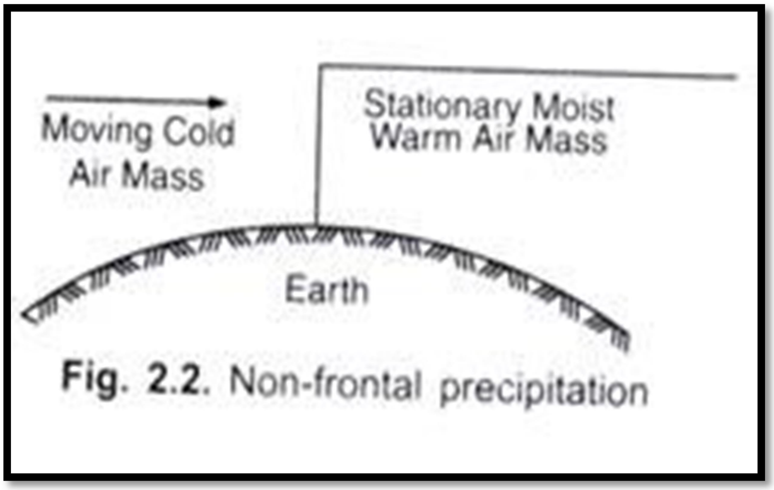

Figure 2.6 Non-frontal precipitation

Source: http://www.yourarticlelibrary.com

For warm front, the less dense air rises over the denser sir mass. Warm front has gentle slope than cold front and move slowly compare to cold front as the rising motion is more gradual along the warm fronts. This type of rainfall is generally less intense but it spreads over a relative large area (Raghunath, 2006).

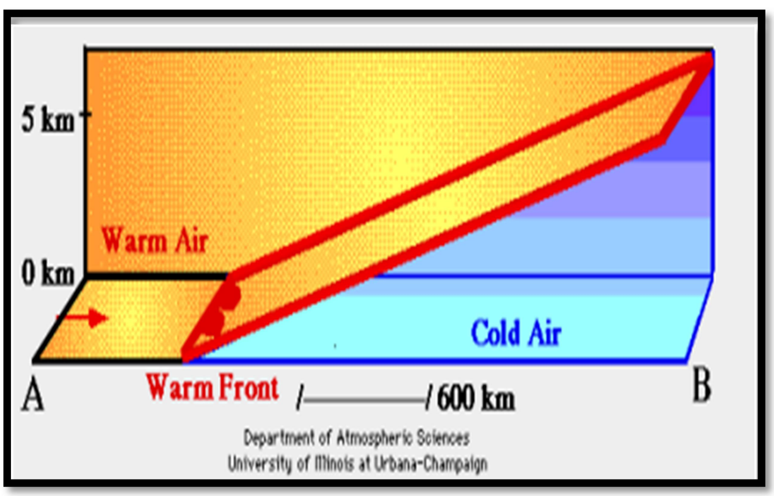

Figure 2.7 Warm front

Source: University of lllinois (2014)

2.5 Precipitation Intensity

Based on Malaysian Meteorological Department (MDM), the precipitation in Malaysia classify as follow:

Table 2.1 Precipitation intensity

Category	Intensity
Slight rain	Rate of fall less than 0.5mm per hour
Moderate rain	Rate of fall 0.5mm to 4mm per hour
Heavy rain	Rate of fall more than 4mm per hour
Slight showers	Rate of fall less than 2mm per hour
Moderate showers	Rate of fall 2mm to 10mm per hour
Heavy showers	Rate of fall more than 10mm to 50mm per hour
Violent showers	Rate of fall more than 50mm per hour

Source: http://www.met.gov.my

2.6 Significant of Precipitation

Precipitation science is essential for numerical modelling, remote sensing, hydrology or forecasting. However, rainfall is difficult to predict due to its irregular spatial occurrence and diversified physical process. It used as primary input for hydrological models to predict stream flow. It also significant to detect the future water availability and study global water cycle through precipitation estimate for over land and oceans. Measuring and predicting precipitation allow early preparation for future events. The ability of the precipitation measurement has a closely relationship with the skill of forecasts. The precise the precipitation measurement, the higher the probability of improved the precipitation data and other meteorological parameters (Tapiador *et al.*, 2012).

2.7 Precipitation Measurement

There are several methods to measure the rainfall. Precipitation data can be obtained from surface gauge measurement and satellite estimates. Rain gauge, radars, and disdrometer are the examples for ground observations precipitation. Rain gauge is a simple instrument that provides direct rainfall record for the certain area. Disdrometer is used to estimate the total precipitation and each rain drop size category to the total. Both instruments suitable practice at small sampling area and they only respond to individual drops. Ground radar present the estimation of precipitate data based on the backscattered echo large catchment area (Tapiador *et al.*, 2012).

2.8 Rain Gauge

Rain gauge is widely used by meteorologists and hydrologist around the world. It considered as the most accurate method to measure the rainfall data as it provides the direct physical measurement of rain (Krishna, 2017). Rain gauge can be classified into conventional and automatic rain gauge.

2.8.1 Conventional Rain Gauge

The picture below depicts the conventional rain gauge. It is a circular cylinder with a diameter of 203mm (8 inch). Inside the cylinder consist of a funnel and a plastic measuring tube. Rain water is collected inside the calibrated cylinder. The cylinder can measure precipitation up to 25mm and the excess precipitation will be captured in the outer metal cylinder. The rim of the funnel is must be 0.3m above the ground.

Figure 2.8 Conventional rain gauge
Source: http://www.met.gov.my

2.8.2 Automatic Rain Gauge

i. Tipping Bucket Rain Gauge

Tipping bucket gauge is the most common recording rain gauge used in Malaysia. It consists of a collector funnel that diverts the rain water to the tipping bucket mechanisms. Below the funnel has a pair of tipping buckets, when one of the buckets receive 0.25mm of precipitation it tips and discharge the rain water into a tank below it. Another bucket takes its position and the process repeats.

200mm/hour is the maximum precipitation that can be detected using tipping bucket. It is the only recording gauge which can install at the remote places (Reddy, 2006).

This type of instrument is not suitable for heavy precipitation which rates above 300mm/hour. Saturation effect is produced at high precipitation rates although this effect is uncommon. The effect is the result of rain water accumulates in the collector funnel faster than the draining capacity of buckets. Rain water evaporates from the collector funnel or bucket due to little precipitation also another issue. The collector is blocked by leaves and insects or dust in the mechanism could affect the measurement timing that relative to other instruments (Tapiador *et al.*, 2012).

Figure 2.9 Tipping bucket gauge
Source: http://www.met.gov.my

ii. Weighing Bucket Type Rain Gauge

The rain gauge consists of a built in bucket that is supported by a spring. As water enters the bucket, its weight increases and a direct measurement of precipitation is produced. The movement of the bucket is transmitted to the recording pen where its content is marked on a clock work driven chart. The record of rainfall for this gauge is in the form of mass curve graph. Mass curve is a plot of cumulative rainfall value against time.

This modern gauge instrument is less common and more expensive. The effect of saturation is not an issue for this type rain gauge (Tapiador *et al.*, 2012). During heavy Aside from measure the rainfall, it also can record snowfall. It is suitable use at a region where the precipitation is in the form of water droplet and snow (Patil and Tandon, 2017).

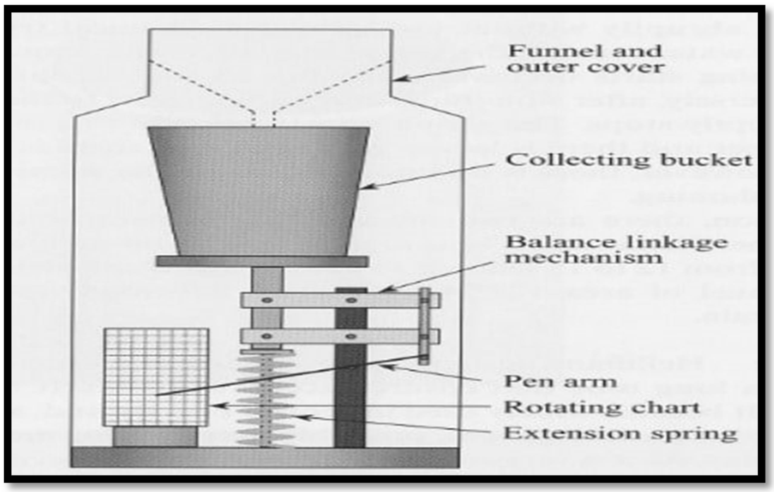

Figure 2.10 Weighing bucket type rain gauge
Source: https://theconstructor.org

iii. Natural Syphon Type Rain Gauge

The mechanism of this typical rain gauge is almost similar with weighing bucket type rain gauge. The rain water is collected at the rectangular container via the funnel. The float at the bottom of the container rises as the water level increases in the container. As the float rises, the rainfall is recorded on a rotating clock drum driven by the pen that attracted the float through a lever system.

When the float reaches the maximum level, the syphon wills start operate and the water is released out of the container through the connecting pipe. All water inside the container is drained out. It is the common standard recording rain gauge used in India. The graph formed by this instrument is known as mass curve of rainfall. They are most expensive compare to the non-recording rain gauge.

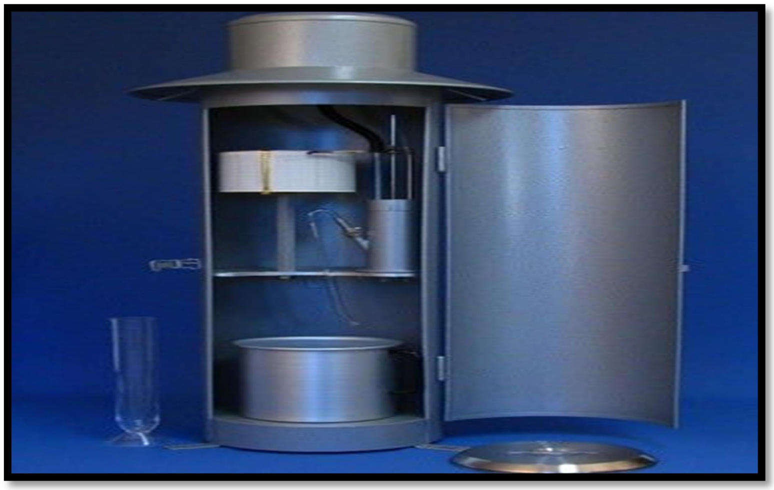

Figure 2.11 Natural syphon type rain gauge
Source: https://theconstructor.org

2.9 Radar

Radar system is a feasible technology that used to record rainfall orientation and movement. This is because the collected data can be providing more detailed information relate to the vertical and horizontal rain structure. It also can determine the signal interference and rain distribution. Evaluate and classify type of rainfall event is easily using radar system as large number of ground radar is available. Range height indicator (RHI) is one of the radar displays that can used to classify the types of precipitation. The height of rain, cell size of rain and reflectivity values can be obtained from RHI raster scan. Meanwhile, from the RHI views can observe the vertical variability of rain structure at instantaneous time (Badron *et al.*, 2015). Suitable used to forecast the flood event and can detect dangerous meteorological phenomena.

Figure 2.12 Terminal doppler radar at KLIA
Source: Nordila (2015)

2.10 Disdrometer

Disdrometer is an instrument that can measure the size distribution of rain drop and estimate the total precipitation. Drop size distribution is the crucial parameter for microwave-based estimation of rainfall (Tapiador *et al.*, 2012).

Figure 2.13 Disdrometer at Everglades National Park
Source: NOAA (1999)

2.11 Location of Rain Gauges

Several precautions and requirement when selecting a site for rain gauge must be follow strictly according to the Indian Standards (Reddy, 2006). Here are the precautions: (a) The rain gauge must be placed at ground level, (b) The rain gauge should be located in the regions that is free of obstacles, (c) The distance of rain gauge from any obstacles shall be twice the height of the obstacle, (d) The rain gauge installed at the hill area must be shield from high winds, (e) The rain gauge shall be surrounded by an open fence area, (f) The location of rain gauge should be easily access, and (g) The rain gauge should be maintenance regularly.

2.11.1 Rain Gauge Network

According to Subramanya (2013), World Meteorological Orgainzation (WMO) recommends as follow:

Table 2.2 Rain gauge network

Location	Category
In flat regions of temperate, Mediterranean and tropical zones	Ideal – 1 station for 600 to 900 km^2 Acceptable – 1 station for 900 to 3000 km^2
In mountainous regions of temperate, Mediterranean and tropical zones	Ideal – 1 station for 100 to 250 km^2 Acceptable – 1 station for 25 to 1000 km^2
In arid and polar zones	1 station for 1500 to 10 000 km^2 depending on the feasibility

Source: Subramanya (2013)

In rain gauge station, 10 percent of the gauge should be self-recording type in order to know the rainfall intensity in the station.

2.12 Climate Change

Climate change is unstoppable and inevitable. Changes of precipitation frequency and intensity have a direct relationship with the global warming and climate change. Global warming is caused by anthropological impacts including urbanization, burning of fossil fuel and emission of greenhouse gases. A research have been done by the climatic research unit from University of East Anglia had proven there is an exponential increase in global temperature from 1945 to 1973. It is believed that the extreme increase of temperature is the result of urbanization and emission of carbon. The effect of rapid economic development in the urban area on climate change is the rise of temperature that caused by urban activities and buildings. Thus, these change in temperature has bring immediate effect to the global rainfall distribution (Brohan *et al.*, 2006).

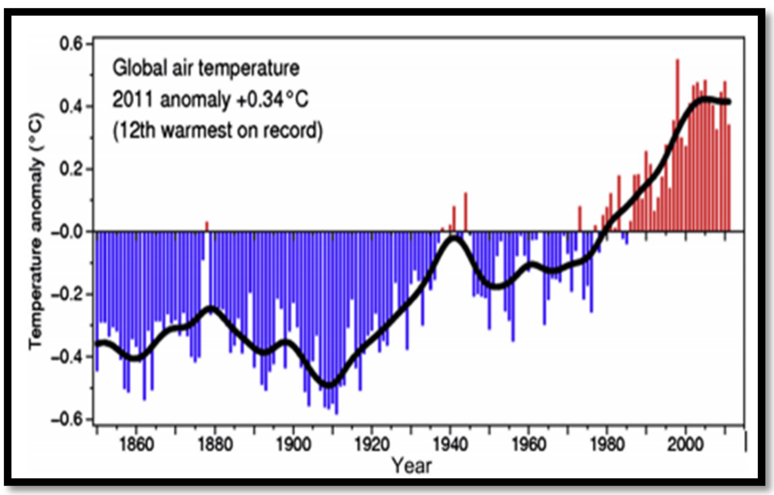

Figure 2.14 Global temperature anomaly from 1850 to 2010

Source: Brohan et al. (2006)

Another study done by NOAA-NCDC (2011) depicts the data from 1950 to 1970 has more negative precipitation anomalies than positive precipitation anomalies. After 1970, the precipitation anomalies fluctuate frequently between positive and negative because it follows the rise of global air temperature. Hence, it is proven that beyond 1970s there is a close relationship between global temperature increase and changes of precipitation (National Oceanic and Atmospheric Administration, 2012).

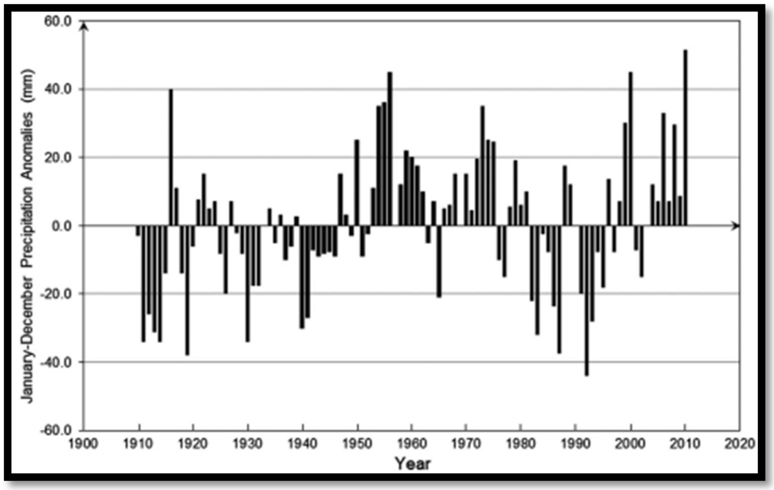

Figure 2.15 Global precipitation anomalies from 1910 to 2010
Source: NOAA-NCDC (2011)

A scientific report published by Malaysian Meteorological Department (MDM) on 2009 showed the trend of annual temperature at four different meteorological stations located at Kuching, Kota Kinabalu, Kuantan and Petaling Jaya. Each of this station represent different region of Malaysia. From the figure 2.14, it is obviously all temperature trends for four stations are increasing. Among the four stations Kuching was the least increase is due to the slower urban development and largest forest area within Sarawak compare to other district. 1972, 1982, 1987, 1991, and 1997 recorded strong El Nino events that occurred in Malaysia. All the stations had recorded maximum annual temperature during these five years. Sarawak and eastern Peninsular Malaysia had the lower temperature than Sabah and western Peninsular Malaysia (MDM, 2009).

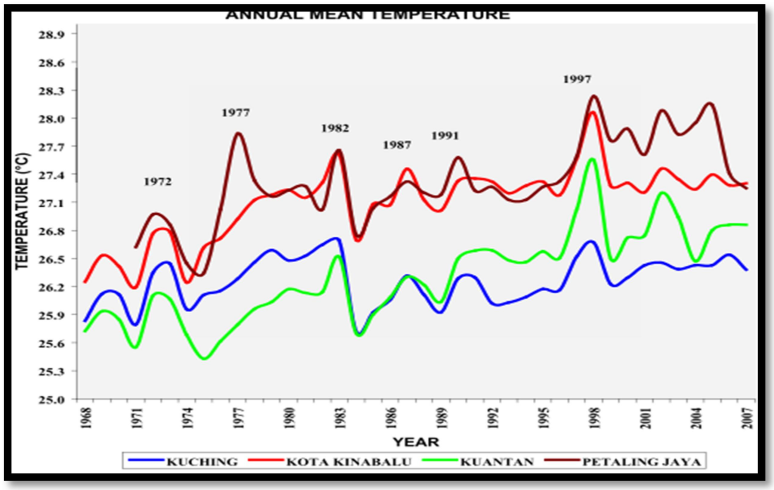

Figure 2.16 Annual mean temperature trend for 4 meteorological stations in Malaysia

Source: Malaysian Meteorological Department (2009)

The report also proven that the variable of rainfall from 1951 to 2005 for Peninsular Malaysia is due to the changes of global temperature. Figure 2.17 shows the standardized annual rainfall anomaly of Peninsular Malaysia. It is used to evaluate the pattern of rainfall. El Nino and La Nina events that occurred within this period will be indicated. This is to ensure better understanding on how these events affect the pattern of rainfall in Peninsular Malaysia. From the figure below, it is clearly shown that dry years are more frequent happened from 1975 to 2005 compare to from 1951 to 1975. El Nina events occurred in 1963, 1997 and 2002 had been recorded as the most three driest years in Peninsular Malaysia. Nevertheless, most of the La Nina events happened in Peninsular Malaysia resulted wet years for the specific region (Malaysian Meteorological Department, 2009).

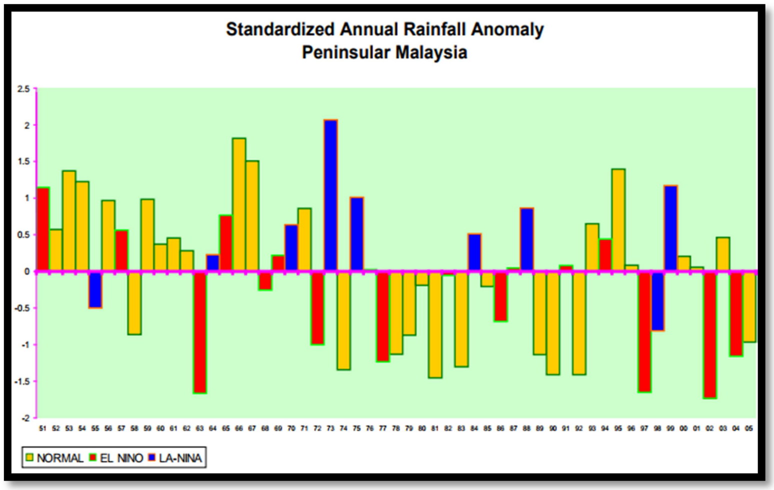

Figure 2.17 Standardized annual rainfall anomaly from 1951 to 2005
Source: Malaysian Meteorological Department (2009)

Figure 2.18 depicts the Peninsular Malaysia seasonal precipitation pattern maps. The trend of seasonal rainfall in 1998 to 2007 is decreasing as compare to in 1961 to 1990 except for June July August (JJA) only. The wettest months occurred in March April May (MMA) whereas June July August (JJA) was the driest months for Peninsular Malaysia. Besides, September October November (SON) and December January February (DJF) are the best evidence to show the difference seasonal pattern of rainfall between the east and west side of Peninsular Malaysia. Eastern Peninsular Malaysia suffered higher amount of rainfall during SON while western Peninsular Malaysia experienced higher rainfall intensity during DJF. Minimal rainfall amount was experienced at the north western of Peninsular Malaysia during SON (Malaysian Meteorological Department, 2009).

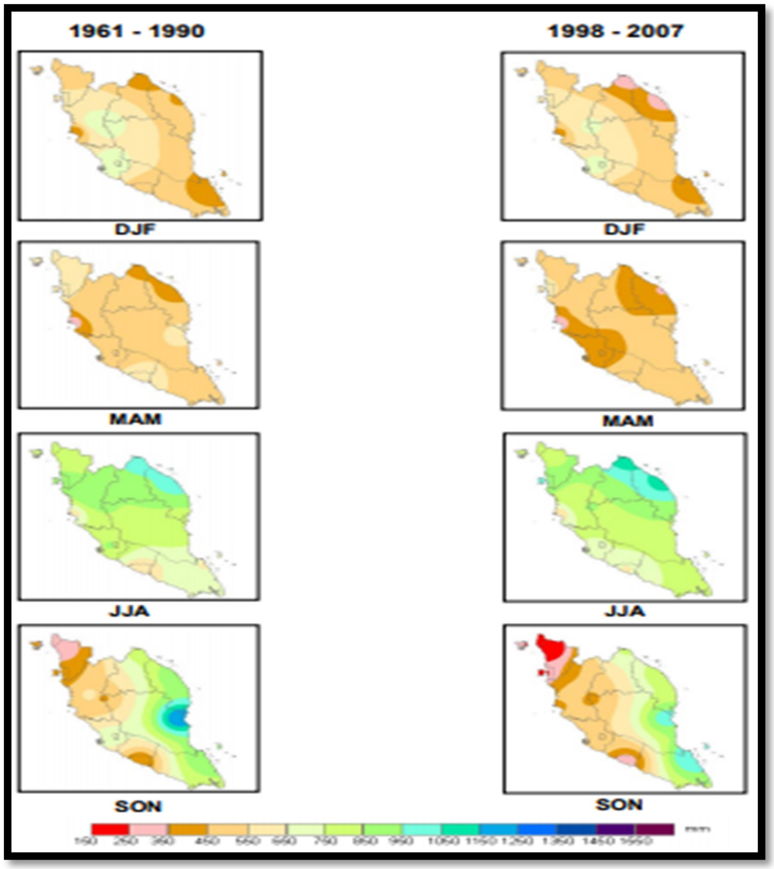

Figure 2.18 Long term mean rainfall

Source: Malaysian Meteorological Department (2009)

2.13 Wind Flow

Schewe and Levermann (2012) believed that the temperature increase in the late of 21st century and the early of 22nd century will cause the monsoon precipitation change frequently and shifts up to 70 percent below the normal level. Not only Indian summer monsoon is affect, the onset of monsoon over countries in Southeast Asia countries such as Malaysia, Philippines, Singapore or Thailand may delay 15 days in the future (Ashfaq *et al.*, 2009). Seasonal reversals of wind flows pattern are one of the factors that influence the climate of Southeast Asia. Four types of monsoon seasons are formed in Malaysia due to the changes of wind pattern (Malaysian Meteorological Department, 2017).

2.13.1 Northeast Monsoon

Northeast monsoon began in November until March and it is characterized by a constant wind blow from east or 10 to 30 knots of northeasterly wind. Northeast monsoon is also known as wet season because during these period Southeast Asian countries especially southern Indonesia, east coast of Peninsular Malaysia and southern Thailand will experience rainy season. East coast states that located in Peninsular Malaysia such as Pahang, Kelantan or Terengganu will receive more intensity of rainfall. Heavy rainfall is the result of the surge of cold air from the outbreaks from Siberia. Northwest region of Peninsular Malaysia receive less rainfall due to the existence of Titiwangsa range which obstruct the wind flow (Fakaruddin *et al.*, 2015).

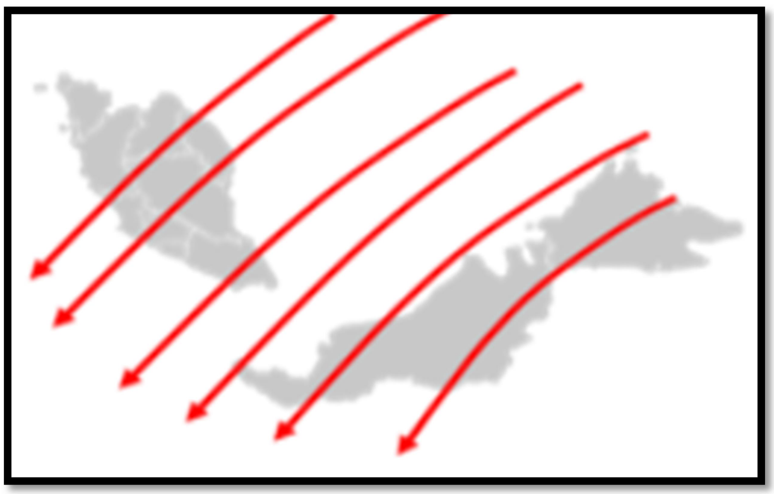

Figure 2.19 Northeast monsoon

Source: http://www.met.gov.my

2.13.2 Southwest Monsoon

Western parts of the Peninsular Malaysia tend to receive higher rainfall during southwest monsoon. It is commenced from May until September and called as northern hemisphere summer monsoon. The wind blow from southwest and it is a light wind which approximately below 15 knots. Atmosphere more stable so less intense convection precipitation is developed, thus most states in the country experience dry days more than wet days (Fakaruddin *et al.*, 2015).

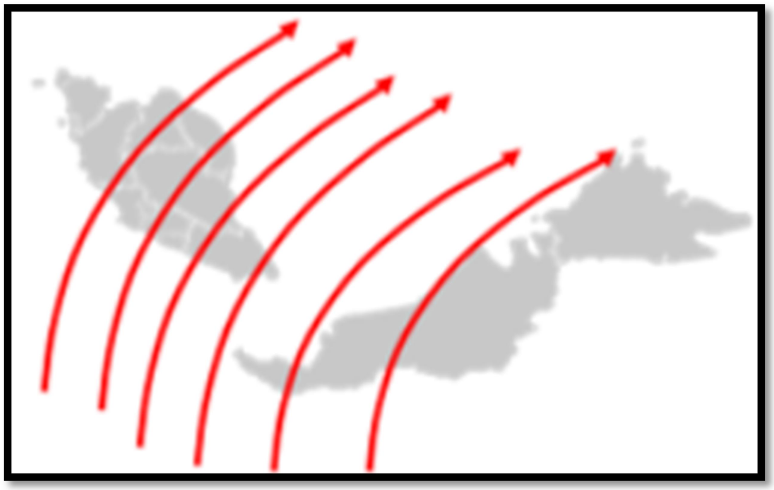

Figure 2.20 Southwest monsoon
Source: http://www.met.gov.my

2.13.3 Inter-Monsoon

Inter-monsoon is established from March to early May and October to mid-November. The wind is frequently varies and the speed less than 10 knots. Strong convection clouds are formed over the west states of Peninsular Malaysia, Sarawak and Sabah in the late of mornings and early afternoons. As a result during inter-monsoon season these region often experience thunderstorms in the afternoon (Fakaruddin *et al.*, 2015).

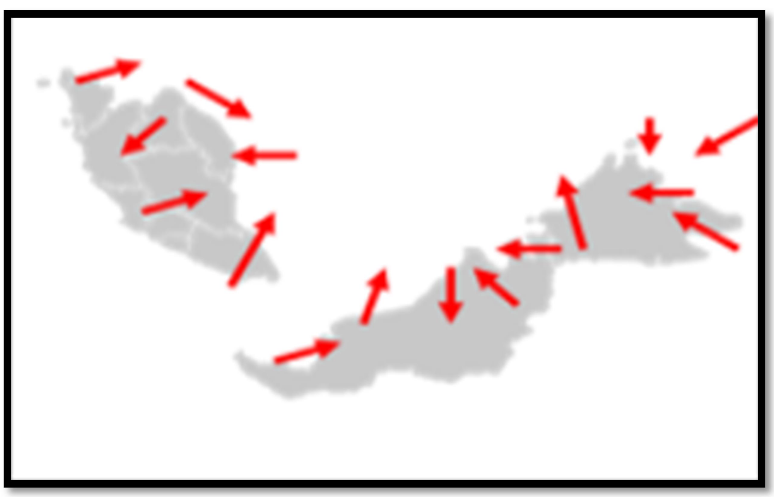

Figure 2.21 Inter-monsoon
Source: http://www.met.gov.my

2.14 Flood

Flood can be defined as a temporary condition where a dry land area is inundated partially or completely by water as a result from the rapid accumulation of surface runoff water or overland of inland. It is an environmental hazard that is unpredicted and forced by pushing factors such as urbanization and change of climate. This event will cause primary and secondary long term impact to people. Primary impact referred to the direct effects to people includes the damage of public property and infrastructures, loss of human life, shortage of resources and failure of sewerage system. Meanwhile, secondary long term effect lead people suffer from loss of family member, homeless, or spread of infectious disease (Hua, 2014). 9 percent of the country is located in the floodplain area with estimated a total of 4.915 million of people is affected by flood (Tahir *et al.*, 2015).

Since 20th century global warming, flood events have been intensified rapidly. Flooding events occurred in Southeast Asian countries can proof that monsoon rainfall is changing nowadays (Loo *et al.*, 2015). This is because the intensity of rainfall increases during monsoon seasons not only can cause flooding events but also a major source for landslide event (Billa *et al.*, 2004). These monsoon flooding events have negatively impacted the Southeast Asia people. Hence, without a doubt the patterns of precipitation have been changed globally in recent. In Malaysia, flood occurrence is categorized into two categories known as flash flood and monsoon flood (Tahir *et al.*, 2015).

2.14.1 Flash Flood

Flash flood is the result of high rainfall intensity take place in the urban area. It is formed faster than monsoon flood event and has high effect on the public infrastructure of urban area because of the drainage system failure. The effect is caused by the limited time that available for the preparation for flood mitigation and evacuation. Flash flood usually happen at rapid grows urban area such as Kuala Lumpur and Penang. Based on Tahir et al (2015), in 2012, 6 flash floods event is recorded at Kuala Lumpur. The worst flash flood event happened at 2 May 2012, which has the substantial effect on the infrastructure and result financial damage to the government.

Figure 2.22 Flash flood in Klang Valley
Source: The Star Online (2012)

2.14.2 Monsoon Flood

In general, flash flood takes a few hours for the water to return to its normal level whereas monsoon flood can take up to a month for the water to recover back to its original level. Monsoon flood can be characterized as a natural disaster that occurs due to the alter pattern of wind flow. Kelantan, Pahang, Sabah and Sarawak tend to receive higher intense storm compare to west coast of Peninsular Malaysia during wet season. Several methods are developed to prevent or reduce monsoon floods include improve drainage system, deepen the river, construct a flood warning system, organize awareness campaigns and fortifications. Although monsoon flood causes severe negative impact to society but it also give several advantages. The advantages for these flood event are increase nutrients for some soils, fertilize soil and recharge the ground water (Taib *et al.*, 2016).

Figure 2.23 Monsoon flood in Terengganu
Source: The Sun Daily (2017)

2.15 Missing of Precipitation Data

A sufficient long term record of rainfall data is needed for all water related studies. Rainfall data should be consistent and continuity in order to obtain accurate results from such studies. Nonetheless, these series of rainfall data often contain missing values due to certain reasons including the instrument failure, absence of observer, and vandalism of recording rain gauges (Caldera *et al.*, 2016).

2.16 Traditional Method for Analysis Missing Data

Several traditional techniques such as station average method, normal ratio method and quadrant method have been introduced to analysis the missing rainfall data.

2.16.1 Station Average Method

This method also called as simple arithmetic average method is the simplest equation used to estimate the missing precipitation data. Value of missing rainfall data is determined by taking the average of the rain gauge station's record. This method is applied when the normal annual rainfall at the stations are within 10 percent of the normal annual rainfall at interpolation station which is station X (Subramanya, 2013). Rainfall records should be at least from 3 surrounding rain gauges to provide good results.

$$P_x = \frac{1}{m}[P_1 + P_2 + \ldots + P_m] \quad 2.1$$

2.16.2 Normal Ratio Method

This method is preferable when the normal annual precipitations at the index stations are greater than 10 percent of the normal annual rainfall at interpolation station (Subramanya, 2013). The percentage differ might occur in a region where there has larger elevation difference or where high annual variability but has low average annual precipitation. Minimum 3 surrounding rain gauge stations are generally applied in normal ratio method.

$$P_x = \frac{N_x}{M}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \ldots + \frac{P_m}{N_m}\right] \quad 2.2$$

2.16.3 Quadrant Method

This method assumes that each station weight is inversely proportional to its distance from the estimated point. The missing value is calculated by weighted average of the rainfall at the surrounding rain gauge stations (Subramanya, 2013).

$$P_x = \frac{\sum_{i=1}^{N} \frac{1}{d^2} p_i}{\sum_{i=1}^{N} \frac{1}{d^2}} \quad 2.3$$

2.17 Spatial Interpolation Method

Spatial interpolation method is the most advanced technique to determine the spatial of rainfall data. It calculates an unknown value from a set of known values sample that distributed over the area. This method can be categorized into two main groups which is geostatistical method and deterministic method (Sarann, 1997).

2.18 Deterministic Method for Analysis Missing Data

This method includes simple mathematical calculations and interpolate based on the surrounding values. Inverse Distance Weighting (IDW), Global Polynomial interpolation and Local Polynomial interpolation methods are the examples for deterministic method.

2.18.1 Inverse Distance Weighting (IDW) Method

Inverse Distance Weighting (IDW) is the most simple interpolation method. This technique assumes things that are close to one another are more similar compare to those that are further. IDW uses the measured values from the surrounding of prediction location to estimate a value for unmeasured location. The closest the measured values to the prediction location will have stronger influence to the predicted value. This method assumes that for each measured point will has a local effect that diminishes with distance. It offers greater weights for points that are closer to the prediction location, hence it called as Inverse Distance Weighted (Johnston *et al.*, 2013).

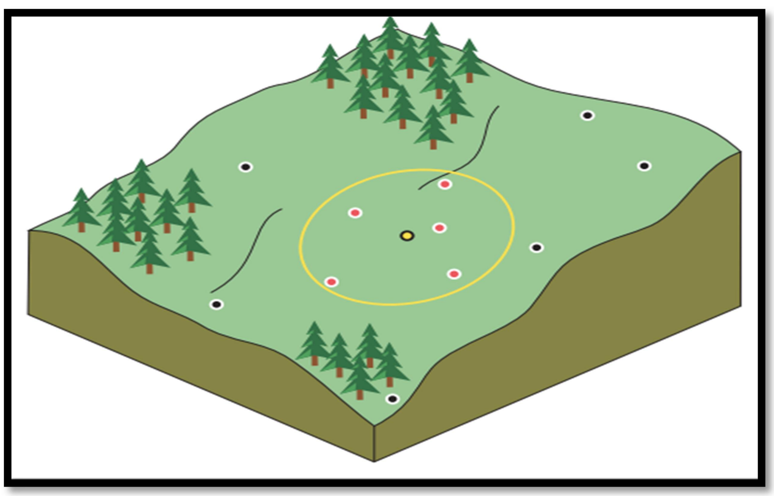

Figure 2.24 Inverse Distance Weighting (IDW) method
Source: Johnston et al. (2013)

The above figure depicts that how IDW works. It used 5 measured points (red point) from the surrounding of prediction location to estimate the unknown point (yellow point).

$$\hat{Z}(s_0) = \sum_{i=0}^{N} \lambda_i Z(s_i) \quad (2.4)$$

The value $\hat{Z}(s_0)$ is the prediction value for location s_0 whereas $Z(s_i)$ is the observed value for location s_i. N is the total measured sample point numbers around the prediction location and λ_i is the weight gave to each measured point.

$$\lambda_i = d_{i0}^{-p} / \sum_{i=1}^{N} d_{i0}^{-p} \quad (2.5)$$

$$\sum_{i=1}^{N} \lambda_i = 1 \quad (2.6)$$

Equation 2.5 and 2.6 show the formula to calculate the weights. The parameter p will reduce the weight when distance (d_{i0}) between prediction location and measured location becomes larger. The weights are scaled so that the sum of weight is equal to 1.

According to Bhowmik and Cabral (2006), Inverse Distance Weighting method provide more greater predictive skill compare to kriging method for small sampled datasets. This method work best for even spacing and dense sample point sets. If the sampling point is sparse, the result obtained might not sufficient to represent the desired surface (Johnston *et al.*, 2013). The advantages of this technique are: (a) Estimate extreme terrain changes, (b) Well interpolate result for dense and even space point and, (c) Amount of sample points can be increase or decrease to influence cell values. Nevertheless, it is not capable for use in mountainous areas.

2.18.2 Global Polynomial Interpolation

Global Polynomial interpolation will develop a smooth mathematical surface from the input sample points. The surface of Global Polynomial varies slowly and gradually using low order polynomials. It also can detect coarse-scale pattern in the data. In general, it is harder to ascribe the physical meaning for more complex polynomial equation. However, there is no assess to predict the errors and the surface produced may be too smooth (Sadeghi *et al.*, 2017). This is because the calculated surfaces are subjected highly to the outliers especially for location at the edges.

This technique is suitable to fit a smooth surface to the sample points when the surface changes slowly from one region to another region within the area of interest. It always referenced as trend surface analysis because it can exam or remove the long range or global trends effect (Johnston *et al.*, 2013).

2.18.3 Local Polynomial Interpolation

Local Polynomial interpolation is considered as moderately quick interpolator. It can fit many polynomials and each of the polynomial located within the specified overlapping neighbourhood. While, Global Polynomial interpolation only can fit a polynomial to the whole surface. It also can specify the section configuration, shape or minimum and maximum number of points to be use. This technique is more flexible compare to the Global Polynomial method since it provided prediction, prediction for standard error, and the number of surfaces condition that are comparable with Ordinary Kriging method (Sadeghi *et al.*, 2017).

2.18.4 Comparison of Deterministic Methods

Based on ArcGIS Geostatistical Analyst (2013), the comparison for the above the tree method is show in the table below:

Table 2.3 Comparison for deterministic methods

Method	**Modelling Time**	**Exact Interpolator**	**Advantages**	**Disadvantages**
Inverse Distance Weighted	Fast	Yes	Decision for few parameters	No assess for error prediction
Global polynomial	Fast	No	Decision for few parameters	No assess for error prediction; large influence at the edge points; too smooth
Local polynomial	Moderate	No	Decision for few parameters	No assess for error prediction

Source: ArcGIS Geostatistical Analyst (2013)

2.19 Geostatistical Method for Analysis Missing Data

Geostatistical method is more complex compare to deterministic method. It interpolates based on analysis of regression obtained from the geostatistical models. Probabilistic models and risk can be determined since this method can generate the errors and uncertainties. It can indicate how good the predictions are (Johnston *et al.*, 2013). Kriging and Cokriging are some of the geostatistical techniques used to interpolate the spatial distribution.

2.19.1 Kriging

The most complex and powerful interpolators compare to the deterministic interpolator. This type of interpolator not only can form a predict surface but it also has the ability to provide some measurement for the accuracy of predictions. Kriging used the information form the sample points to predict the missing value at the unknown location. This method is similar with Inverse Distance Weighting (IDW) because it used a weighted average of sample points to identify the unknown points. The difference between these two methods is in what way those weights are specified. In IDW, the weights are based on distance between prediction location and measured location. In Kriging, weights are depended on distance and the overall arrangement of spatial among the measurement points that help to produce the accurate unknown values (Gruver, 2017).

Kriging is depending on the statistical model and mathematical. The advantages of this technique are ability to produce error surface output and incorporation of variable interdependence. However, it requires more input and more time for the modelling process. This interpolator is moderate quick and can be precise if the data do not have measurement error or smoothed if there is any measurement error in the data. Flexible techniques that allow investigate spatial autocorrelation in the data as it used statistical models which allow prediction, standard error of the prediction, quantile maps and probability. However, the flexibility offer by kriging requires many decision making that is relative to the other methods. Varies kriging types have been developed to use for different types of data and each of it has different underlying assumption such as Ordinary Kriging, Simple Kriging, Universal Kriging and Indicator Kriging (Johnston *et al.*, 2013).

A study has been carried out to obtain the missing precipitation data at South Korea. Four interpolation methods including Ordinary Kriging (OK), Universal Kriging (UK), Inverse Distance Weighing (IDW) and Spline were chosen and compared. It founds out that OK generate the most accurate value while IDW produce values that are closer to the range (Dong *et al.*, 2015). The result depicted from OK also can reduce the error from original data of climate change for South Korea coastal (Dongwoo *et al.*, 2015).

2.19.2 Cokriging

When there are multiple data types available, Cokriging is the best interpolation method to be used. This moderate quick interpolator is almost similar with kriging method. It considers the spatial correlation between variate of interest and secondary variate in order to minimize the variance of estimation error (Sadeghi *et al.*, 2017). If the primary variate is hard to obtain or it is very expensive, Cokriging can used to improve the estimation for interpolate without having too much sample in the primary variate.

This interpolation method can be classified into Ordinary Cokriging, Universal Cokriging, Simple Cokriging, Indicator Cokriging, Disjunctive Cokriging and Probability Cokriging. Indicator Cokriging, Disjunctive Cokriging and Probability Cokriging are nonlinear methods which mean it only can do the exact prediction. On the other hand, Ordinary Cokriging, Universal Cokriging and Simple Cokriging can allow measurement for error models (Johnston *et al.*, 2013).

2.19.3 Comparison of Geostatistical Methods

Based on ArcGIS Geostatistical Analyst (2013), the comparison for the above the tree method is show in the table below:

Table 2.4 Comparison for geostatistical methods

Method	Modelling Time	Exact Interpolator	Advantages	Disadvantages
Kriging	Moderately fast or slower	Yes but without measure for error; No with measure of error	Many decisions for parameter; can provide standard error prediction; very flexible	Need to decide many decisions including the models, parameters, trends, transformations and neighbourhoods
Cokriging	Moderate or slowest	Yes but without measure for error; No with measure of error	Many decisions for parameter; can provide standard error prediction; very flexible	Need to decide many decisions including the models, parameters, trends, transformations and neighbourhoods

Source: ArcGIS Geostatistical Analyst (2013)

2.20 Cross Validation

Cross validation technique is used to evaluate the performance of spatial interpolation method. It will compare the predicted values with the observed values that obtained from the available set of sample data. This means that some values from the observation point were temporarily removed from the original sample data set. Then using the remaining sample data, the value at that location was estimated (Wijemannage *et al.*, 2016). The purpose of this technique is to investigate how good the neighbouring stations estimate the missing data (Taesombat and Sriwongsitanon, 2009). Several performance measurements such a mean absolute error (MAE), root mean square error (RMSE), standardized root mean squared error (SRMSE), and goodness of prediction measure (G) have been applied to evaluate the accuracy of spatial interpolation techniques.

2.20.1 Mean Absolute Error (MAE)

Mean absolute error measured the average difference between predicted value ($\hat{Z}_i$) and observed value (Z_i). The symbol n represents the number of number of rain events. MAE determines the range of error for the calculated values and the error given is in quantitative (Chen *et al.*, 2017). Smaller value of MAE indicates that the predicted value is more precise.

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|Z_i - \hat{Z}_i\right| \qquad 2.7$$

2.20.2 Root Mean Square Error (RMSE)

Root mean square error calculated the average error magnitude. It can help to reflect the sensitivity of interpolation and extreme effects related with the sample data (Chen *et al.*, 2017). Lower RMSE value represent the greater the central tendencies and the smaller the extreme errors (Taesombat and Sriwongsitanon, 2009).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Z_i - \hat{Z}_i)^2}{n}} \qquad 2.8$$

2.20.3 Standardized Root Mean Squared Error (SRMSE)

The spatial interpolation method with the smaller SRMSE value is the better schemes.

$$\mathrm{SRMSE} = \frac{\sqrt{\sum_{i=1}^{n}(Z_i - \hat{Z}_i)^2}}{\frac{1}{n}\sum_{i=1}^{n} Z_i} \qquad 2.9$$

2.20.4 Goodness of Prediction Measure (G)

Goodness of prediction measure showed how effective a prediction. The estimation is perfect if the G value is equal to 100%. If the value obtained is negative then the prediction is less accurate or reliable than the use of average of data values (Dong *et al.*, 2015).

$$G = \left(1 - \frac{\sum_{i=1}^{n}(Z_i - \hat{Z}_i)^2}{\sum_{i=1}^{n}(Z_i - \bar{Z})^2}\right) \times 100 \qquad 2.10$$

2.21 Mean Precipitation over an Area

Areal distribution of precipitation is essential for most hydrologic analysis and watershed management. Usually, distribution of rainfall over a large catchment area is not uniform. Areal precipitation analysis is used to estimate the average precipitation depths over the catchment area. The precise and reliability of the measured rainfall at one gauge is a function of : (a) Distance from the centre of representative area to the gauge, (b) Size of area, (c) Topography at the representative area and (d) Characteristic of local storm pattern. Generally, mean precipitation over an area is analysed using arithmetic average method, thiessen polygon method or isohyetal method (Goyal, 2016).

2.21.1 Arithmetic Mean Method

It is the simplest and fastest method to calculate the mean of precipitation at individual gauge stations in the area. Arithmetic mean method is suitable to adopt if the rain gauges at the station are uniformly distributed and the flat topography at the station (Goyal, 2016).

$$\bar{P} = \frac{1}{m}[P_1 + P_2 + \ldots + P_m] \qquad 2.11$$

2.21.2 Thiessen Polygon Method

Thiessen polygon method is an appropriate method for non-uniform distribution of rain gauges. It is because a weighting factor will be provided to each rain gauge. The area will be subdivided into polygon subareas by refer to the rain gauges as the centres point. Subareas function as the weights for estimation of the watershed average depth. The benefits of this method are it can use nearby rainfall data which the station is located outside the catchment and the importance of measurement is allocated according to spacing of the station. However, this method cannot use in mountainous area due to the orographic influences in basin (Goyal, 2016).

$$\overline{P} = \frac{(P_1A_1 + P_2A_2 +_{\dots} + P_mA_m)}{(A_1 + A_2 +_{\dots} + A_m)} \qquad 2.12$$

2.21.3 Isohyetal Method

Isohyetal method depends on the interpolation between the rain gauges. The location of the rain gauges will be plotted on a map. On the map, the amount of rainfall values for each rain gauge will be recorded. Then perform an interpolation between the rain gauges and plot the selected increments of rainfall amount. Finally, identify the depths for each interpolation and connect it to form an isohyetal map. It is the most accurate and flexible equation to determine the mean precipitation over an area. Hence, this method is useful for large number of station which proves that it is more feasible than thiessen polygon method. It also can compute average areal precipitation at mountainous area (Goyal, 2016).

$$\overline{P} = \frac{(P_1A_1 + P_2A_2 +_{\dots} + P_mA_m)}{(A_1 + A_2 +_{\dots} + A_m)} \qquad 2.13$$

2.22 Isohyetal Map

Isohyetal is a word that comes from Greek. Iso mean equal and hyetal mean rain. The information required to produce an isohyetal map is the location of rain gauge stations and its rainfall data (Kuok, 2013). It is a map that depicts contour map of precipitation which is very similar to the topographic contour map (Manning, 1997). Each contour line will have equal amount of rainfall along its length. The contour line for isohyetal map is called as isohyet. An isohyetal map can simply create in ArcGIS 10.2 platform through the spatial interpolation techniques. From the map, we can know the spatial distribution of rainfall at a particular location.

In a contour map, the elevation of all known points will be plotted on a map. Then, contour line is produced by joining all the same elevation of known points together. The difference between the elevations of contour is known as contour interval.

Similarly, for an isohyetal map the value of precipitations at respective rain gauge stations are plotted on a suitable map. After that, isohyetal map is developed by drawing the isohyets. The isohyetal lines are formed based on the interpolation between gauge stations. The rainfall between two gauge stations is assumed varies linearly while constructing the isohyets (Jain, 2005).

2.23 Related Software in Development of Isohyet Map

Nowadays, several different types of software have been developed to plot the isohyetal map. This software includes Arcgis 10.2, FlowWorks, Surfer 10, Hydstra, Caris, Idrisi and MicroSurvey (Kuok, 2013).

2.23.1 ArcGIS 10.2

Geographical Information System (GIS) is a worldwide recognizes tool that is used for mapping distribution of spatial and its trend. This tool is useful because it can integrate and analyse spatial information from different layers or themes. GIS software also can use in many different ways such as produce crime mapping, manage properties and networks, establish and monitor the routes, invent and manage resources and so on. Figure below shows the relationship of Esri products (Johnston *et al.*, 2013).

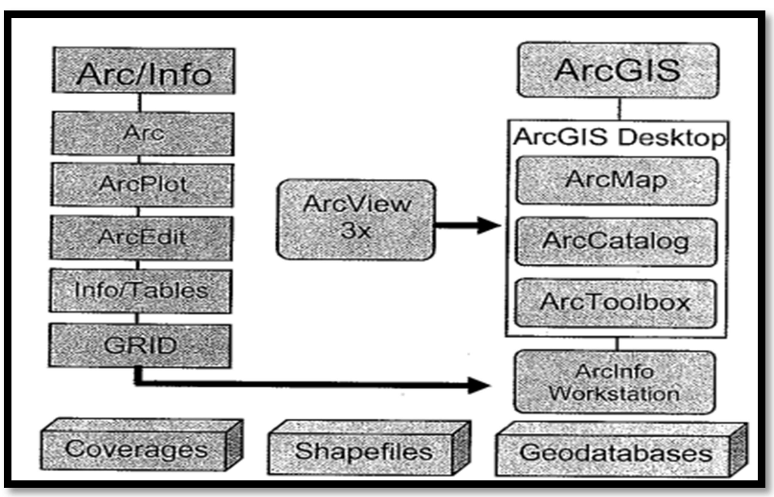

Figure 2.25 Relationship between ESRI products
Source: https://www.wou.edu/las/physci/taylor/es341/arcGIS_intro.pdf

ArcGIS 10.2 is one of the professional GIS applications that are created by Environmental Systems Research Institute (Esri). This application contains two programs that are ArcMap and ArcCatalog. ArcMap is a tool to analyse or edit the spatial data whereas ArcCatalog is used to view and manage the file of spatial data. Through ArcGIS spatial analyst toolbar, contours can easily create for a set of data. It is commonly used to develop a dataset of contour from a set of elevation data through this software. In ArcGIS spatial analyst, it offers many different types of spatial interpolation method include deterministic and geostatistical methods which allow users to choose the most suitable one to generate surface grid from the point data (Johnston *et al.*, 2013).

2.23.2 FlowWorks

FlowWorks is an effective web-based suite that used to monitor, analysis and report tools to make job more simple. It can help to establish the effective management in all monitoring systems, check the status of flow monitoring, conduct real time analysis, and set warning or alarms via a single interface. This software transforms the raw data obtained from other sources into actionable information. One of features of this tool is the ability to develop high quality and dynamic rainfall isohyetal maps from the available rainfall data (Oraevskiy, 2016).

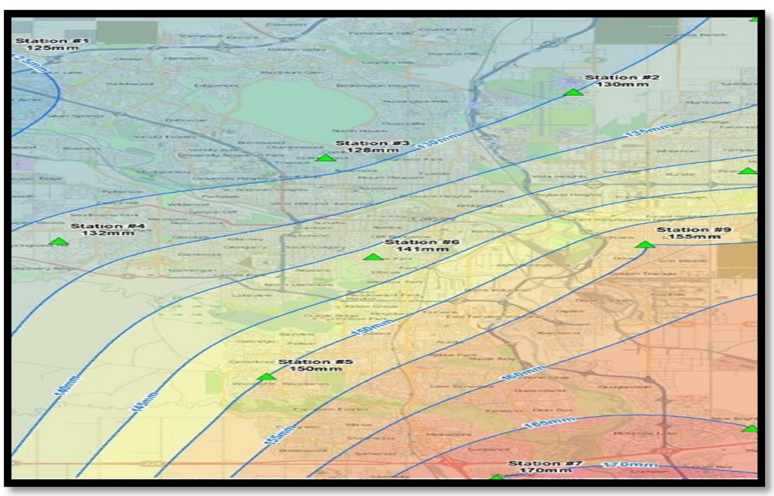

Figure 2.26 Isohyetal map
Source: FlowWorks (2016)

For FlowWorks software, it used contour lines to illustrate the rainfall distribution over a region. Above figure shows the isohyetal map generated by

FlowWorks. The red colour bands indicate the areas have higher precipitation, whereas the green colour bands indicate the areas have less precipitation (Oraevskiy, 2016).

2.23.3 Surfer 10

Starting from 1984, more than 100,000 engineers and scientists around the world recognized Surfer software's power and its simplicity. The outstanding ability of contouring and gridding has made this software to be the perfect choice to work with XYZ data. It also used by different disciplines people like geologists, oceanographers, hydrologists, climatologists, and more. This software package is suitable to run under Window XP SP 2, Window Vista and Window 7 (Golden Software, 2011).

Surfer 10 is consider as the most powerful and flexible program used to develop contour map and create three-dimensional surface mapping (Kuok, 2013). This tool can interpolates irregular spacing XYZ data into a regular spacing grid. The grids also can be imported from United States Geological Survey (USGS) and other sources. The grid is needed to form different maps which include image, vector, contour, 3D surface map, 3D wireframe maps, and shaded relief. Surfer can produce best and quality map that represent the input data (Golden Software, 2011).

2.24 Related Studies about Rainfall Interpolation

Varies studies of spatial interpolation method have been carried out by several researchers. Here are some of the examples:

i. Spatial interpolation of monthly precipitation in Selangor, Malaysia – comparison and evaluation of methods (Nadiah et al., 2014).

ii. Extreme rainfall analysis on the December 2014 flood, Pahang (Azhar et al., 2016).

iii. Comparison of spatial interpolation methods for rainfall data over Sri Lanka (Wijemannage et al., 2016).

iv. Comparison of spatial interpolation methods for precipitation in Ningxia, China (Hao and Chang, 2013).

v. Comparing rainfall interpolation techniques for small subtropical urban catchments (Knight et al., 2005).

vi. Create a missing precipitation data based on spatial interpolation methods in not covered areas by region climate change scenario (Dongwoo et al., 2015).

vii. Selection of optimum spatial interpolation method to complement an area missing precipitation data of RCP climate change scenario (Dongwoo et al., 2015).

viii. An analysis of climate change in Peninsular of Malaysia using remote sensing techniques (Hashib et al., 2011).

ix. Impact of climate change and its variability on the rainfall pattern in Sarawak river basin (Bong et al., 2009).

x. Assessment of the changes of climate in Bangladesh using Geospatial interpolation of climate variables (Saha and Islam, 2016).

2.24.1 Spatial Interpolation of Monthly Precipitation in Selangor, Malaysia – Comparison and Evaluation of Methods

This study evaluated the five GIS interpolation methods including Inverse Distance Weighting (IDW), Local Polynomial (LP), Global Polynomial (GP), Ordinary Kriging (OK), and Universal Kriging (UK) using cross validation for precipitation in the two main basins in Selangor which are Selangor and Langat basin. 21 rain gauges stations from the 1970 to 2010 were chosen and interpolated using the five methods stated above. Cross validation was adopted to assess the performance of each interpolation technique. Root mean square error (RMSE) and standardized root mean square method (SRMSE) are the two common diagnostic statistics to determine the accuracy of the spatial interpolation method. RMSE statistic can be used for all the local methods, but SRMSE only can be used for kriging because variance is needed for computation. According to Chang (2010), a well perform Kriging method should have smaller RMSE and the value for SRMSE is close to 1. From this journal it proven that Ordinary Kriging and Universal Kriging obtained the smallest RMSE value. Therefore, these kriging methods are the optimum technique for interpolating rainfall in Selangor (Nadiah *et al.*, 2014).

2.24.2 Extreme Rainfall Analysis on the December 2014 Flood, Pahang

December 2014 several districts in Malaysia suffered extreme rainfall that lead to a tremendous flood event occurred. The purpose of this paper is to study the pattern of rainfall distribution from 15 to 29 December 2014 at Pahang state. The rainfall data were collected from 94 rain gauge stations in Pahang. The rainfall pattern map is developed through ArcGIS 10.1.2 software by applied Inverse Distance Weighting (IDW) and Kriging. The December 2014 rainfall event is compared with 25 years historical rainfall at nine areas located in Pahang which are Temeris, JKR Kg. Manchis, Kg. Kedaik, Sg. Kepasing, Kampung Batu Gong, Kuala Tahan, Ulu Tekai, Kg Salong and Kg. Merting. From the analysis, it is proven that the value of rainfall event on December 2014 was exceeded the value of recorded historical events. This showed that extreme rainfall event had occurred in December 2014 in Pahang state. IDW was used to get the cumulative rainfall event because it is more accurate than kriging method. This is because when compare the data at particular study area IDW did not change any data whereas the kriging had changed the original data. For instance, one day historical rainfall amount for kawasan Ulu Tekai should be 1511mm. The data plotted in the map using IDW was between the ranges of 1451 to 1700mm so it is accepted. However, the data obtained using kriging is between 701 to 900mm so it is rejected because outside the range. This clearly showed that IDW is more suitable to use to interpolate the missing rainfall data for Pahang state compare to kriging. Hence, the extreme rainfall happened in December 2014 had caused serious flood event in Pahang (Azhar *et al.*, 2016).

2.24.3 Comparison of Spatial Interpolation Methods for Rainfall Data over Sri Lanka

This journal studies the spatial variation of precipitation at Sri Lanka. Five interpolation techniques such as Ordinary Kriging (OK), Universal Kriging (UK), Spline (S), Inverse Distance Weighting (IDW) and Topo to Raster (TR) were selected, assessed and compared the monthly and annually total rainfall for 350 rain gauge stations. The monthly and annually rainfall data for 4 years such as 2000, 2005, 2008, and 2010 were collected from Department of Meteorology. The isohyetal maps were developed through ArcGIS by applying spatial interpolation method. This paper used cross validation to compare the observed values with the interpolated values and the 25 locations (observed data) were chosen from the available 350 rain gauge stations. Mean absolute error (MAE), standardized root mean square error (SRMSE) and goodness of prediction measure (G) were adopted to evaluate the accuracy of each technique. The ideal spatial interpolation method was determined by the smallest value of MAE, SRMSE, and G obtained from the rainfall data. Through this study kriging interpolation methods showed the extreme values were underestimated whereas the Inverse Distance Weighting and Spline showed performed better in estimating extreme values. However, according the result from MAE, SRMSE and G, the most suitable technique for interpolation the monthly and annually total precipitation data of Sri Lanka are Ordinary Kriging and Universal Kriging techniques. Thus, out of the five methods kriging method showed better performance and selected as the optimum spatial interpolation method for rainfall in Sri Lanka (Wijemannage *et al.*, 2016).

2.24.4 Comparison of Spatial Interpolation Methods for Precipitation in Ningxia, China

In this paper, six spatial interpolation methods such as Kriging, Cokriging, Inverse Distance Weighting, Radial Basis Functions, Global Polynomial and Local Polynomial were chose to generate 20 years missing annual mean rainfall data. The low density data is collected from the meteorological station from 1991 to 2010. The study area is located at Ningxia, China. This is because the rain gauge station located at the northwest of China is limited due to the complex terrain at there. Each of these six methods has its own advantages and disadvantages so none of them can perform perfect in all other cases. The optimum method selected must be related closely to the characteristics for the sets of discrete data. Cross validation is used to check the accuracy of these methods. Mean absolute error and mean reliable error were used as the criteria of validation because of high sensitivity. From the analysis, IDW perform the worst since it obtained the biggest MAE and MRE value. While, polynomial interpolation methods cannot pass via many measured points. Local Polynomial is more accurate than global polynomial. This is because Global Polynomial considers the global trend. The best interpolation method in Ningxia, China was cokriging with the Gaussian model because the elevation had been considered (Hao and Chang, 2013).

2.24.5 Comparing Rainfall Interpolation Techniques for Small Subtropical Urban Catchments

This journal focused on evaluates suitable interpolation method for a small subtropical urban catchment with dense rain gauge network. The rainfall data were obtained from 11 rain gauge stations that located in Brisbane area. Thirteen storms events starting from 1995 were chose for interpolation. Inverse Distance Weighting (IDW), Thin Plate Smoothing Spline (TPS) and Ordinary Kriging were the three spatial interpolation methods selected to interpolate the measured point at unsample area. Delete one validation method is used to compare and evaluate all the above techniques. Root mean squared error, root mean squared error as percentage of the mean, bias, and model efficiency were the four statistics to study the performance of spatial interpolation methods. For individual storm events, Spline and Ordinary Kriging methods provided more accurate value than IDW whereas for four storm events kriging and IDW perform almost similar result. But, IDW was the better method to produce reliable rainfall data in Brisbane's small urban catchment. This is due to the small set of data was analysed in the study so it is more superior compare to kriging method (Knight *et al.*, 2005).

2.24.6 Create a Missing Precipitation Data based on Spatial Interpolation Methods in Not Covered Areas by Region Climate Change Scenario

This study presents the different interpolation methods that are used to find the missing data at the coastal areas in South Korea. The climate scenario data was obtained from KMA Korea Meteorological Administration. However, some points in the data which located near to the islands or coastal areas were missing. In order to determine the missing data, geostatistical tools from ArcGIS was used. Inverse Distance Weighting (IDW), Ordinary Kriging (OK), Spline (S) and Natural Neighbour were selected to interpolate the missing points. 4185 grids were formed in the South Korea coastal area through the spatial interpolation methods mentioned above. In this paper, the accuracy assessment was applied to choose the optimal methods was mean absolute error (MAE), mean squared error (MSE), percent of BIAS (PBIAS) and goodness of prediction (G). In conclusion, Spline method has lowest value of standard deviation compare to other but Ordinary Kriging obtained the lowest value for MAE, MSE and G which mean this method is more accurate than other methods. Natural neighbour method only can generate value for internal area so it is not suitable to predict the missing data. Through this study, IDW and Ordinary Kriging methods are the most suitable method used in coastal area in South Korea (Dongwoo *et al.*, 2015).

2.24.7 Selection of Optimum Spatial Interpolation Method to Complement an Area Missing Precipitation Data of RCP Climate Change Scenario

Inverse Distance Weighting (IDW), Ordinary Kriging (OK), Universal Kriging (UK), and Spline (S) methods were selected to generate the missing precipitation data in urban area of South Korea. ESRI ArcGIS had been used to generate the unknown or missing data in the particular region. The most accurate interpolation method will be chosen to generate the missing data according to future climate change scenario. The missing future precipitation data of climate change scenario is important to the future planning for water resource for South Korea. Precipitation data was collected from KMA Korea Meteorological Administration. ArcGIS produced the missing precipitation data through the spatial interpolation method to the coastal area. It is the area where data of climate change scenario is not given by the KMA. In this study, a total of 4186 grids were missing so reliable interpolation method is important to produce climate data, daily and monthly precipitation data. Four statistics were selected to evaluate the performance of interpolation method including mean absolute error (MAE), mean square error (MSE), percent of BIAS (PBIAS) and goodness of prediction (G). During the estimation of precipitation value at coastline areas, IDW and kriging methods tend to produce overestimate value whereas spline produces almost similar value to the actual value. However, Ordinary Kriging showed the most accurate value during the cross verification for the August precipitation data compare to other methods. This means it can produce reliable and accurate precipitation data even in remote areas (Dongwoo *et al.*, 2015).

2.24.8 An Analysis of Climate Change in Peninsular of Malaysia using Remote Sensing Techniques

This paper analysed the impact of climate change to rainfall quantity in Peninsular Malaysia. According to Hashib et al. (2011), changes of rainfall pattern, duration, density and magnitude are the impacts of climate change. These changes can lead to tremendous weather events such as droughts, floods, cyclones and typhoons. Since mid of 20th century, the global average temperature have been raised due to the concentration of greenhouse gases increased. For instance, the average of global temperature from 1990 until 2000 had been raised of 1 to 4°C (IPCC, 2007). Climate change analysis is essential and the statistics can be used to predict the occurrence of extreme weather events. 32 years rainfall data were used to study the temporal and spatial distribution of precipitation for Peninsular Malaysia using tropical rainfall measuring mission (TRMM) data. The rainfall maps were produced via ArcGIS using kriging interpolation method. From this paper, the minimum rainfall occurred in 2012 and the maximum rainfall occurred in 1984. The total rainfall received in 2012 is 28, 081.62 mm per year whereas annual rainfall received for 1984 is 39, 812.95 mm per year. The total accumulated rainfall dropped about 5,696.63mm in the early of 90's. The analysed result for the trend of rainfall in Peninsular Malaysia showed a negative linear trend line. This means that the accumulated rainfall amount is decreasing. Hence, the quality of rainfall is affected by the climate change and there is a correlation between the temperature and rainfall (Hashib *et al.*, 2011).

2.24.9 Impact of Climate Change and Its Variability on the Rainfall Pattern in Sarawak River Basin

This journal evaluated the impact of climate change to the variation of rainfall pattern in Sarawak river basin. The author believed that global warming is the main reason that contributes to the change of climate. The total area for Sarawak river basin is 1435km^2 and consist 2 main tributaries which are river kanan and river kiri. The aim of this paper is to determine the available water for the basin in future due to the change of climate. It is important for the preparation of adaptability measures. The rainfall pattern of Sarawak river basin was studied using time series for annual rainfall and mean areal rainfall. The trend for temperature and evaporation also had been discussed. This is because temperature and evaporation have a direct relationship to the rainfall intensity and it may affect rainfall pattern. Four rainfall stations with up to 30 years data had been chosen for the time series for annual rainfall. While, seven rainfall stations with 30 years data was selected for the total mean annual areal rainfall. All annual and mean areal rainfall graphs showed an increasing trend from the beginning until the nowadays. The mean annual temperature from 1988 to 2008 on Sarawak river basin also showed an increasing trend of 0.135°C. Moreover, the rate of evaporation showed a rising trend of 0.065mm too. Hence, it was proven that the increase of rainfall intensity and its change of rainfall pattern in this basin are because of the rise of temperature and evaporation rate. The impact of climate change such as flood and drought events need to study for better prepare for appropriate measurement for future in Sarawak river basin. Some measurement such as water conservation, changes in the practice of design and improve the monitor and forecast system had been suggested by the author to solve the effect of climate change (Bong *et al.*, 2009).

2.24.10 Assessment of the Changes of Climate in Bangladesh Using Geospatial Interpolation of Climatic Variables

Climate change and global warming is one of the most serious issues in Bangladesh. Since the country only had limited resources available. Climate change in a particular area usually measure over a long period of time such as 30 years and above. Thus, it is important to understand the present condition of climate and its future changes to make appropriate policy and strategies to overcome the climate change problem. In this journal, 60 years climate data were collected from Bangladesh Meteorological Department (BMD). The researcher focuses on the minimum and maximum temperature and daily rainfall from 1951 to 2010. The data was divided into four seasons categorize including pre-monsoon (March – May), monsoon (June – September), post-monsoon (October – November) and dry season (December – February). The data interpolated using Inverse Distance Weighting (IDW), Kriging and Local Polynomial. The interpolation method was evaluated by root mean square error (RMSE). Kriging method was found obtained the lowest value of RMSE for both interpolations of temperature and rainfall data. The minimum and maximum temperature was increase during pre-monsoon and monsoon and decrease during post-monsoon and dry season proven the climate is changing in Bangladesh. The rainfall is increasing in the monsoon season whereas the rainfall is decreasing during dry season. As from the observed changes in both temperature and rainfall, it is true that the climate is changing in Bangladesh. Proper planning and strategies should be prepared to overcome the effect of climate change (Saha and Islam, 2016).

CHAPTER 3

METHODOLOGY

3.1 Introduction

Rainfall is an important parameter for the hydrological cycle. Accurate rainfall data is useful for water management and climate studies. The difficulties to estimate the rainfall at a catchment area are the spatial variability of rainfall, missing data and insufficient network of rain gauge stations. All these difficulties must be considered and included in the estimation of rain fields. Hydrologists interpolate the rainfall from point measurements to account the spatial variation of rainfall (Knight *et al.*, 2005). A number of spatial interpolation methods have been developed to estimate missing values of meteorological parameter. Generally, these methods can be classified into two categorized that are deterministic methods and geostatistical methods.

Geographical Information system (GIS) is used to generate the map of rainfall spatial distribution for Klang river basin. The spatial analyst toolbar offer in the ArcGIS software can help to find the estimated rainfall values in the unsampled location. Cross validation is used to evaluate the accuracy of each interpolation methods. In this study, mean absolute error (MAE), root mean square error (RMSE) and goodness of prediction measure (G) are three statistics used to characterize the performance of the two interpolation methods. The aim of this quantitative assessment is to choose the best interpolation method for Klang river basin. Based on Fredolin et al. (2012), climate change is recognized as the most serious environmental problems for all countries in 21th century. By comparing the monthly and annually rainfall maps produced via ArcGIS can assist to detect the extreme weather events occurred due to the change of climate. Thus, it is importance to identify the impacts of climate change and find a way to adopt the adverse effects.

3.2 Flow Chart of the Study

Figure 3.1 shows the overall process for this study:

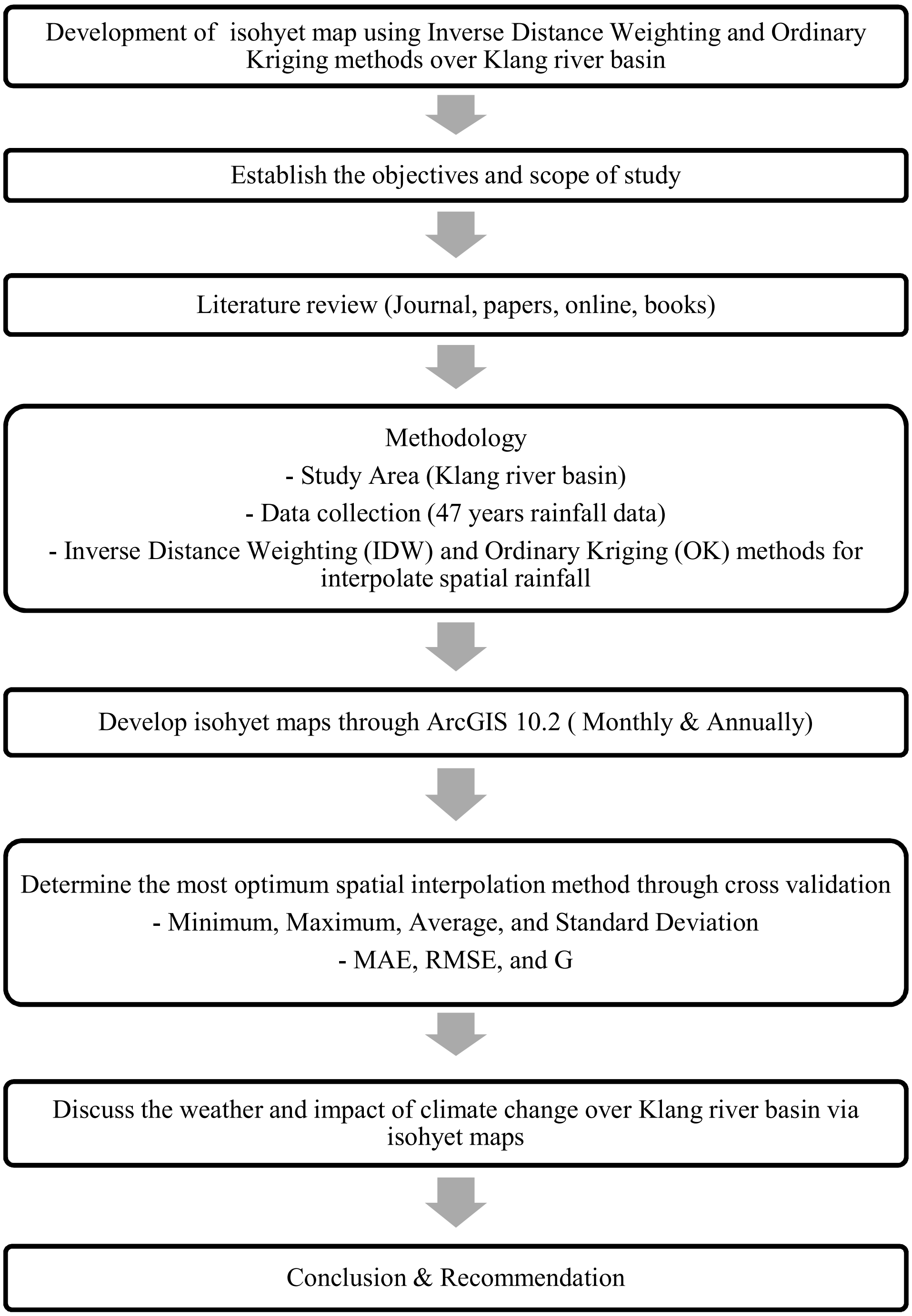

Figure 3.1 Flow chart of the study

3.3 Study Area

The area of this study is Klang river basin that located at the west part of Peninsular Malaysia. The Klang river begins at the Titiwangsa mountain and it is bonded with two states which are federal territory of Kuala Lumpur and Selangor before it discharges into Straits of Malacca. It also called as Sungai Seleh. The river is around 120 kilometres long. It drains a basin of approximately 1288 km^2 and consists of 11 major tributaries. The tributaries consist of Keruh river, Penchala river, Ampang river, Kuyoh river, Batu river, Gombak river, Damansara river, Kerayong river, Jinjang river and Bunus river. Klang river basin spreads over 9 government authorities and has an approximately 5% annual growth rate. 44% of land use in Klang Valley is dominated by urban development, 7% for commercial activity, 15% for agriculture and 34% forest reserves(Akrami *et al.*, 2013). Rapid development had contributed flash floods in Klang Valley especially after 2 to 3 hours heavy rain.

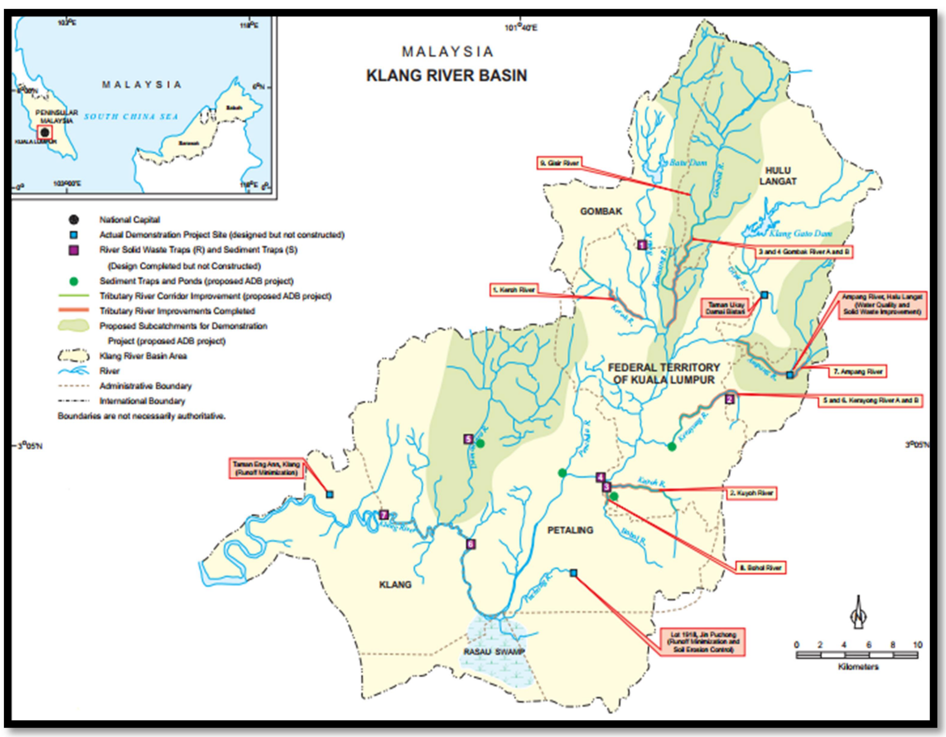

Figure 3.2 Klang Valley river basin

Source: Asian Development Bank report (2007)

3.4 Data Collection

In this study, about 47 years rainfall data from 1970 to 2016 located at the inside and outside Klang river basin is obtained from Department of Irrigation and Drainage (DID). Figure 3.3 shows the rainfall data analysis process. Rainfall data from ten stations will be classified into four different categorizes which is monthly and annually average rainfall before and after 2000 for the assessment of climate in the basin. Rain gauge stations that have outliers or extreme error due to wrong coordinates and different units, missing Meta data, missing records of rainfall for some period will be removed before use the data. Generally, the network of rain gauge stations normally is sparse and the available rainfall data is insufficient to describe or characterize the spatial distribution of rainfall. It is necessary to estimate rainfall at unsampled location from the surrounding rain gauge stations. The missing rainfall data can be estimated using interpolation technique in order to produce isohyet map through ArcGIS 10.2. Spatial interpolation method can help produce high spatial resolution rainfall data that is essential for all research works. Metrological data such as temperature or wind speed will not be included in this study.

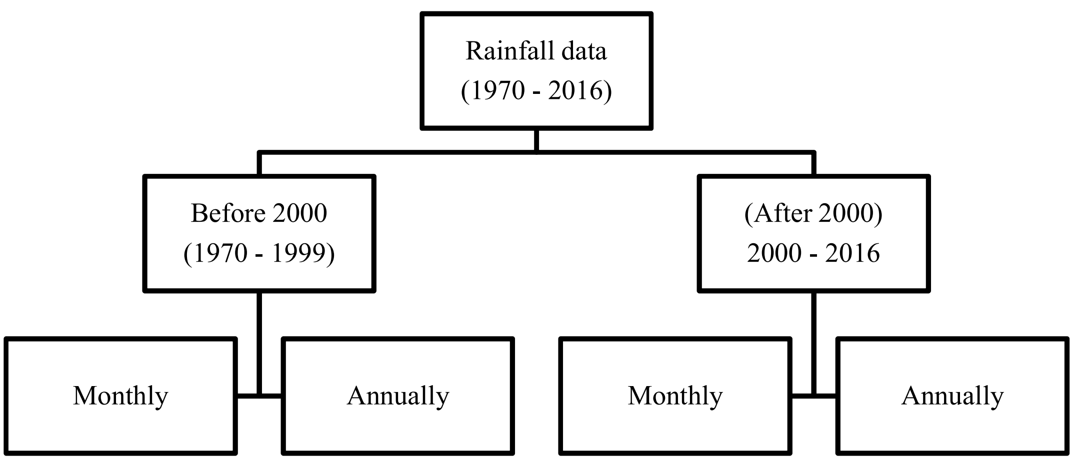

Figure 3.3 Analysis process of rainfall data

3.5 Software

Geographical information system (GIS) can use to capture, store, manipulate, analyse, manage, and present all kinds of geographical data. Key word for this software is geography, it means that the data is related to some position on the earth's surface and some portion of the data is spatial. Location of data can be expressed as address, postal code, latitude and longitude. GIS assist organization or individual to understand the spatial patterns and its relationships better by relating all the data together. This is because geospatial tool and software can combine people and methods together to produce spatial analysis, manage large datasets and all information is displayed in a map form. A map developed can contain multiple layers of different information. All the separate map layers combined to make a single map.

In addition, GIS is a powerful tool in making decision and solving problem because different information can contrast and compared using this modern software. The information may include income, population, landscape, level of education, type of soil, type of vegetation, roads, schools or storm drains can be input to the system. People can easily compare different object locations to discover how these objects relate to each other. Three dimensional images often produced via GIS system and it is very useful. For instance, geologists used the images to study the faults of earthquake. Engineer used GIS to develop road network system or transportation infrastructure whereas water manager adopted GIS to calculate the demand and forecast water supply, monitor drought, assess of flood damage and stormwater system design.

Analysis of rainfall data is difficult due to the limited sample data available. This is because of the expensive cost for installation and limited resources that affect the data collection only can conduct in certain locations. But now with the aid of 170 geoprocessing tools from ArcGIS, the spatial analysis can perform easily form the limited data. The raster surface can generated through the interpolation tools offer by ArcGIS such as Inverse Distance Weighting, Kriging, Spline, Natural Neighbours and Topo to Raster. For example, ArcGIS can help to produce isohyet map for rainfall distribution by applying the spatial interpolation methods to missing area.

3.6 Method

Several number of interpolation methods have been developed to estimate the spatial rainfall distribution based on the existing rain gauge measurement. It is believed that the area that is close to each other will has similar characteristics of rainfall. Spatial interpolation technique help to estimate the missing value at unsampled points depend on a weight of observed value. This method can be group into deterministic and geostatistical methods.

Deterministic interpolation methods used mathematical formulas to determine the smoothness for the resulting surface. The predicted value is calculated based on the existing surrounding measured value. Meanwhile, geostatistical interpolation methods are depending on the statistical model which consists of autocorrelation. This means that it also can provide some accuracy or measurement for the predictions. This interpolation technique also called as stochastic method. In this study, Inverse Distance Weighting and Kriging methods are choose to interpolate spatial rainfall data.

3.6.1 Inverse Distance Weighting (IDW) Method

Inverse Distance Weighting (IDW) is a deterministic method of interpolation. It usually used to estimate the missing values in geographical and hydrology science. Its idea is assume the attribute value of estimated point is the weighted average of measured points at the surrounding neighbourhood. IDW interpolate the spatial data by using the concept of distance weighting. The weights are influence by the distance between the estimated points to measured points. It is a process which uses a scattered set of recognized points to assign values to the unrecognized points. The general formula for IDW is as follows:

$$\hat{Z}(s_0) = \sum_{i=0}^{N} \lambda_i Z(s_i) \qquad 3.1$$

Where:

$\hat{Z}(s_0)$ = Predicted value for location s_0

N = Number of measured sample points

λ_i = Weights assigned to each measure point

$Z(s_i)$ = Observed value at location s_i

The formula for weights as follow:

$$\lambda_i = d_{i0}^{-p} / \sum_{i=1}^{N} d_{i0}^{-p} \qquad 3.2$$

$$\sum_{i=1}^{N} \lambda_i = 1 \qquad 3.3$$

Where:

d_{i0} = Distance between prediction and measured locations

N = Number of measured sample points

λ_i = Weights assigned to each measure point

p = Power parameter

The accuracy of IDW is affected by the value of power parameter p. Weights are inversely proportional to the distance. The larger distance between prediction and measured locations, the smaller the value of weight. The value power parameter will influence how fast the weights decrease. The sum of the weights is assumed equal to 1 as no decrease with the distance so that each weight will be same.

This technique considers the spatial of data as straight lines that connect to the points of measure without any smoothing. Sometimes the non-smoothing property of IDW can give better cross validation result as it takes actual measurement to be the variability factors. This method is the simplest one compares to others interpolation method. The estimated values produce through IDW will not outside the measurements. However, it does not have assessment for error prediction, the maximum and minimum values only occur in the sample data, and the quality of interpolation may be reduce if the distribution of sample data is uneven.

3.6.2 Kriging Method

Kriging can categorize into several types including ordinary, simple and universal. It is based on the statistical relationships and spatial to determine and calculate the surface. In Kriging analysis, selection of a semivariogram model plays an important role in analyse geostatistical data. Before perform the interpolation, this method begins with the estimation for semi variance and the estimation parameters for the model first. In this study, I choose Ordinary Kriging (OK) because according to Grimes and Pardoiguzuquiza (2010) Ordinary Kriging can produce reliable and accurate result in estimation rainfall data at the unsampled locations. The equation 3.4 shows the model of Ordinary Kriging. The value for constant mean μ is assumed unknown. Equation 3.5 depicts the formula for Ordinary Kriging. It used a set of known data $Z(s_i)$ to estimate the unknown value $\hat{Z}(s_0)$ at the unsample location.

$$Z(s) = \mu + \varepsilon(s) \qquad 3.4$$

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i) \qquad 3.5$$

Where:

$\varepsilon(s)$ = Random error

μ = Mean

$\hat{Z}(s_0)$ = Predicted value for location s_0

N = Number of measured sample points

λ_i = Weights assigned to each measure point

$Z(s_i)$ = Observed value at location s_i

$$\sum_{i=1}^{N} \lambda_i = 1 \qquad 3.6$$

To ensure uniform unbiasedness, the sum of the weights must equal to 1. Although the formula of Ordinary Kriging may look similar to Inverse Distance Weighting method, but there is some difference between these methods. The weight (λ_i) in IDW is rely on the distance between the estimated points and prediction location whereas the weight (λ_i) in OK not only depend on the distance but also on the overall spatial arrangement of the measured points. Spatial autocorrelation must be quantified first before use the spatial arrangement in the weights. Hence, the weight in OK based on prediction location distance, spatial relationships between measured values surround the prediction locations and a fitted model to measured points.

3.7 Accuracy Assessment

Identify appropriate interpolation methods of climate data is critical to ensure obtained a correct and accurate representation of climate fields. Cross validation technique is used to determine the performance of each interpolation method. It also called as rotation estimation. To select the most optimum interpolation method from the above two techniques, the estimated values and the observed values were quantitatively compared. This means that excludes certain points in the original data series and compares these values with the estimated one. Cross validation can assist to select between different prediction methods, search strategies and weighting procedures. In this study, three statistics will be used to compare and assess the spatial interpolation methods. These including mean absolute error (MAE), root mean square error (RMSE), and goodness of prediction measure (G). The method with the minimum of those errors will be chosen as the optimum spatial interpolation technique over Klang river basin.

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|Z_i - \hat{Z}_i\right| \tag{3.7}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Z_i - \hat{Z}_i)^2}{n}} \tag{3.8}$$

$$G = \left(1 - \frac{\sum_{i=1}^{n}(Z_i - \hat{Z}_i)^2}{\sum_{i=1}^{n}(Z_i - \bar{Z})^2}\right) \times 100 \tag{3.9}$$

Where:

n = Number of rainfall events

Z_i = Observed value from position i

$\hat{Z}_i$ = Estimated value from position i

$\bar{Z}$ = Average observed rainfall

3.8 Climate Change Assessment

Climate change is a serious environmental issue for all countries around the world. It can causes significant changes in precipitation, wind flow pattern, or temperature. IPCC (2007) concluded that the average global temperature is increased due to the emission of greenhouse gases. The greenhouse gas will affect many natural systems such as increase amount of runoff, changes of marine ecosystem and change in ice and snow. It also proven that climate change has given most effects on weather. This is due to change in intensity, amount and type of precipitation can lead to tremendous events including droughts, floods, typhoons and cyclones occur. The forecast weather pattern has been become more and more difficult to predict because of the climate change. Hence, climate change is a huge challenge for a fast development country like Malaysia especially for Klang river basin. It consists of largest urban city of Malaysia that is Greater Kuala Lumpur and the surrounding towns in Selangor. For instance, Klang Valley had experienced extreme weather events like water shortage and several flash floods in 2014. In this study, the impact of climate change over the river basin can be study through the rainfall distribution map developed using ArcGIS software. By comparing the monthly and annually rainfall intensity and its pattern produced via isohyet map, the changes and variability of climate over the study area can be easily observe and identify.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Rainfall data from ten rain gauge stations that situated near Klang river basin had collected from Department of Irrigation and Drainage (DID) and was utilized in this study. About 47 years rainfall data (1970 to 2016) was analysed using Microsoft Excel before created isohyet map through Esri's ArcGIS 10.2. For this study, data which consisted more than 20 percent of missing data had been filtered out. The rainfall data was divided into four different sets which were monthly average rainfall from 1970 to 1999, monthly average rainfall from 2000 to 2016, annually average rainfall from 1970 to 1999 and annually average rainfall from 2000 to 2016.

Each dataset had been interpolated using one deterministic and one geostatistical methods. There were several number of deterministic and geostatistical methods had been provided in the Geostatistical Analyst. In this study, Inverse Distance Weighting (IDW) was selected as the deterministic method whereas Ordinary Kriging (OK) was chosen as the geostatistical method. Each interpolator had generated twelve-four monthly average isohyet maps and two annually average isohyet maps for before 2000 and after 2000 respectively. From the maps, it can be seen that six stations located inside the Klang river basin whereas four stations located outside the region. The outside stations were aimed to increase the accuracy of interpolation for Klang river basin.

Then, cross validation was performed with help of Geostatistical Analyst to determine which method was the good interpolator for Klang river basin. Minimum, maximum, average, standard deviation, mean absolute error (MAE), root mean square error (RMSE), and goodness of prediction (G) were applied to identify the performance of each spatial interpolation method. Lastly, the isohyet maps generated by the optimum spatial interpolation method had been used to analysis the impact of climate change in the Klang river basin region.

4.2 Isohyet Map

Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) interpolations were applied to produce the monthly and annually isohyet maps for Klang river basin. These two interpolators were conducted using ESRI's ArcGIS 10.2 with the aid of Geostatistical Analyst tool. In this study, the rainfall data was divided into four classes which were monthly average rainfall before 2000, monthly average rainfall after 2000, annually average rainfall before 2000 and annually average rainfall after 2000. A total of fifty-two interpolated images were prepared through ArcGis 10.2 using Inverse Distance Weighting and Ordinary Kriging interpolators.

4.2.1 Inverse Distance Weighting (IDW) Method

For this study, twelve-four isohyet maps that represented monthly average rainfall before and after 2000 and two isohyet maps represented annually average rainfall before and after 2000 had been created by ArcGIS Geostatistical Analyst using Inverse Distance Weighting interpolation (deterministic method).

4.2.1.1 Monthly

The isohyet maps for monthly average rainfall before and after 2000 for Klang river basin had been formed using Inverse Distance Weighting (IDW) technique as follow:

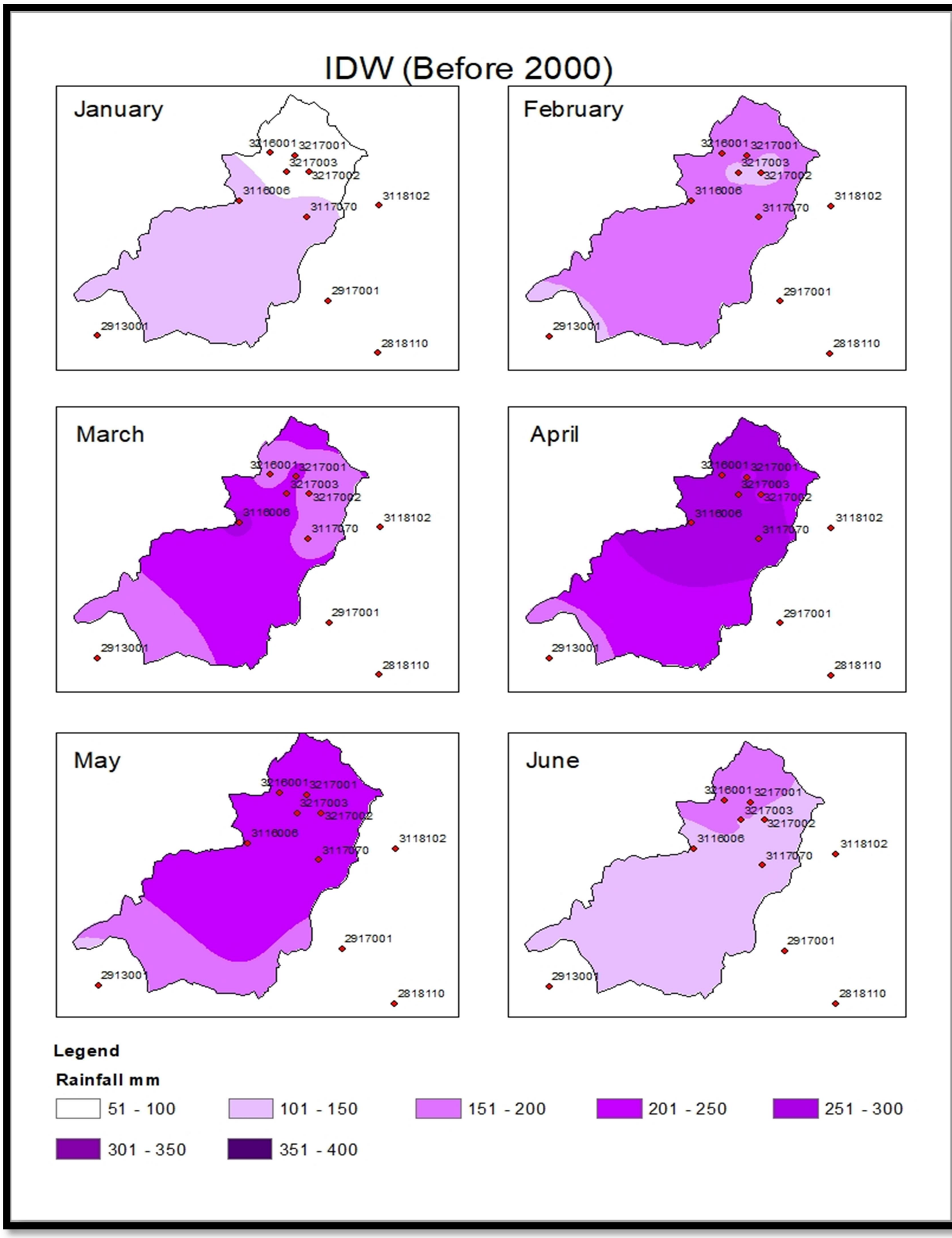

Figure 4.1 Monthly isohyet maps using IDW before 2000 (January – June)

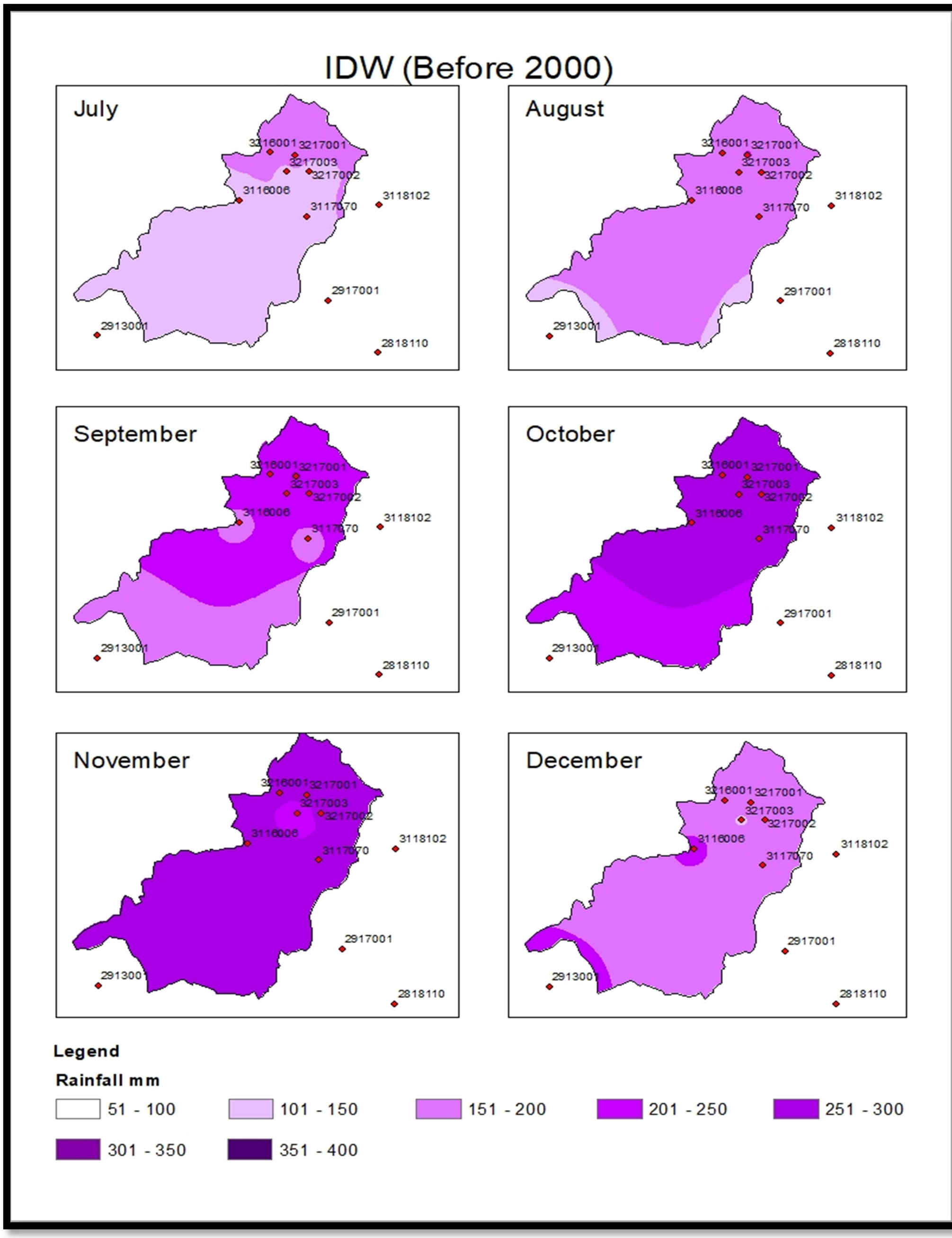

Figure 4.2 Monthly isohyet maps using IDW before 2000 (July – December)

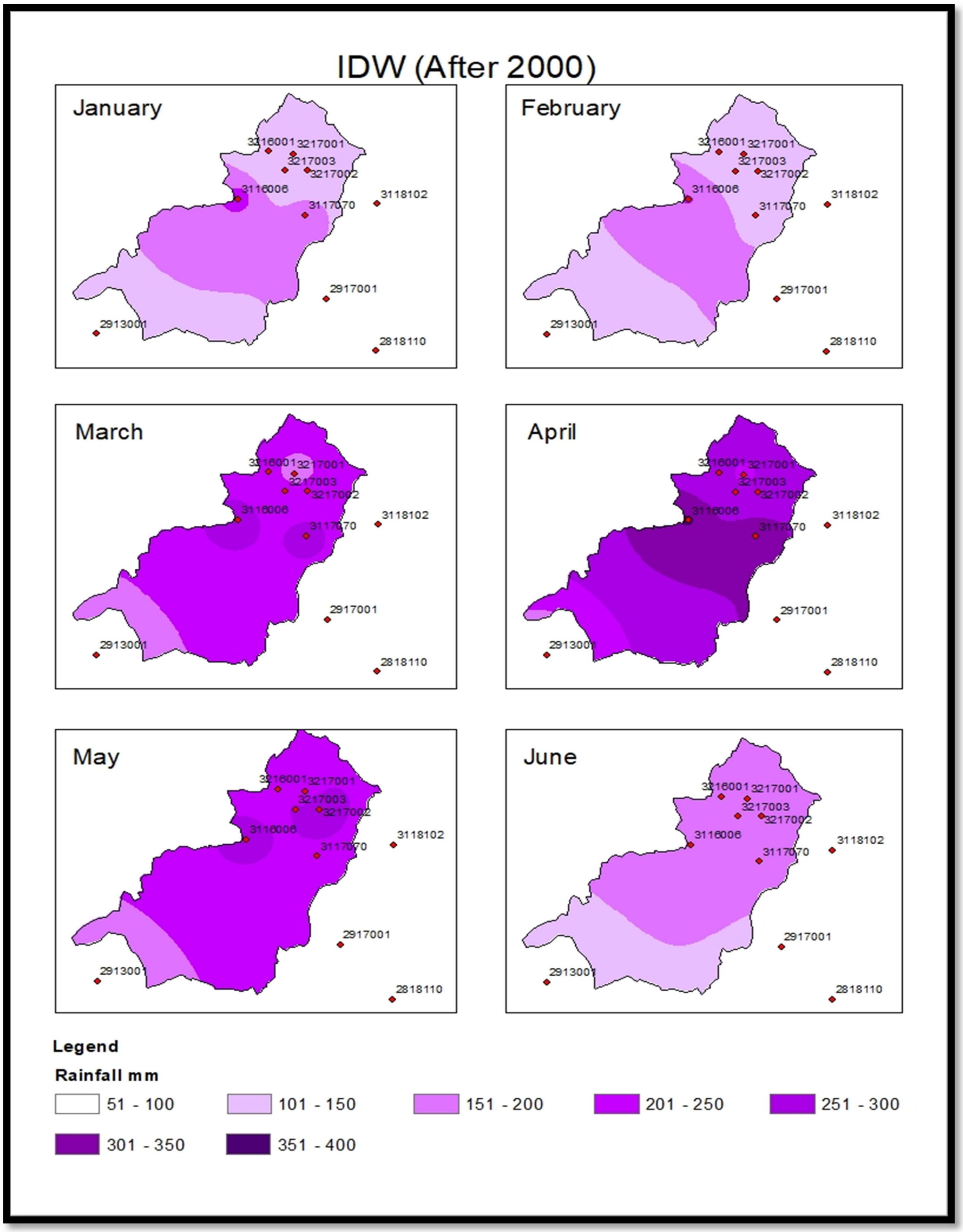

Figure 4.3 Monthly isohyet maps using IDW after 2000 (January - June)

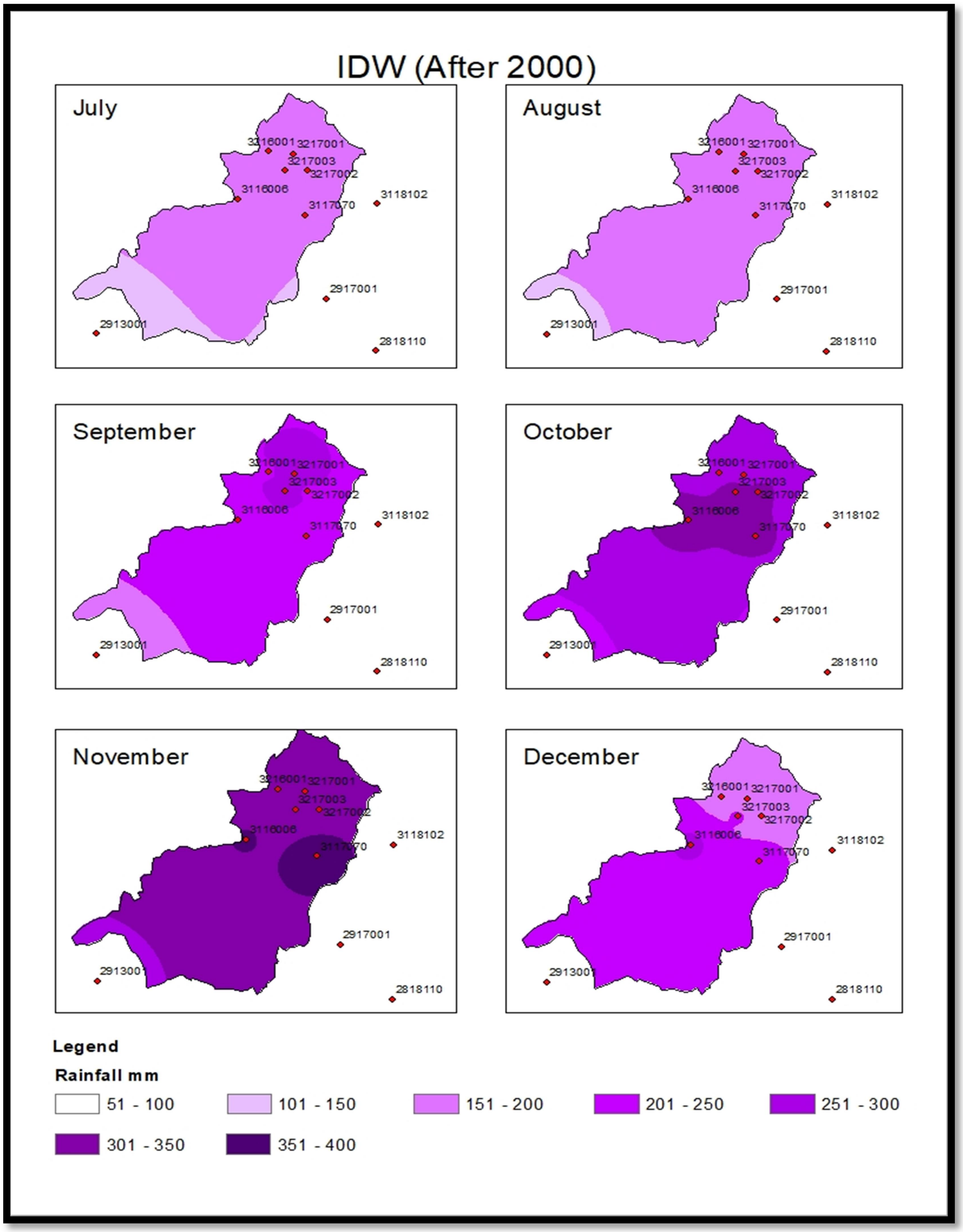

Figure 4.4 Monthly isohyet maps using IDW after 2000 (July – December)

4.2.1.2 Annually

The isohyet maps for annually average rainfall before and after 2000 over Klang river basin had been formed using Inverse Distance Weighting (IDW) technique as follow:

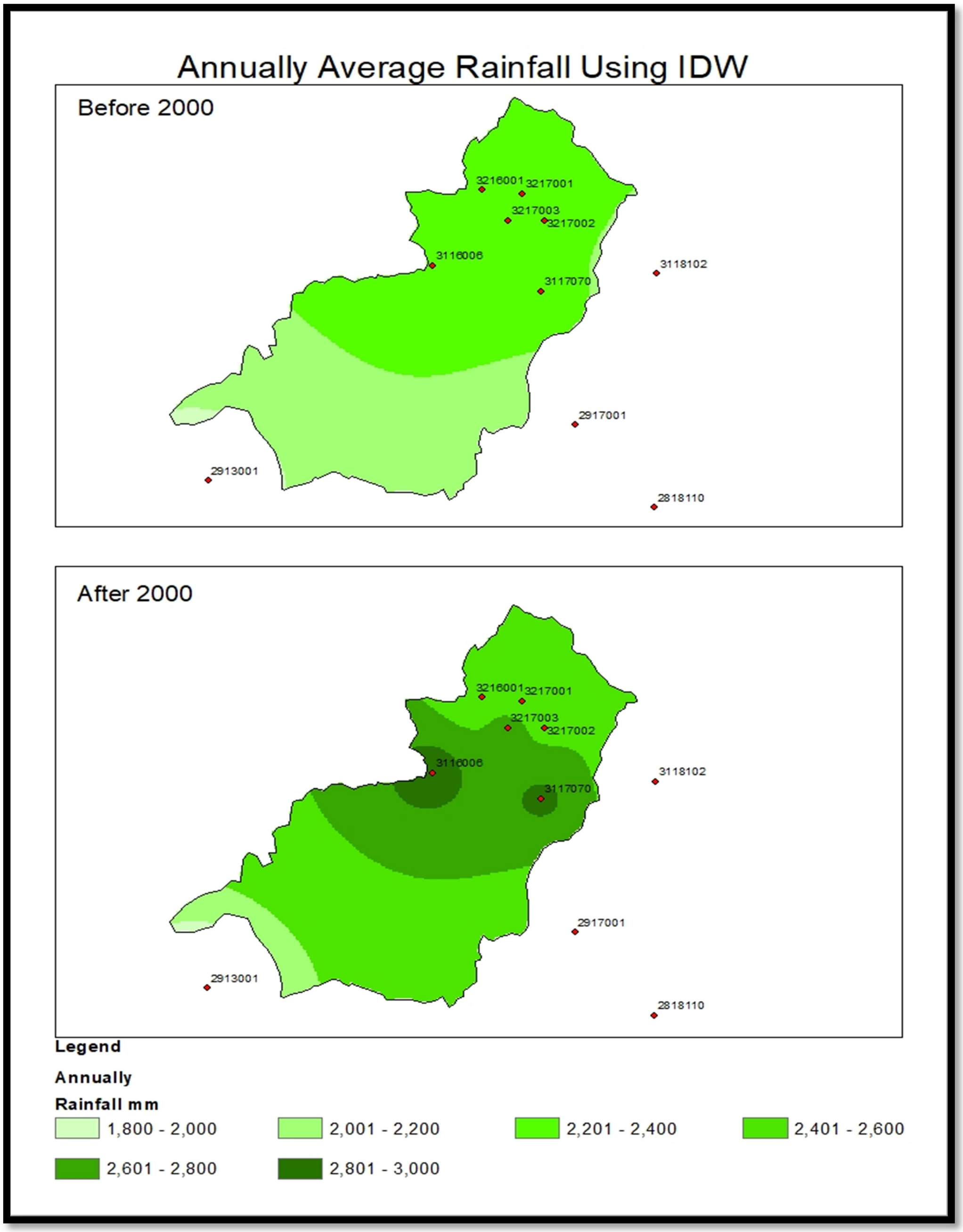

Figure 4.5 Annually isohyet maps using IDW before and after 2000

4.2.2 Ordinary Kriging (OK) Method

In this study, Ordinary Kriging (OK) interpolation (geostatistical method) was used to produce another twelve-four isohyet maps that represented monthly average rainfall before and after 2000 and two isohyet maps represented annually average rainfall before and after 2000 via ArcGIS Geostatistical Analyst.

4.2.2.1 Monthly

The isohyet maps for monthly average rainfall before and after 2000 had been formed for Klang river basin using Ordinary Kriging (OK) technique as follow:

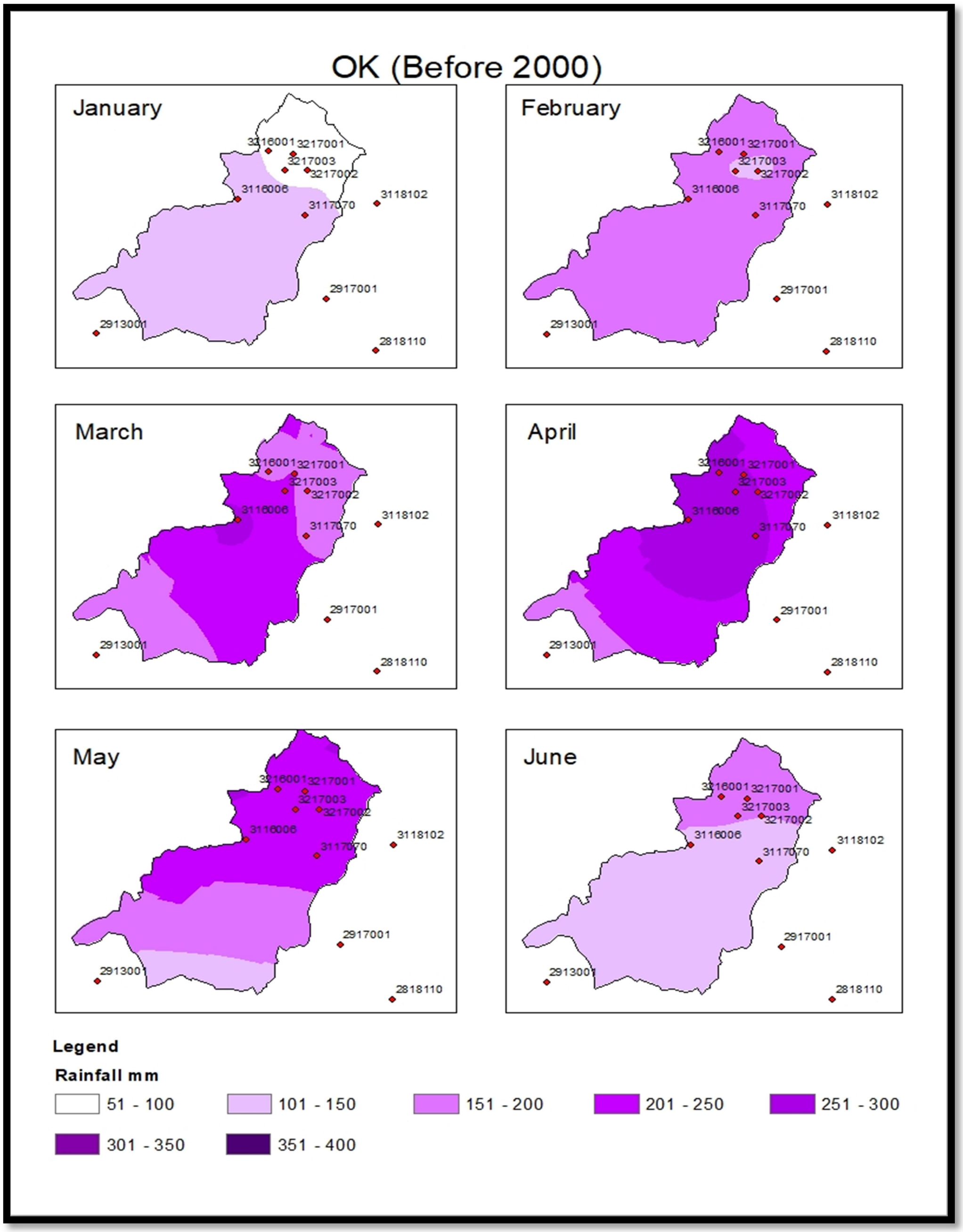

Figure 4.6 Monthly isohyet maps using OK before 2000 (January – June)

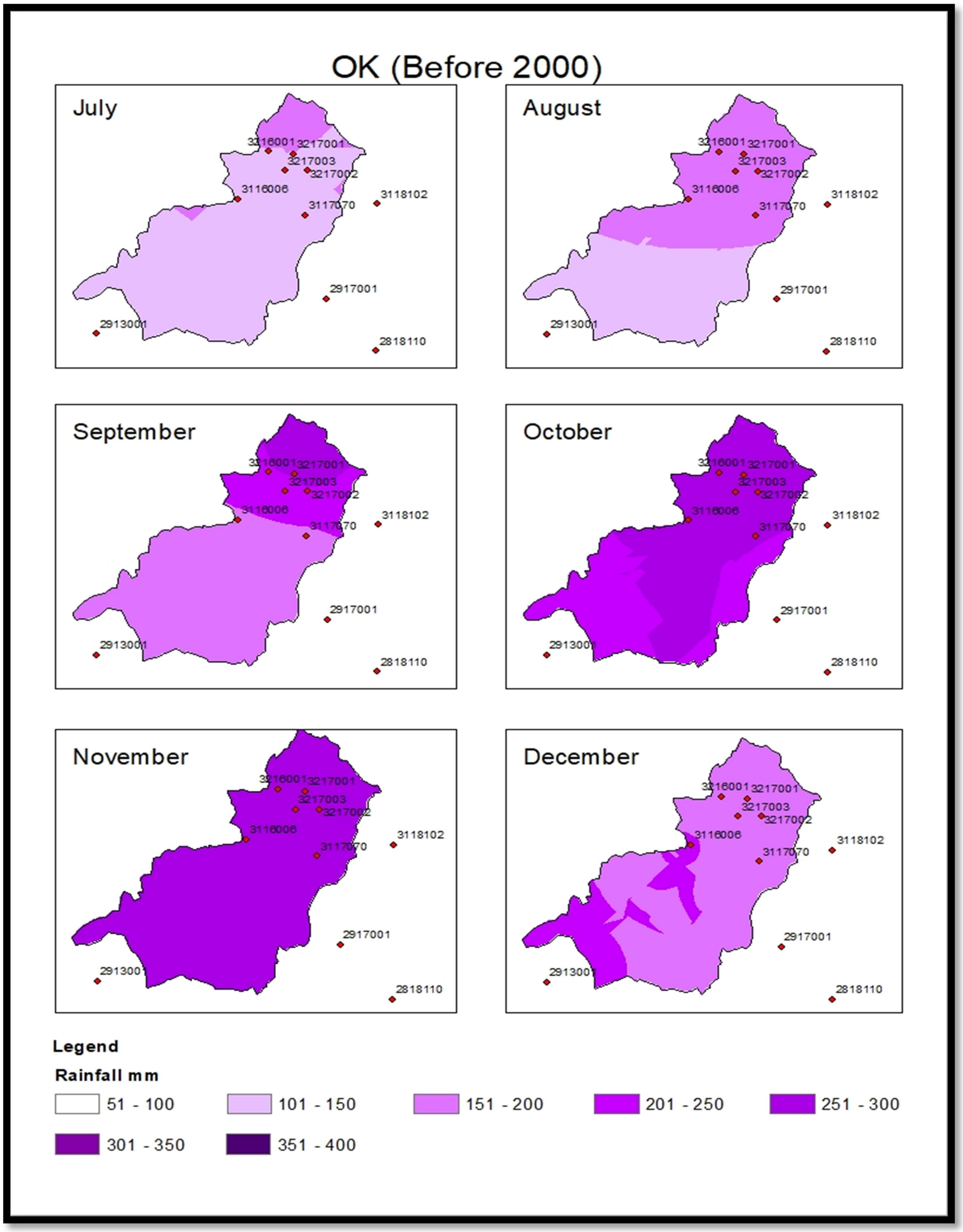

Figure 4.7 Monthly isohyet maps using OK before 2000 (July – December)

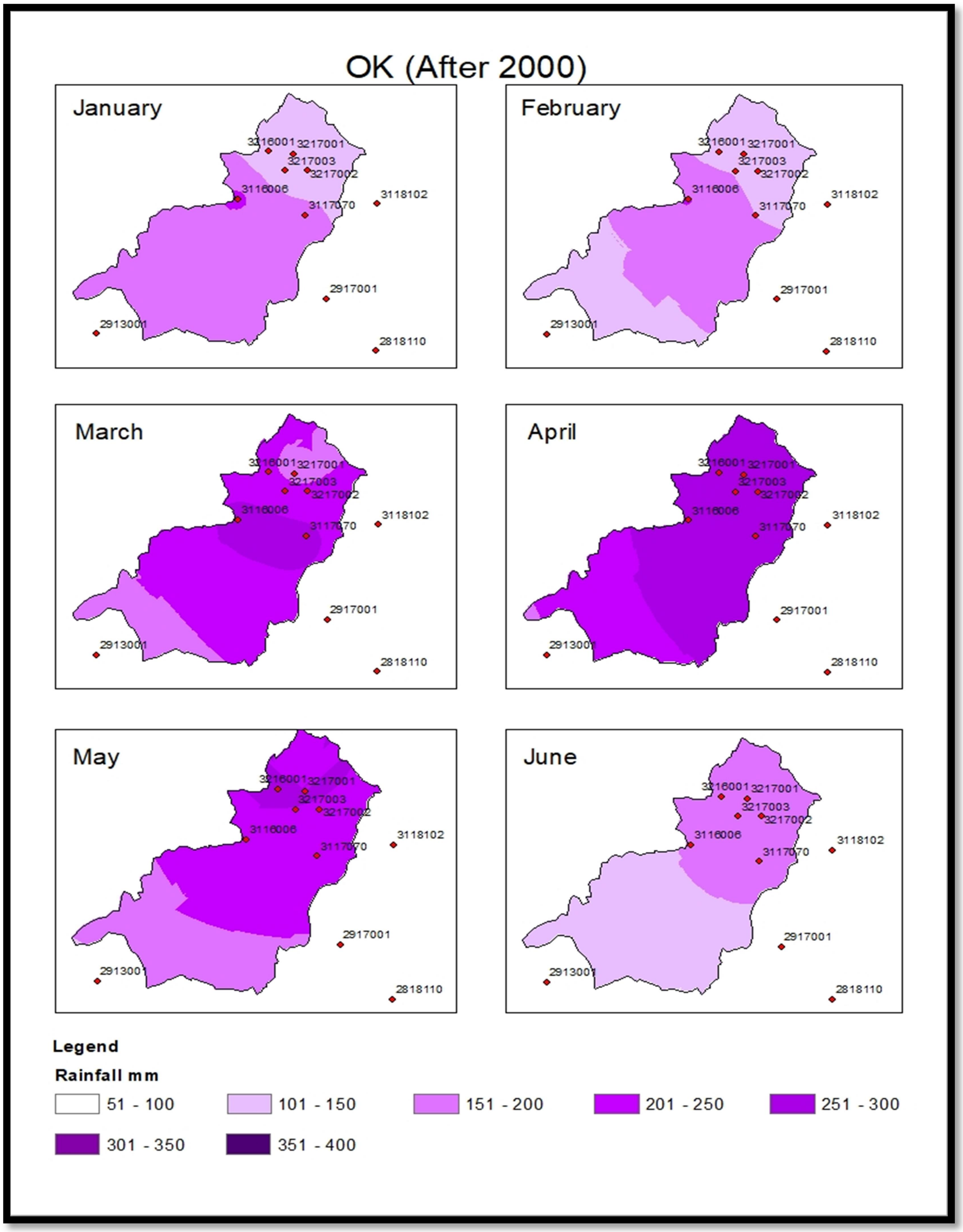

Figure 4.8 Monthly isohyet maps using OK after 2000 (January – June)

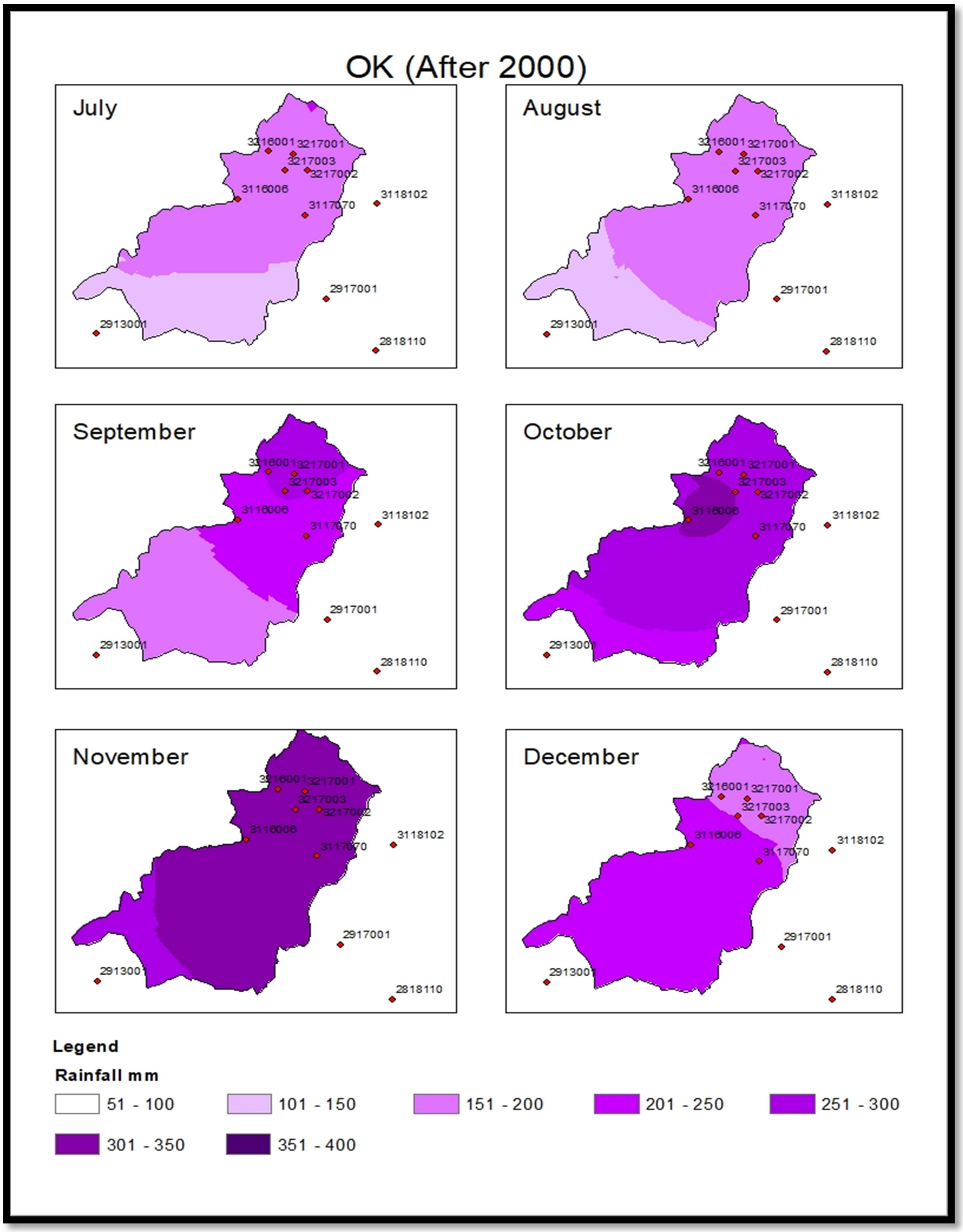

Figure 4.9 Monthly isohyet maps using OK after 2000 (July – December)

4.2.2.2 Annually

The isohyet maps for annually average rainfall before and after 2000 had been formed over Klang river basin using Ordinary Kriging (OK) technique as follow:

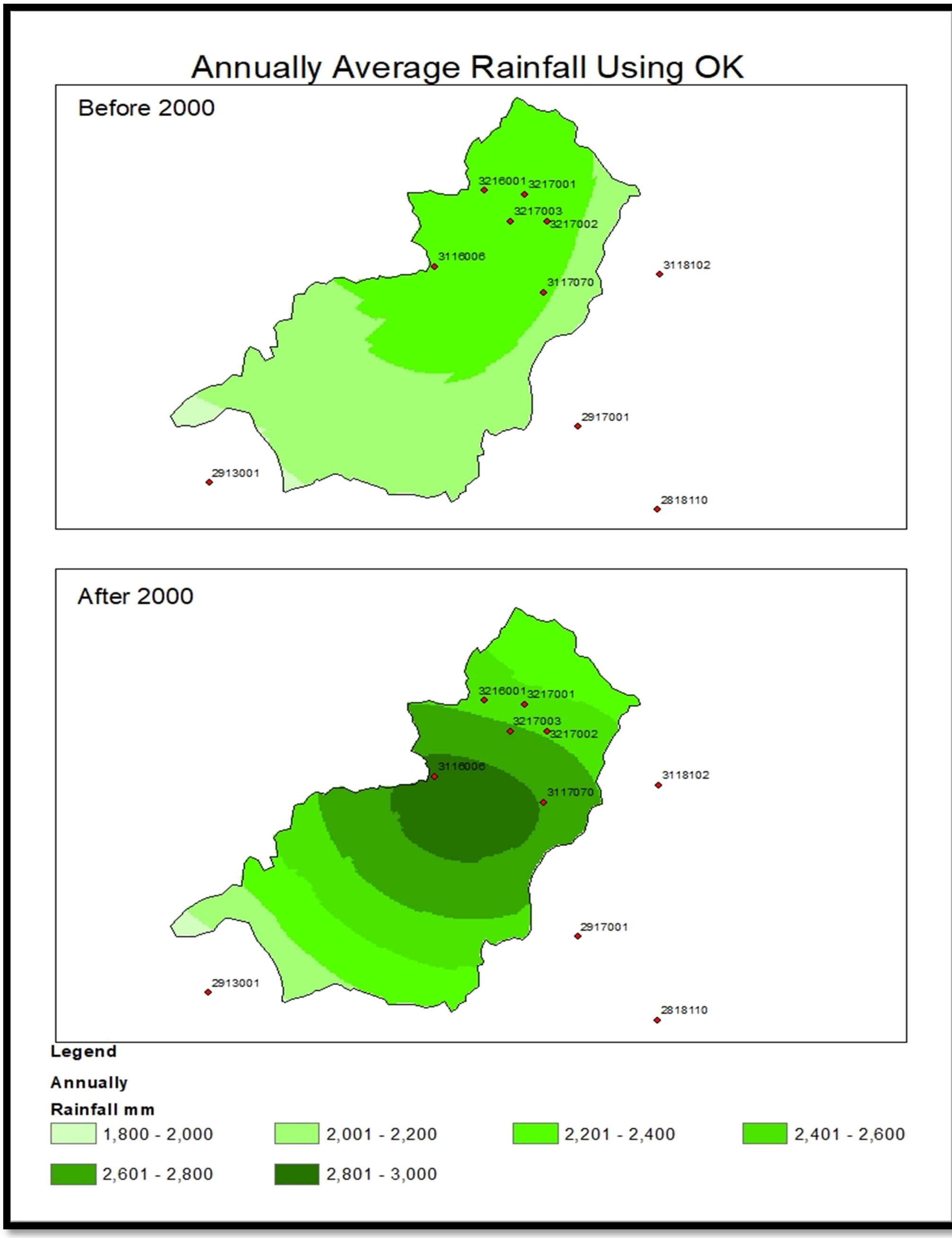

Figure 4.10 Annually isohyet maps using OK before and after 2000

4.3 Accuracy Evaluation

Cross validation is most simple method used to determine the accuracy of a spatial interpolator. This technique was performed by remove one rainfall data from the dataset and then the remaining data will be used to estimate the deleted rainfall data (Sterling *et al.*, 2003). This validation process can be easily executed with the aid of Geostatistical Analyst in ArcGIS. In this study, cross validation had been carried out to determine performance of Inverse Distance Weighting method (IDW) and Ordinary Kriging (OK) in order to find out which method can provide the best predicted interpolate data.

Three statistics such as mean absolute error (MAE), root mean square error (RMSE) and goodness of prediction (G) were calculated and used as the indicator to assess these two different interpolation methods. MAE and RMSE were used to test the accurate of the interpolated data. Lower value of MAE and RMSE indicate that the interpolator has smaller error and greater central tendencies (Taesombat and Sriwongsitanon, 2009). Meanwhile, G was utilized to describes the how good the interpolation method. Positive value of G means it is more reliable than the sample mean (Dongwoo *et al.*,2015).

In addition, maximum, minimum, average and standard deviation also were used in the study to compare the measured and interpolated data before used the above three statistical indicators. These parameters can aid to evaluate how accurate the interpolator estimates an unknown value. As a conclusion, for this study the interpolation method that has minimize of those error will be choose as the optimum spatial interpolation method for Klang river basin.

4.3.1 Minimum Value

Table 4.1 showed the result of minimum value from observed rainfall, Inverse Distance Weighting (IDW) and Ordinary Kriging (OK). From the table below, it can be clearly seen that Inverse Distance Weighting tends to overestimate all the minimum rainfall values for every month before and after 2000. Similarly, for annually before and after 2000 Inverse Distance Weighting were also overestimated the minimum values. Hence, Ordinary Kriging is more reliable than Inverse Distance Weighting method over Klang river basin.

Table 4.1 Compare the minimum value from observed rainfall, IDW and OK

Period		Min		
		Observed Rainfall	**IDW**	**OK**
Monthly before 2000	January	79.00	89.72	88.16
	February	127.86	149.03	148.51
	March	142.37	197.38	189.84
	April	158.40	232.78	188.56
	May	121.02	194.62	131.35
	June	95.00	130.73	114.01
	July	125.97	139.84	138.51
	August	124.59	148.60	128.44
	September	158.86	192.18	158.82
	October	210.60	243.05	216.58
	November	213.29	243.70	255.06
	December	145.50	160.62	166.88
	Average	141.872	176.85	160.39
Monthly after 2000	January	80.85	119.52	115.02
	February	97.56	128.07	126.42
	March	137.41	203.28	204.27
	April	161.79	264.57	253.44
	May	128.66	216.01	156.61
	June	104.03	142.82	94.81
	July	105.79	150.13	94.37
	August	125.11	169.99	158.99
	September	148.19	209.15	171.43
	October	213.52	257.82	213.92
	November	262.58	330.97	321.30
	December	158.47	180.92	192.10
	Average	143.66	197.77	175.22
Annually before 2000	1970 - 1999	1839.12	2103.28	1970.60
Annually after 2000	2000 - 2016	1799.90	2430.58	2213.20

4.3.2 Maximum Value

Table 4.2 compared the maximum value of actual value with the maximum value obtained from Inverse Distance Weighting (IDW) and Ordinary Kriging (OK). Basically, almost the entire maximum values extracted from Inverse Distance Weighting were underestimated. However, three months at before 2000 (July, August, and October) and two months at after 2000 (March and July) were displayed closer maximum value to the actual one. Thus, Ordinary Kriging was selected for Klang river basin because its maximum values were considering more near to the actual maximum rainfall values for monthly and annually.

Table 4.2 Compare the maximum value from observed rainfall, IDW and OK

Period		**Max**		
		Observed Rainfall	**IDW**	**OK**
Monthly before 2000	January	131.70	109.89	114.78
	February	188.45	158.61	168.26
	March	263.56	213.37	220.15
	April	284.67	249.86	277.79
	May	245.43	233.84	246.87
	June	170.78	153.00	158.09
	July	183.33	162.50	150.10
	August	201.98	186.95	182.96
	September	251.94	241.01	254.64
	October	275.41	270.64	288.51
	November	291.97	268.73	273.21
	December	212.66	196.66	209.56
	Average	225.16	203.76	212.08
Monthly after 2000	January	216.68	154.65	168.87
	February	202.09	158.07	164.47
	March	276.93	233.41	229.99
	April	353.28	296.55	369.87
	May	272.12	252.20	263.33
	June	196.59	185.78	187.36
	July	186.21	181.07	204.00
	August	211.14	183.64	190.79
	September	271.94	257.44	264.37
	October	324.97	305.00	307.44
	November	373.74	343.54	348.37
	December	264.97	205.85	222.06
	Average	262.56	229.77	243.41
Annually before 2000	1970 - 1999	2372.53	2307.94	2319.18
Annually after 2000	2000 - 2016	2936.97	2606.75	2690.73

4.3.3 Average Value

Table 4.3 presented the result of average rainfall value from observed and predicted. Based on this table, all the average values generated by Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) seem to be close to the real average value. However, the average value generated using Ordinary Kriging performs better because its value was slightly closer to the actual average value. Therefore, Ordinary Kriging was more preferred over Klang river basin.

Table 4.3 Compare the average value from observed rainfall, IDW and OK

Period		**Average**		
		Observed Rainfall	**IDW**	**OK**
Monthly before 2000	January	101.75	96.65	100.78
	February	154.13	154.01	155.21
	March	202.06	204.26	203.64
	April	234.85	251.06	244.75
	May	209.37	223.14	216.90
	June	137.28	145.24	139.62
	July	146.22	150.65	145.46
	August	160.88	170.77	162.96
	September	206.39	222.60	212.39
	October	249.61	260.87	260.15
	November	263.85	257.14	263.10
	December	183.28	173.55	181.89
	Average	187.47	192.50	190.57
Monthly after 2000	January	135.82	129.72	136.33
	February	138.91	139.62	141.72
	March	212.98	218.52	218.67
	April	276.36	280.92	289.86
	May	220.26	237.96	228.51
	June	153.69	169.32	158.96
	July	159.76	171.08	170.33
	August	172.77	177.86	177.26
	September	218.86	238.81	225.26
	October	272.00	287.40	278.11
	November	330.62	338.52	338.67
	December	197.40	193.98	199.23
	Average	207.45	215.31	213.58
Annually before 2000	1970 - 1999	2155.28	2225.35	2193.36
Annually after 2000	2000 - 2016	2451.41	2546.39	2535.89

4.3.4 Standard Deviation

Table 4.4 displayed the standard deviation value of raw rainfall data, Inverse Distance Weighing (IDW) and Ordinary Kriging (OK). All the standard deviation values developed through Inverse Distance Weighting (IDW) were underestimated compare to the observed value. Anyhow, Ordinary Kriging (OK) was performed better because all the standard deviation values are much closer to the actual standard deviation value. Hence, Ordinary Kriging was more appropriately used for Klang river basin.

Table 4.4 Compare the standard deviation from observed rainfall, IDW and OK

Period		**Standard Deviation**		
		Observed Rainfall	**IDW**	**OK**
Monthly before 2000	January	19.94	6.17	9.21
	February	18.93	2.98	5.58
	March	30.42	5.61	10.23
	April	41.89	11.09	24.94
	May	43.16	12.71	34.87
	June	23.74	7.66	15.44
	July	22.61	7.48	4.17
	August	25.32	12.15	18.45
	September	38.32	17.78	30.65
	October	25.57	10.60	21.73
	November	22.31	7.95	5.18
	December	25.69	10.48	13.83
	Average	28.16	9.39	16.19
Monthly after 2000	January	39.90	11.74	15.08
	February	31.67	8.67	12.24
	March	45.09	9.43	7.84
	April	53.65	11.28	30.58
	May	46.06	12.33	32.47
	June	34.78	13.99	32.41
	July	29.18	10.12	31.35
	August	26.58	4.77	9.85
	September	41.82	16.89	34.18
	October	42.57	14.44	28.36
	November	31.54	4.15	8.30
	December	32.14	7.53	8.32
	Average	37.92	10.45	20.92
Annually before 2000	1970 - 1999	192.10	64.12	120.20
Annually after 2000	2000 - 2016	351.21	52.40	138.36

The bar charts below showed the summarize minimum, maximum, average and standard deviation performance of Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) methods for monthly and annually rainfall estimation. It can be clearly seen that Ordinary Kriging (OK) produced closer minimum, maximum, average and standard deviation value for monthly and annually rainfall estimation compared to Inverse Distance Weighting (IDW).

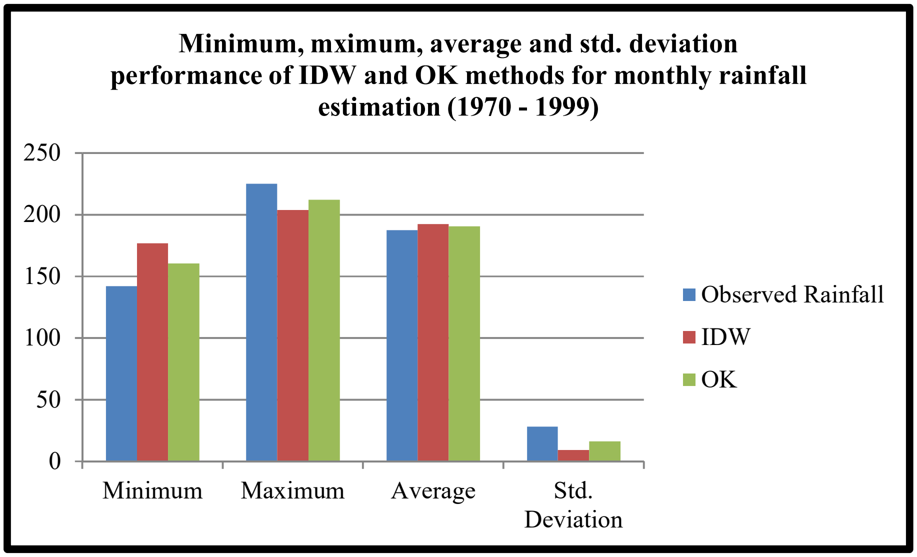

Figure 4.11 Minimum, maximum, average and standard deviation performance of IDW and OK methods for monthly rainfall estimation (1970 – 1999)

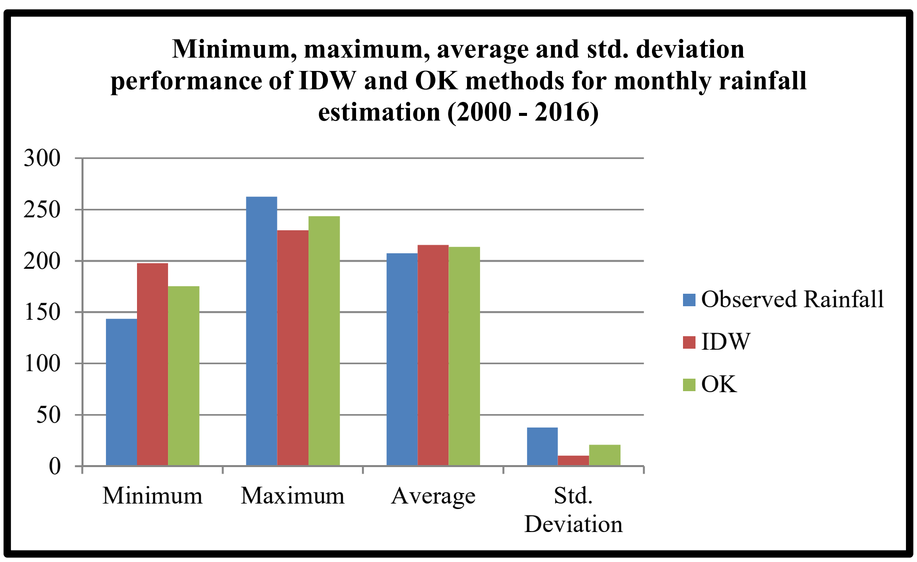

Figure 4.12 Minimum, maximum, average and standard deviation performance of IDW and OK methods for monthly rainfall estimation (2000 - 2016)

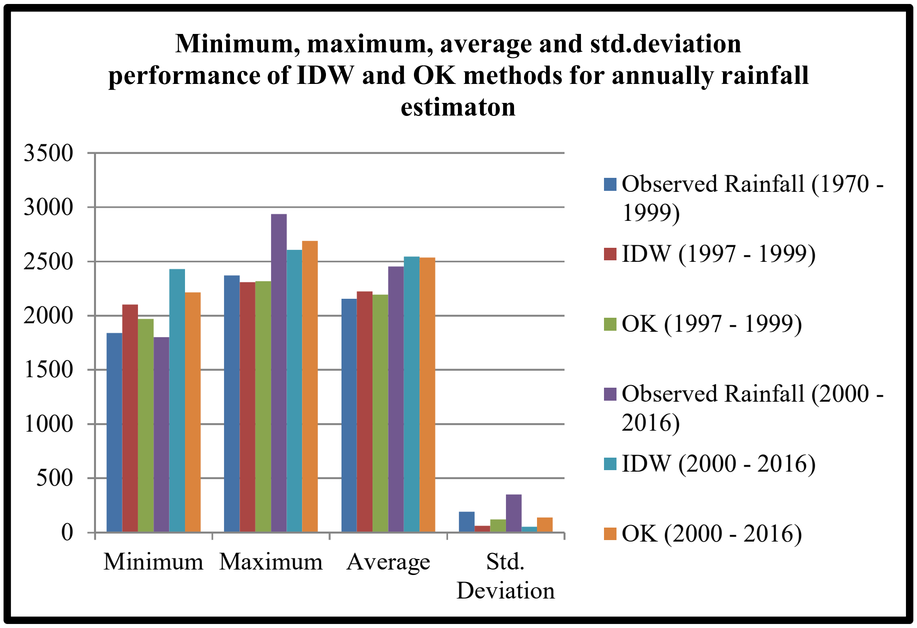

Figure 4.13 Minimum, maximum, average and standard deviation performance of IDW and OK methods for annualy rainfall estimation

4.3.5 Mean absolute Error (MAE), Root Mean Square Error (RMSE), and Goodness of Prediction (G)

Table 4.5 showed the result of mean absolute error (MAE), root mean square error (RMSE) and goodness of prediction (G) obtained from the Inverse Distance Weighting (IDW) and Ordinary Kriging (OK). From the table below, majority value of MAE and RMSE generated by Ordinary Kriging were lower. Besides, the most of the G value generated using Ordinary Kriging were positive value that was near to 100 percent. Through figure 4.14,4.15, 4.16, 4.17 and 4.18, Ordinary Kriging interpolator was showed has the smaller MAE and RMSE and higher accurate percentage for G compared to Inverse Distance Weighting interpolator. Therefore, Ordinary Kriging was selected for Klang river basin.

Table 4.5 MAE, RMSE, and G value for IDW and OK

Period		**IDW**			**OK**		
		MAE	**RMSE**	**G**	**MAE**	**RMSE**	**G**
Monthly before 2000	January	17.9	20.8	-21.2	15.1	17.5	13.9
	February	14.4	19.0	-12.4	15.1	19.0	-11.5
	March	22.0	32.5	-27.1	25.8	36.1	-56.2
	April	31.8	40.4	-3.4	22.3	30.9	39.4
	May	23.9	37.0	18.4	26.6	41.5	-2.5
	June	14.5	19.9	21.9	13.3	16.7	45.0
	July	20.4	22.4	-8.9	17.7	21.1	3.5
	August	16.0	18.3	41.8	9.2	11.3	77.9
	September	22.9	28.3	39.2	12.6	16.1	80.5
	October	13.7	19.3	36.5	17.6	27.4	-27.2
	November	21.9	26.6	-58.1	20.3	25.2	-42.1
	December	24.3	27.6	-28.0	20.9	25.4	-8.4
Monthly after 2000	January	29.8	42.4	-25.6	29.9	38.4	-3.0
	February	27.9	35.3	-38.3	27.8	35.4	-39.2
	March	40.0	48.5	-28.6	36.8	45.2	-11.7
	April	39.9	55.4	-18.6	53.5	79.4	-143.1
	May	29.1	41.1	11.5	25.3	35.4	34.5
	June	24.5	28.1	27.4	17.2	19.1	66.4
	July	16.8	23.8	25.8	25.9	36.1	-69.8
	August	20.9	27.6	-20.0	24.2	28.9	-31.4
	September	26.4	34.9	22.6	17.6	19.5	75.9
	October	32.7	36.1	20.2	25.2	27.6	53.3
	November	23.3	32.8	-20.5	26.5	35.7	-42.1
	December	27.0	33.3	-19.4	25.4	30.8	-2.2
Annually before 2000	1970 - 1999	135.1	167.9	15.1	103.1	119.8	56.8
Annually after 2000	2000 – 2016	267.6	345.9	-7.8	204.2	295.3	21.5

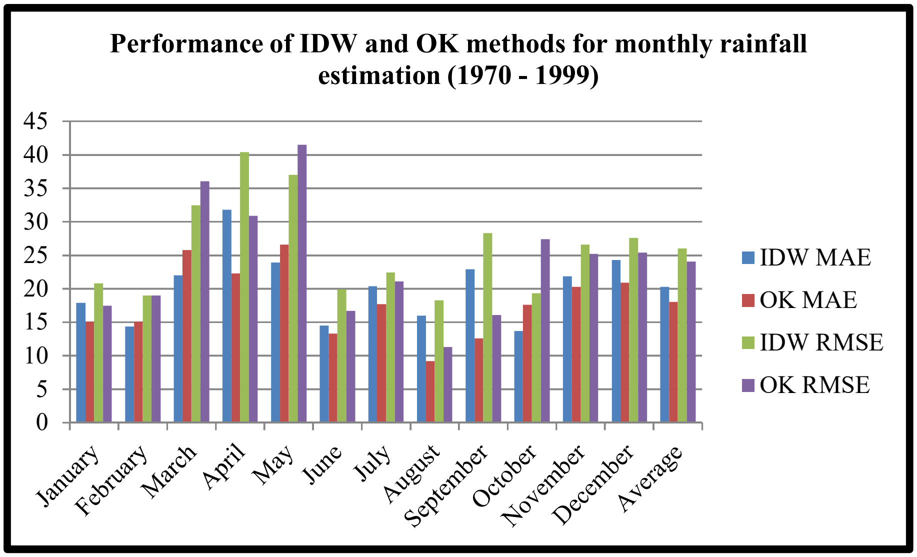

Figure 4.14 Performance of IDW and OK methods for monthly rainfall estimation (1970 – 1999)

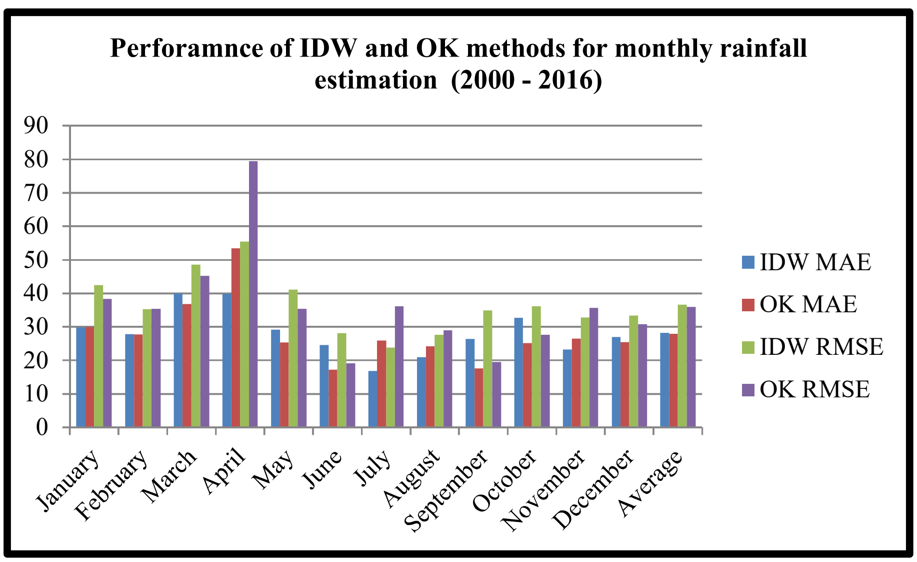

Figure 4.15 Performance of IDW and OK methods for monthly rainfall estimation (2000 – 2016)

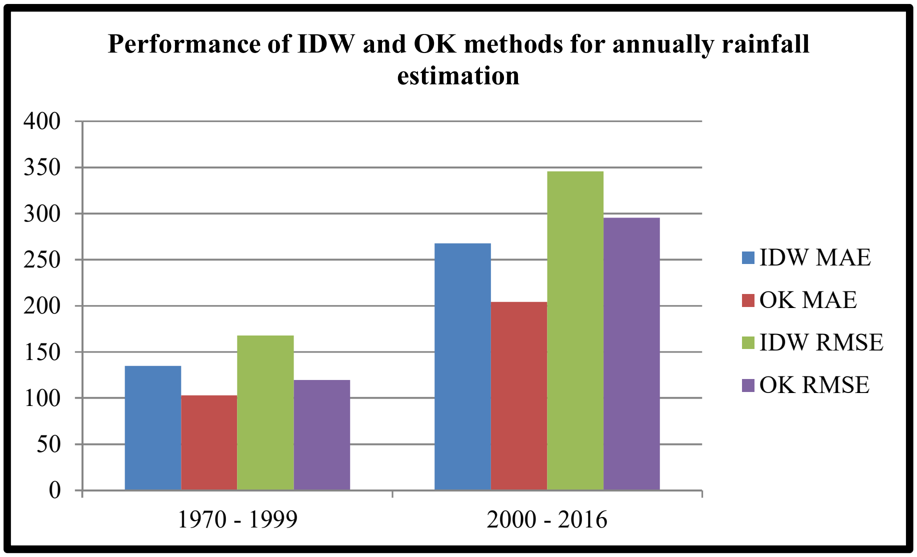

Figure 4.16 Performance of IDW and OK methods for annually rainfall estimation

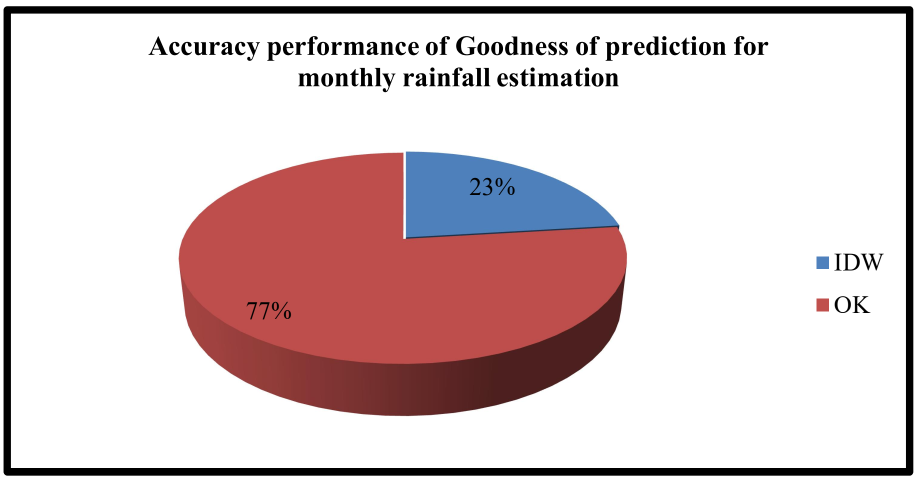

Figure 4.17 Accuracy performance of G between IDW and OK for monthly rainfall estimation

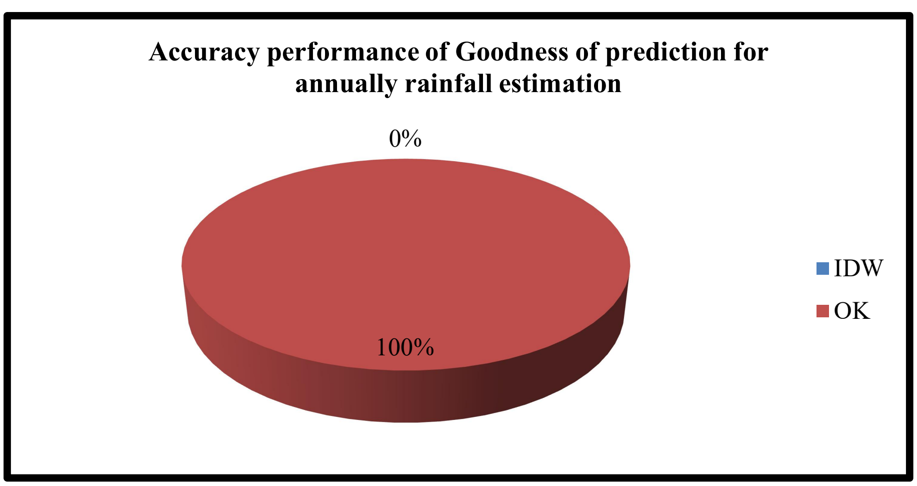

Figure 4.18 Accuracy performance of G between IDW and OK for annually rainfall estimation

4.3.6 Summary

In conclusion, Ordinary Kriging (OK) method had produced minimum, maximum, average and standard deviation values that were closer to the actual observed value. This proven that Ordinary Kriging (OK) had the lower variation of estimate value than Inverse Distance Weighting (IDW). Other than that, it also generated lower MAE, RMSE and positive value of G which was closer to the 100 for majority month and annually. Thus, Ordinary Kriging was the most optimum interpolation method to be adopted for Klang river basin and the maps will selected to analysis the impact of climate change within the study area.

4.4 Climate Assessment

Klang river basin was one of the most important basins in Selangor. This is because the middle catchment of this basin was covered by the most populated area within Kuala Lumpur. While, at the upper catchment of Klang river basin included Gombak and Hulu Langat and the lower catchment that comprised the Klang and Petaling. Therefore, it was an essential to understand the seasonal and annual rainfall characteristics in this basin using the isohyet maps.

In this study, the climate condition of Klang river basin had been analysed through the monthly and annually isohyet maps that plotted using optimum spatial method. Through the maps, it helped to identify the rainfall patterns distribution over Klang river basin. The rainfall distributions before and after 2000 also had been compared in order to analysis the changing rainfall pattern in the basin. The impact of climate was extremely important for this basin especially at the middle part of the catchment which consists of the most development area in Malaysia. Thus, the effect of climate change had been detected through the monthly and annually isohyet maps for Klang river basin.

4.4.1 January Average Rainfall Before and After 2000

From the figure 4.19, it can be clearly seen that the January average rainfall had been increased after 2000 for the entire basin especially at the Ladang Edinburgh Site 2. This station was situated in Kepong area which was closer to the federal territory of Kuala Lumpur. January was one of the driest months in Klang river basin. The average rainfall was around 118.78mm.The maximum average rainfall before 2000 was obtained at Ladang Edinburgh Site 2 (3116006) with 129.36mm. Meanwhile, the minimum average rainfall before 2000 was obtained at Ibu Bekalan Km. 16 (3217001) with 79mm. This station was situated at Gombak area, Selangor which was the upper part of the basin. On the other hand, the maximum average rainfall after 2000 was also found in Ladang Edinburgh Site 2 (3116006) with 216.68mm. While, the minimum average rainfall after 2000 was occurred in Smk Bandar Tasik Kesuma (2818110) with 80.85mm. The station was located at Semenyih area, Selangor.

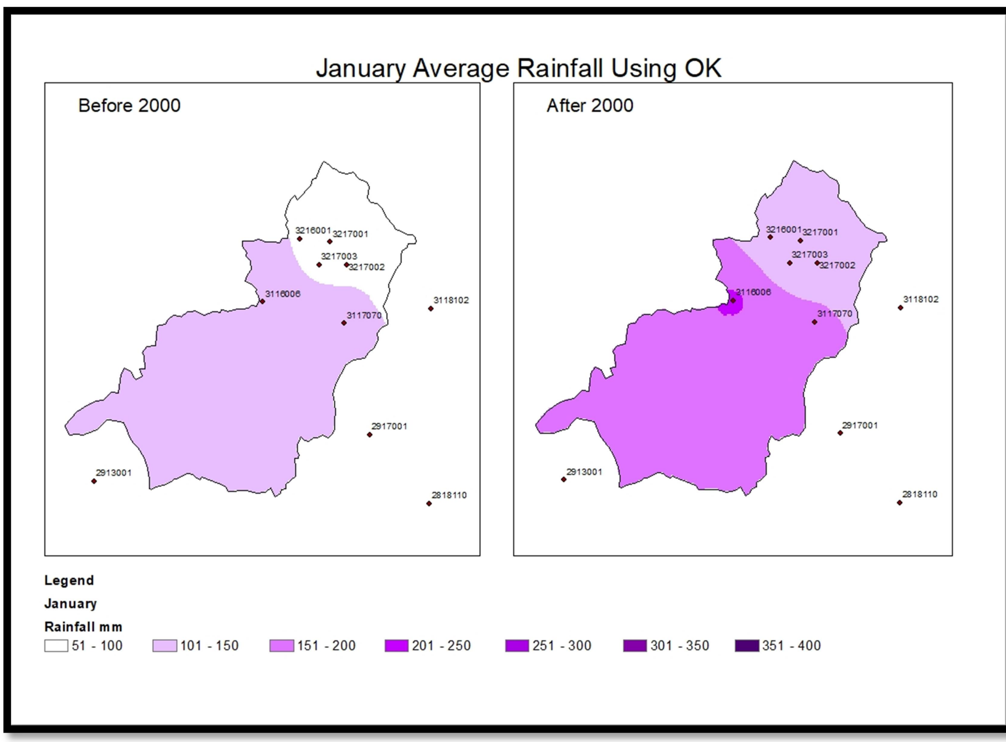

Figure 4.19 January isohyet maps (Before and after 2000)

From table 4.6, the highest rainfall value increased was found in Ladang Edinburgh Site 2 (3116006) with 87.31mm whereas the highest value of rainfall increased was in Smk Bandar Tasik Kesuma (2818110) with 1.55mm. Based on figure 4.20, the trend of January average rainfall was increasing for all stations.

Table 4.6 January average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	After 2000	
1	2818110	Smk. Bdr Tasik Kesuma	79.30	80.85	1.55
2	2913001	P/Kwln P/S Telok Gong	131.70	145.91	14.21
3	2917001	Setor JPS. Kajang	119.87	170.69	50.83
4	3118102	Sek. Keb. Kg. Lui	86.01	122.65	36.64
5	3116006	Ldg. Edinburgh Site 2	129.36	216.68	87.31
6	3117070	Pusat Penyelidikan Jps Ampang	111.36	169.37	58.01
7	3216001	Kg. Sg. Tua	96.74	119.10	22.36
8	3217001	Ibu Bekalan Km. 16	79.00	108.33	29.33
9	3217002	Empangan Genting Klang	94.88	110.44	15.56
10	3217003	Ibu Bekalan Km.11	89.26	114.18	24.92
		Total	1017.49	1358.19	340.71

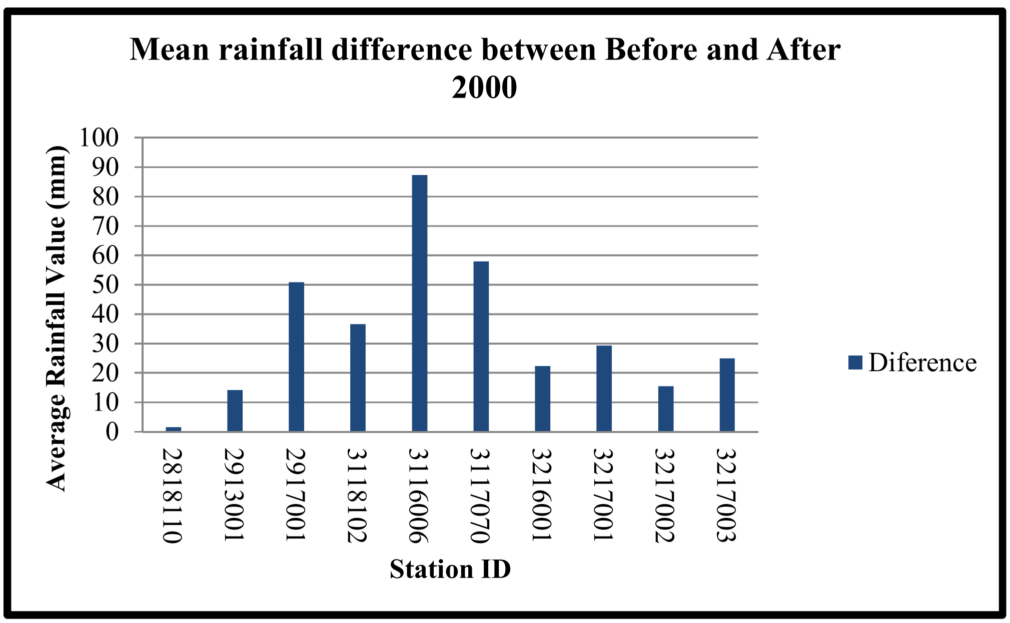

Figure 4.20 Mean January rainfall difference between before and after 2000

4.4.2 February Average Rainfall Before and After 2000

From the figure 4.21, it can be clearly seen that the February average rainfall had been decreased after 2000 was decreasing dramatically at the upper and lower catchment of Klang river basin. February was the third driest month in the Klang river basin. The average rainfall was around 146.52mm. The maximum average rainfall before 2000 was obtained at Ladang Edinburgh Site 2 (3116006) with 188.45mm. This station was located in Kepong area and was closer to the federal territory of Kuala Lumpur. Meanwhile, the minimum average rainfall before 2000 was obtained at Smk Bandar Tasik Kesuma (2818110) with 127.86mm. This station was situated at Semenyih area, Selangor. On the other hand, the maximum average rainfall after 2000 was also found in Ladang Edinburgh Site 2 (3116006) with 202.09mm. While, the minimum average rainfall was occurred in P/Kwln P/S Telok Gong (2913001) with 97.56mm. The station was located at Telok Gong area, Selangor.

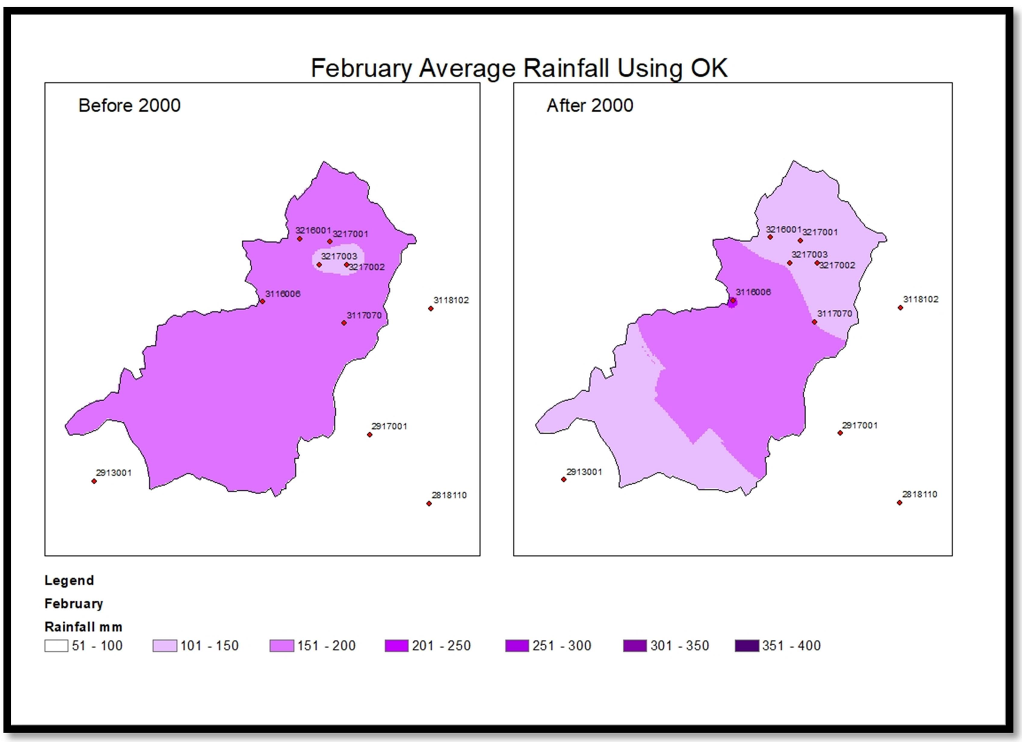

Figure 4.21 February isohyet maps (Before and after 2000)

From table 4.7, the highest rainfall value increased was found in Setor JPS Kajang (2917001) with 23.44mm whereas the highest rainfall value decreased was in P/Kwln P/S Telok Gong (2913001) with 46.11mm. Based on figure 4.22, the trend of February average rainfall was decreasing for all stations except for Setor JPS Kajang (2917001), Ladang Edinburgh Site 2 (3116006), and Ibu Bekalan Km.11 (3217003).

Table 4.7 February average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	After 2000	
1	2818110	Smk. Bdr Tasik Kesuma	127.86	107.52	-20.34
2	2913001	P/Kwln P/S Telok Gong	143.67	97.56	-46.11
3	2917001	Setor JPS. Kajang	152.00	175.44	23.44
4	3118102	Sek. Keb. Kg. Lui	149.94	142.80	-7.14
5	3116006	Ldg. Edinburgh Site 2	188.45	202.09	13.64
6	3117070	Pusat Penyelidikan Jps Ampang	185.84	149.76	-36.08
7	3216001	Kg. Sg. Tua	153.12	125.38	-27.73
8	3217001	Ibu Bekalan Km. 16	152.73	118.29	-34.44
9	3217002	Empangan Genting Klang	142.46	124.26	-18.20
10	3217003	Ibu Bekalan Km.11	145.20	146.03	0.83
		Total	1541.28	1389.14	-152.14

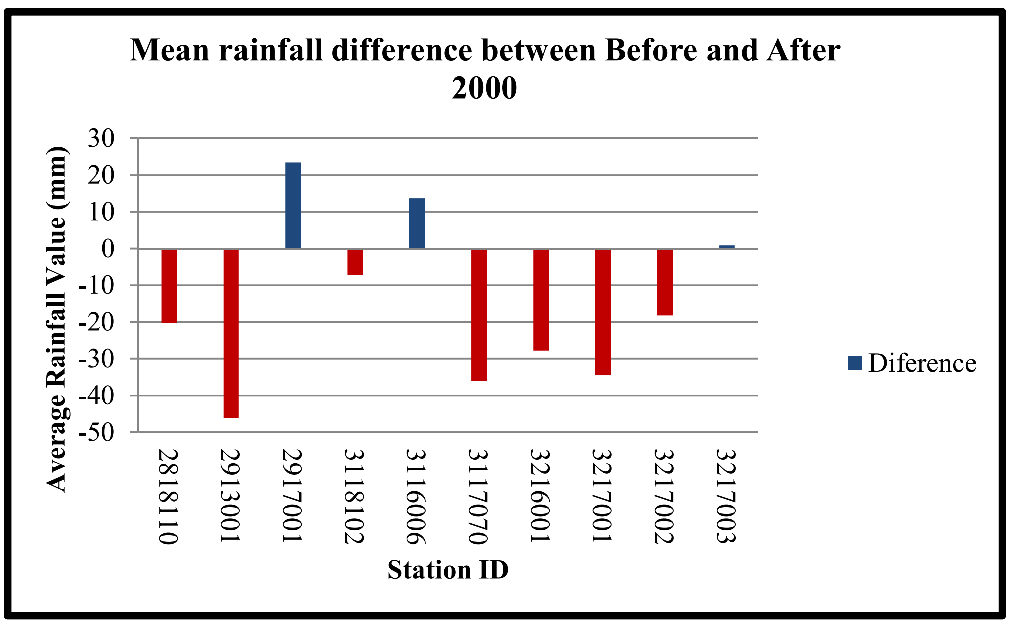

Figure 4.22 Mean February rainfall difference between before and after 2000

4.4.3 March Average Rainfall Before and After 2000

From the figure 4.23, it can be clearly seen that the March average rainfall had been increased after 2000 especially at the upper and middle catchment of Klang river basin. The average rainfall was around 207.52mm. The maximum average rainfall before 2000 was obtained at Ladang Edinburgh Site 2 (3116006) with 263.56mm. This station was located in Kepong area and was closer to the federal territory of Kuala Lumpur. Meanwhile, the minimum average rainfall before 2000 was obtained at P/Kwln P/S Telok Gong (2913001) with 142.37mm. This station was situated at Telok Gong area, Selangor. On the other hand, the maximum average rainfall after 2000 was also found in Ladang Edinburgh Site 2 (3116006) with 276.93mm. While, the minimum average rainfall after 2000 was occurred in P/Kwln P/S Telok Gong (2913001) too with 137.41mm.

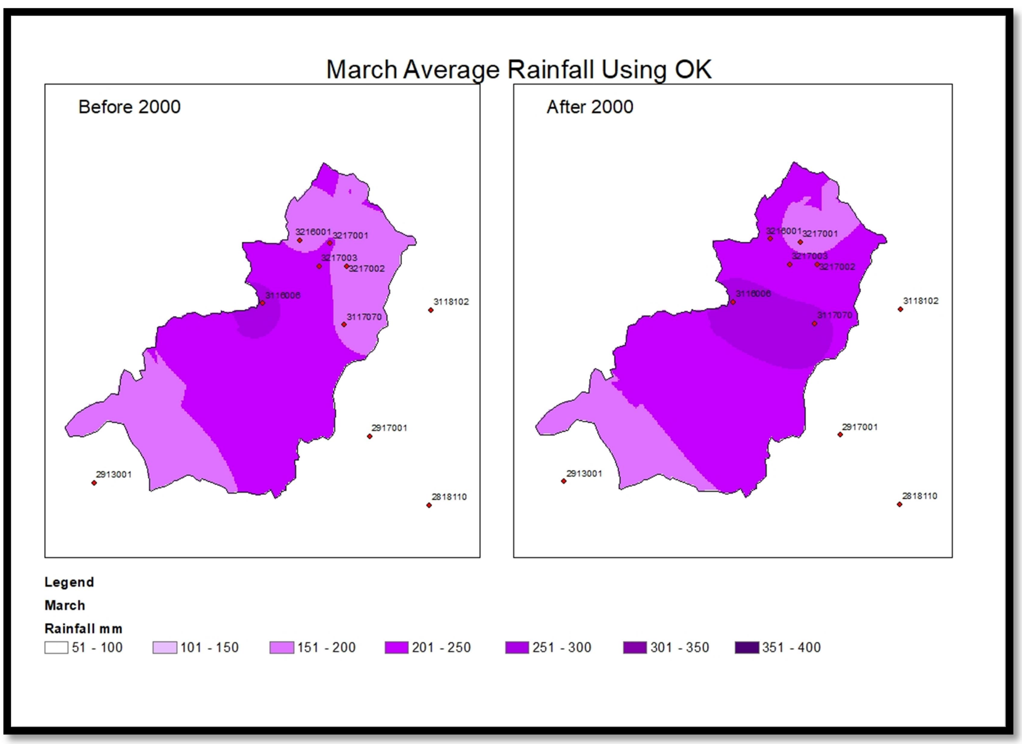

Figure 4.23 March isohyet maps (Before and after 2000)

From table 4.8, the highest rainfall value increased was found in Pusat Penyelidikan JPS Ampang (3117070) with 76.62mm whereas the highest rainfall value decreased was in Smk Bandar Tasik Kesuma (2818110) with 42.31mm. Based on figure 4.24, the trend of March average rainfall was increasing for all stations except for Smk Bandar Tasik Kesuma (2818110), P/Kwln P/S Telok Gong (2913001) and Ibu Bekalan Km 16 (3217001).

Table 4.8 March average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	**After 2000**	
1	2818110	Smk. Bdr Tasik Kesuma	208.15	165.83	-42.31
2	2913001	P/Kwln P/S Telok Gong	142.37	137.41	-4.95
3	2917001	Setor JPS. Kajang	225.98	244.50	18.52
4	3118102	Sek. Keb. Kg. Lui	198.92	209.56	10.64
5	3116006	Ldg. Edinburgh Site 2	263.56	276.93	13.37
6	3117070	Pusat Penyelidikan Jps Ampang	193.83	270.46	76.62
7	3216001	Kg. Sg. Tua	190.95	210.35	19.40
8	3217001	Ibu Bekalan Km. 16	201.23	173.21	-28.03
9	3217002	Empangan Genting Klang	189.60	209.47	19.87
10	3217003	Ibu Bekalan Km.11	205.98	232.09	26.11
		Total	2020.58	2129.82	109.24

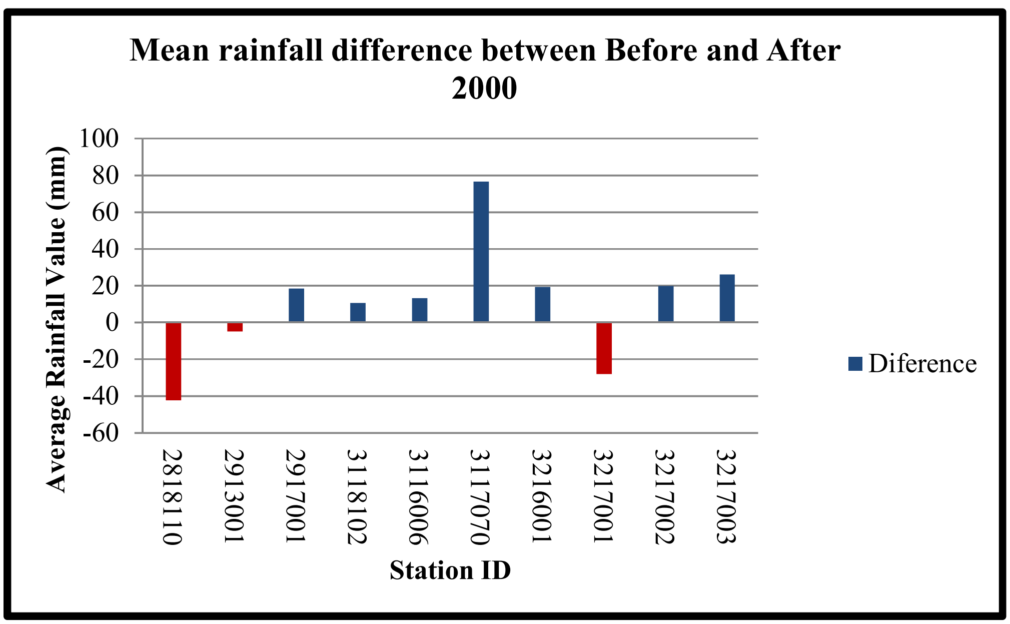

Figure 4.24 Mean March rainfall difference between before and after 2000

4.4.4 April Average Rainfall Before and After 2000

From the figure 4.25, it can be clearly seen that the April average rainfall had been increased after 2000 for the entire basin especially at the upper and middle catchment. April was third wettest month in Klang river basin. The average rainfall was around 255.61mm. The maximum average rainfall before 2000 was obtained at Ibu Bekalan Km 11 (3217003) with 284.67mm. This station was located in Gombak area, Selangor. Meanwhile, the minimum average rainfall before 2000 was obtained at P/Kwln P/S Telok Gong (2913001) with 158.40mm. This station was situated at Telok Gong area, Selangor. On the other hand, the maximum average rainfall after 2000 was found in Ladang Edinburgh Site 2 (3116006) with 353.28mm. This station was in Kepong area, Kuala Lumpur. While, the minimum average rainfall after 2000 was occurred in P/Kwln P/S Telok Gong (2913001) with 161.79mm.

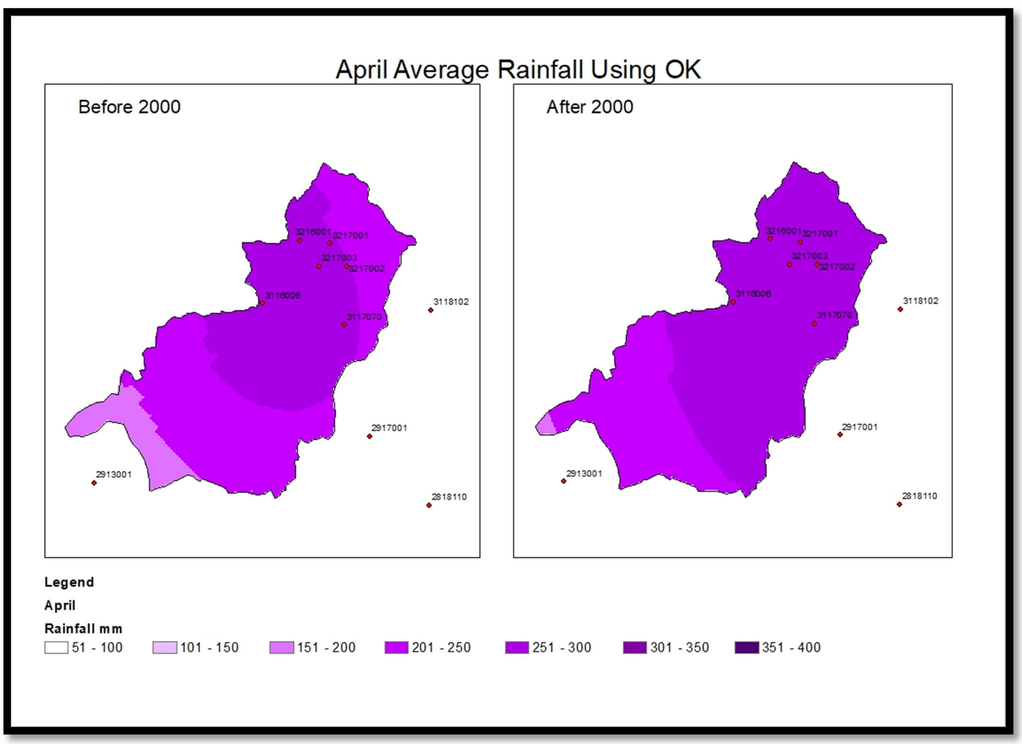

Figure 4.25 April isohyet maps (Before and after 2000)

From table 4.9, the highest rainfall value increased was found in Sek Keb Kampung Lui (3118102) with 93mm whereas the highest value of rainfall decreased was in Ibu Bekalan Km 16 (3217001) with 13.94mm. Based on figure 4.26, the trend of April average rainfall was increasing for all stations except for Ibu Bekalan Km 16 (3217001) and Ibu Bekalan Km 11 (3217003).

Table 4.9 April average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	After 2000	
1	2818110	Smk. Bdr Tasik Kesuma	195.40	266.68	71.28
2	2913001	P/Kwln P/S Telok Gong	158.40	161.79	3.39
3	2917001	Setor JPS. Kajang	221.80	308.42	86.61
4	3118102	Sek. Keb. Kg. Lui	191.21	284.21	93.00
5	3116006	Ldg. Edinburgh Site 2	272.11	353.28	81.17
6	3117070	Pusat Penyelidikan Jps Ampang	276.54	336.27	59.73
7	3216001	Kg. Sg. Tua	256.25	263.31	7.06
8	3217001	Ibu Bekalan Km. 16	246.88	232.94	-13.94
9	3217002	Empangan Genting Klang	245.23	274.53	29.30
10	3217003	Ibu Bekalan Km.11	284.67	282.21	-2.46
		Total	2348.48	2763.63	415.15

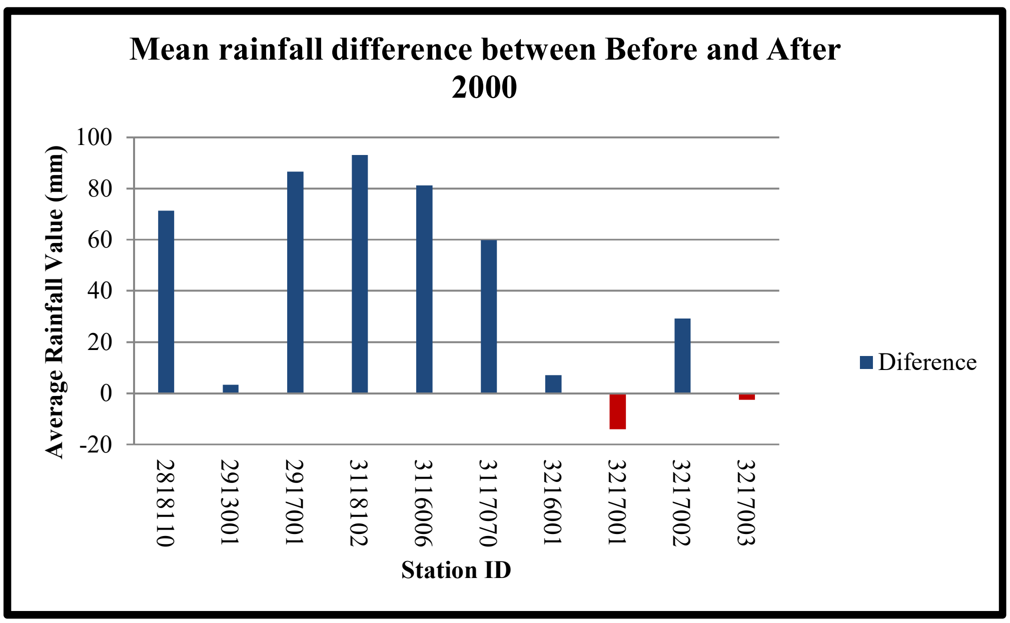

Figure 4.26 Mean April rainfall difference between before and after 2000

4.4.5 May Average Rainfall Before and After 2000

From the figure 4.27, it can be clearly seen that the May average rainfall had been increased after 2000 especially at the lower catchment of Klang river basin. The average rainfall was around 214.82mm. The maximum average rainfall before 2000 was obtained at Ladang Edinburgh Site 2 (3116006) with 245.43mm. This station was located in Kepong area and was closer to the federal territory of Kuala Lumpur. Meanwhile, the minimum average rainfall before 2000 was obtained at P/Kwln P/S Telok Gong (2913001) with 121.02mm. This station was situated at Telok Gong area, Selangor. On the other hand, the maximum average rainfall after 2000 was found in Empangan Genting Klang (3217002) with 216.68mm. This station was located in Gombak area, Selangor. While, the minimum average rainfall after 2000 was occurred in P/Kwln P/S Telok Gong (2913001) with 128.66mm.

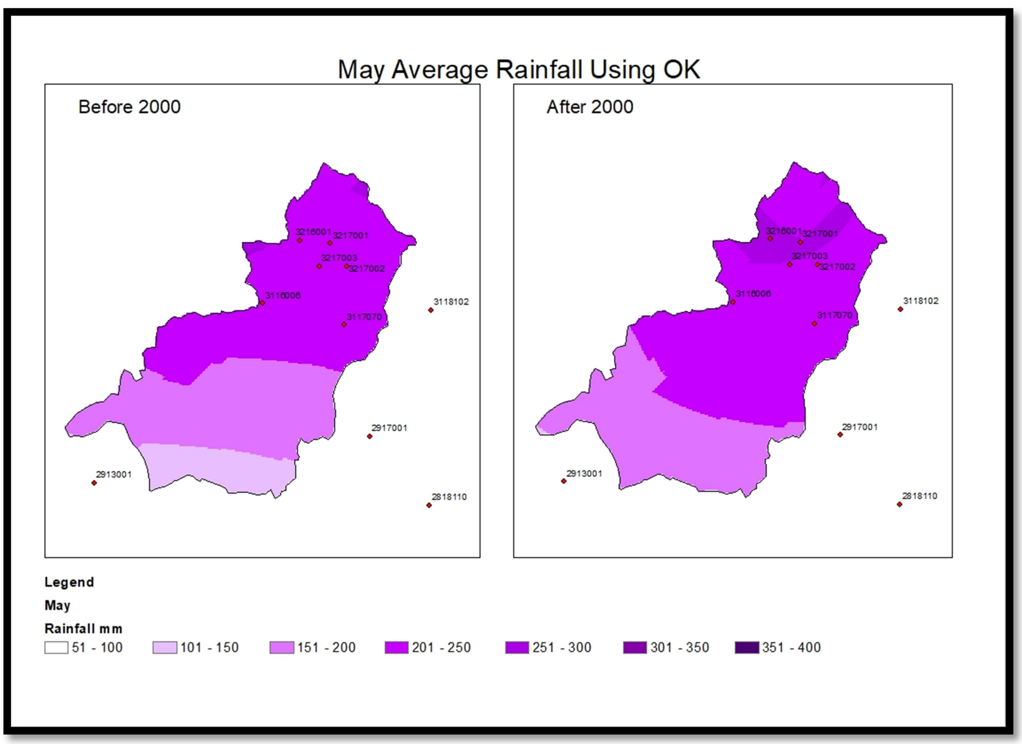

Figure 4.27 May isohyet maps (Before and after 2000)

From table 4.10, the highest rainfall value increased was found in Empangan Genting Klang (3217002) with 44.89mm whereas the highest value of rainfall decreased was in Sek Keb Kampung Lui (3118102) with 26.33mm. Based on figure 4.28, the trend of May average rainfall was increasing for all stations except for Smk Bandar Tasik Kesuma (2818110), Sek Keb Kampung Lui (3118102) and Kampung Sungai Tua (3216001).

Table 4.10 May average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	After 2000	
1	2818110	Smk. Bdr Tasik Kesuma	168.77	159.35	-9.42
2	2913001	P/Kwln P/S Telok Gong	121.02	128.66	7.63
3	2917001	Setor JPS. Kajang	160.74	197.79	37.05
4	3118102	Sek. Keb. Kg. Lui	239.58	213.25	-26.33
5	3116006	Ldg. Edinburgh Site 2	245.43	258.15	12.72
6	3117070	Pusat Penyelidikan Jps Ampang	219.97	249.68	29.71
7	3216001	Kg. Sg. Tua	239.88	236.50	-3.38
8	3217001	Ibu Bekalan Km. 16	235.74	236.47	0.73
9	3217002	Empangan Genting Klang	227.23	272.12	44.89
10	3217003	Ibu Bekalan Km.11	235.37	250.65	15.28
		Total	2093.73	2202.62	108.88

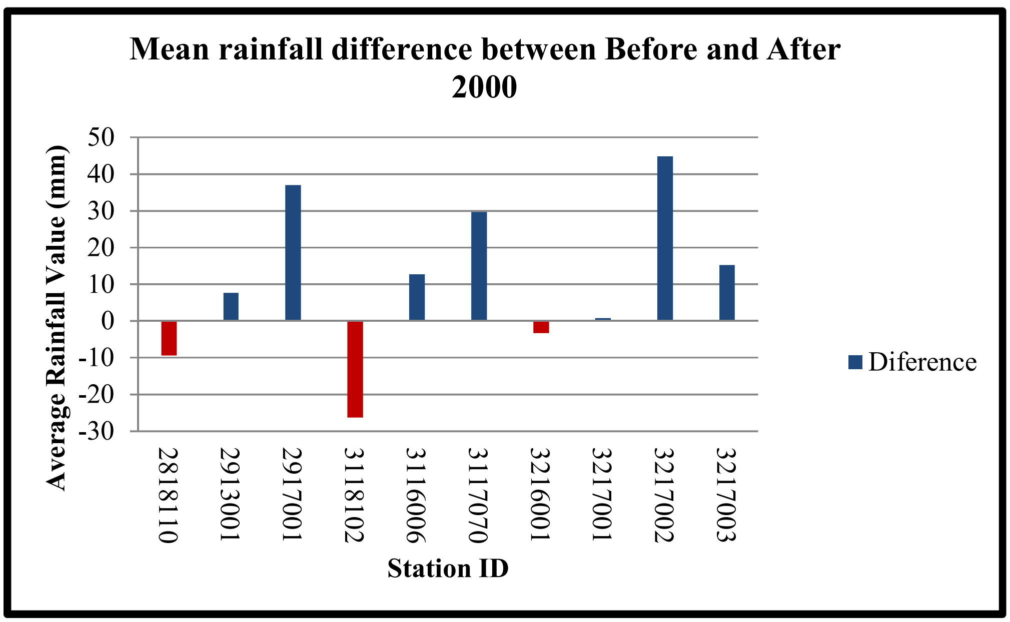

Figure 4.28 Mean May rainfall difference between before and after 2000

4.4.6 June Average Rainfall Before and After 2000

From the figure 4.29, it can be clearly seen that the June average rainfall had been increased a little bit after 2000 especially at the middle catchment of Klang river basin. June was second driest month in Klang river basin. The average rainfall was around 145.49mm. The maximum average rainfall before 2000 was obtained at Kampung Sungai Tua (3216001) with 170.78mm. This station was located in Gombak area, Selangor. Meanwhile, the minimum average rainfall before 2000 was obtained at Smk Bandar Tasik Kesuma with 95mm. This station was situated at Semenyih area, Selangor. On the other hand, the maximum average rainfall after 2000 was found in Ibu Bekalan Km 11 (3217003) with 196.59mm. This station was located in Gombak area, Selangor. While, the minimum average rainfall after 2000 was occurred in P/Kwln P/S Telok Gong (2913001) with 104.03mm. The station was located at Telok Gong area, Selangor.

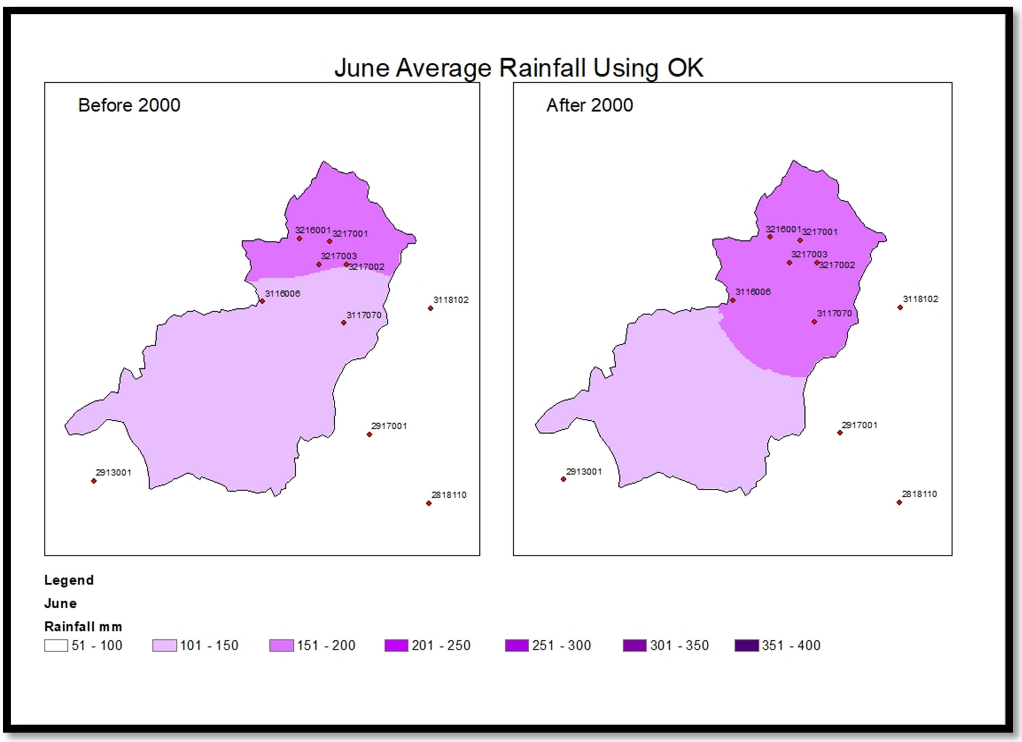

Figure 4.29 June isohyet maps (Before and after 2000)

From table 4.11, the highest rainfall value increased was found in Empangan Genting Klang (3217002) with 46.95mm whereas the highest value of rainfall decreased was in Sek Keb Kampung Lui (3118102) with 12.13mm. Based on figure 4.30, the trend of June average rainfall was increasing for all stations except for Setor JPS Kajang (2917001) and Sek Keb Kampung Lui (3118102).

Table 4.11 June average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	After 2000	
1	2818110	Smk. Bdr Tasik Kesuma	95.00	107.61	12.61
2	2913001	P/Kwln P/S Telok Gong	101.51	104.03	2.51
3	2917001	Setor JPS. Kajang	124.67	118.13	-6.54
4	3118102	Sek. Keb. Kg. Lui	151.38	139.26	-12.13
5	3116006	Ldg. Edinburgh Site 2	142.48	152.18	9.70
6	3117070	Pusat Penyelidikan Jps Ampang	138.30	182.68	44.38
7	3216001	Kg. Sg. Tua	170.78	173.15	2.37
8	3217001	Ibu Bekalan Km. 16	154.30	171.66	17.35
9	3217002	Empangan Genting Klang	144.72	191.68	46.95
10	3217003	Ibu Bekalan Km.11	149.65	196.59	46.94
		Total	1372.79	1536.95	164.16

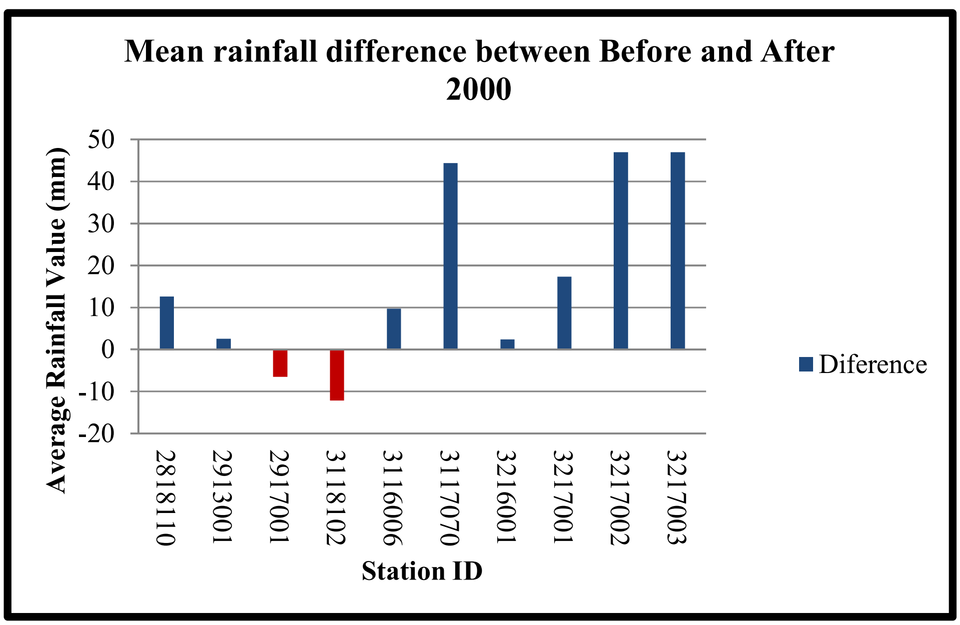

Figure 4.30 Mean June rainfall difference between before and after 2000

4.4.7 July Average Rainfall Before and After 2000

From the figure 4.31, it can be clearly seen that the July average rainfall had been increased after 2000 especially at the upper and middle catchment of Klang river basin. The average rainfall was around 152.99mm. The maximum average rainfall before 2000 was obtained at Ibu Bekalan Km 16 (3217001) with 183.33mm. This station was located in Gombak area, Selangor. Meanwhile, the minimum average rainfall before 2000 was obtained at Ladang Edinburgh Site 2 (3116006) with 125.97mm. This station was situated at Kepong area and was closer to the federal territory of Kuala Lumpur. On the other hand, the maximum average rainfall after 2000 was also found in Ibu Bekalan Km 16 (3217001) with 186.21mm. While, the minimum average rainfall after 2000 was occurred in P/Kwln P/S Telok Gong (2913001) with 105.79mm. The station was located at Telok Gong area, Selangor.

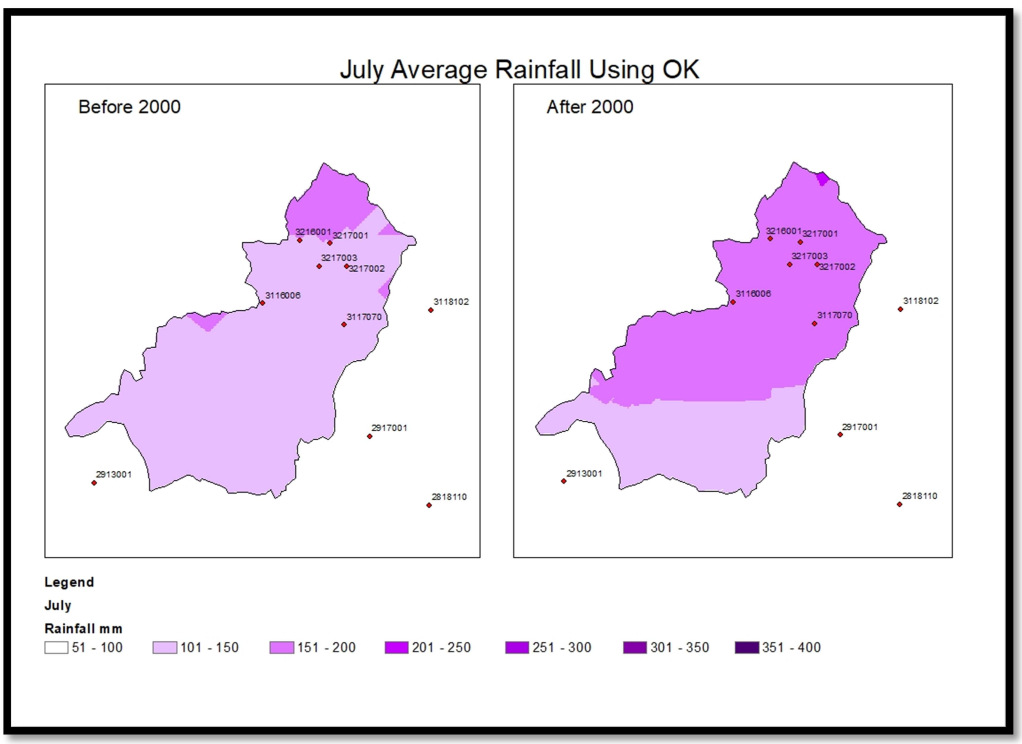

Figure 4.31 July isohyet maps (Before and after 2000)

From table 4.12, the highest rainfall value increased was found in Ladang Edinburgh Site 2 (3116006) with 59.36mm whereas the highest value of rainfall decreased was in P/Kwln P/S Telok Gong (2913001) with 23.27mm. Based on figure 4.32, the trend of June average rainfall was increasing for all stations except for Smk Bandar Tasik Kesuma (2818110), P/Kwln P/S Telok Gong (2913001), Sek Keb Kampung Lui (3118102) and Kampung Sungai Tua (3216001).

Table 4.12 July average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	**After 2000**	
1	2818110	Smk. Bdr Tasik Kesuma	128.14	125.97	-2.16
2	2913001	P/Kwln P/S Telok Gong	129.06	105.79	-23.27
3	2917001	Setor JPS. Kajang	127.20	128.95	1.76
4	3118102	Sek. Keb. Kg. Lui	165.93	156.78	-9.15
5	3116006	Ldg. Edinburgh Site 2	125.97	185.32	59.36
6	3117070	Pusat Penyelidikan Jps Ampang	146.82	173.26	26.44
7	3216001	Kg. Sg. Tua	181.61	173.41	-8.20
8	3217001	Ibu Bekalan Km. 16	183.33	186.21	2.88
9	3217002	Empangan Genting Klang	133.65	184.94	51.29
10	3217003	Ibu Bekalan Km.11	140.54	176.94	36.40
		Total	1462.24	1597.59	135.35

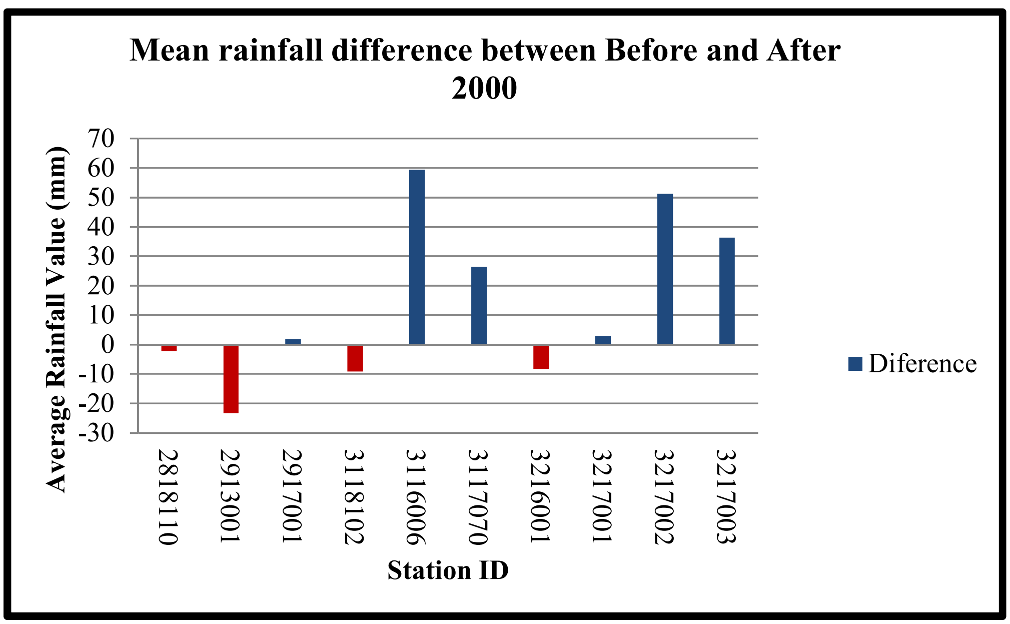

Figure 4.32 Mean July rainfall difference between before and after 2000

4.4.8 August Average Rainfall Before and After 2000

From the figure 4.33, it can be clearly seen that the August average rainfall had been increased a little bit after 2000 especially at the middle catchment of Klang river basin. The average rainfall was around 166.83mm. The maximum average rainfall before 2000 was obtained at Ibu Bekalan Km. 16 (3217001) with 201.98mm. This station was located in Gombak area, Selangor. Meanwhile, the minimum average rainfall before 2000 was obtained at Smk Bandar Tasik Kesuma (2818110) with 124.59mm. This station was situated at Semenyih area, Selangor. On the other hand, the maximum average rainfall after 2000 was found in Sek Keb Kampung Lui (3118102) with 211.14mm. This station was located in Hulu Langat area, Selangor. While, the minimum average rainfall after 2000 was occurred in P/Kwln P/S Telok Gong (2913001) with 125.11mm. The station was located at Telok Gong area, Selangor.

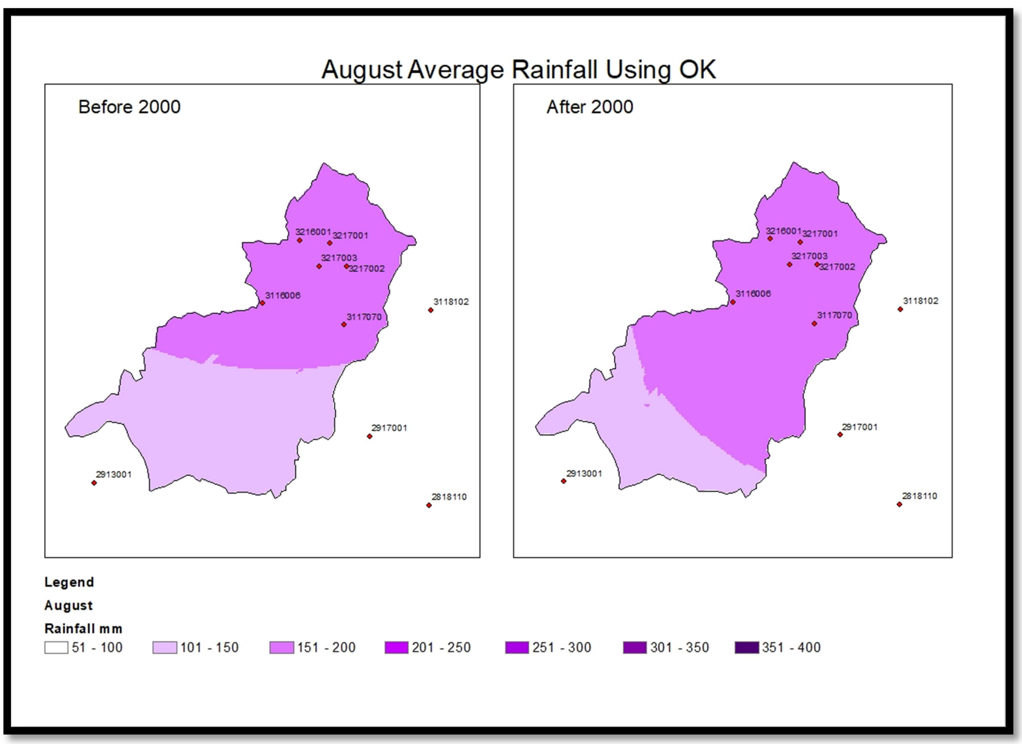

Figure 4.33 August isohyet maps (Before and after 2000)

From table 4.13, the highest rainfall value increased was found in Sek Keb Kampung Lui (3118102) with 59.36mm whereas the highest value of rainfall decreased was in Ibu Bekalan Km 16 (3217001) with 42.73mm. Based on figure 4.34, the trend of August average rainfall was increasing for all stations except for P/Kwln P/S Telok Gong (2913001), Kampung Sungai Tua (3216001) and Ibu Bekalan Km 16 (3217001).

Table 4.13 August average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	**After 2000**	
1	2818110	Smk. Bdr Tasik Kesuma	124.59	137.00	12.41
2	2913001	P/Kwln P/S Telok Gong	139.69	125.11	-14.58
3	2917001	Setor JPS. Kajang	127.44	184.41	56.96
4	3118102	Sek. Keb. Kg. Lui	152.93	211.14	58.21
5	3116006	Ldg. Edinburgh Site 2	161.69	175.68	14.00
6	3117070	Pusat Penyelidikan Jps Ampang	163.35	185.07	21.72
7	3216001	Kg. Sg. Tua	183.51	169.94	-13.57
8	3217001	Ibu Bekalan Km. 16	201.98	159.25	-42.73
9	3217002	Empangan Genting Klang	184.11	201.30	17.19
10	3217003	Ibu Bekalan Km.11	169.53	178.78	9.25
		Total	1608.82	1727.68	118.86

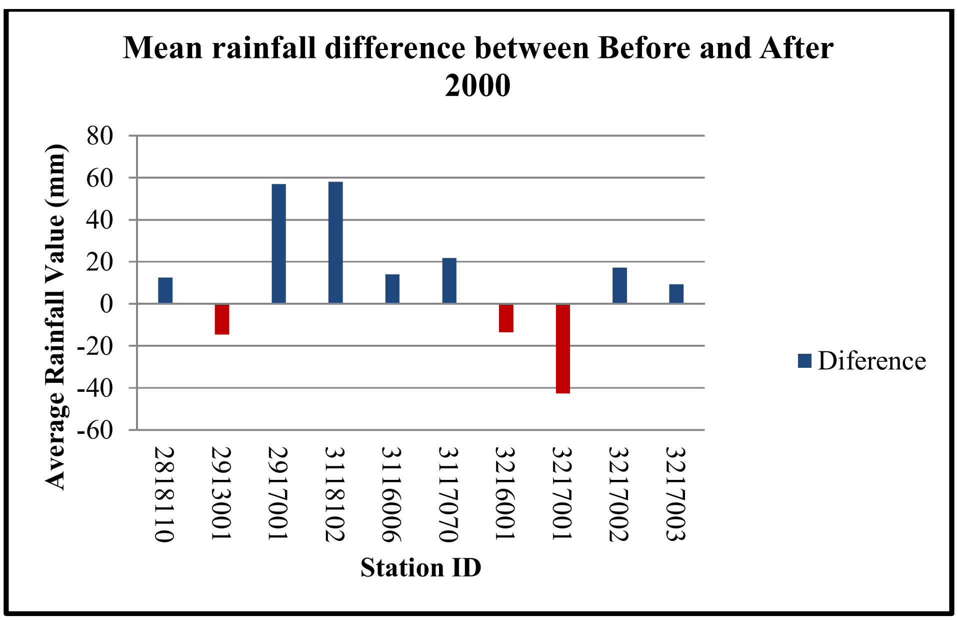

Figure 4.34 Mean August rainfall difference between before and after 2000

4.4.9 September Average Rainfall Before and After 2000

From the figure 4.35, it can be clearly seen that the September average rainfall had been increased a little bit after 2000 especially at the middle catchment. The average rainfall was around 212.63mm. The maximum average rainfall before 2000 was obtained at Ibu Bekalan Km. 16 (3217001) with 251.94mm. This station was located in Gombak area, Selangor. Meanwhile, the minimum average rainfall before 2000 was obtained at P/Kwln P/S Telok Gong (2913001) with 124.59mm. This station was situated at Telok Gong area, Selangor. On the other hand, the maximum average rainfall after 2000 was also found in Ibu Bekalan Km. 16 (3217001) with 271.94mm. While, the minimum average rainfall after 2000 was occurred in P/Kwln P/S Telok Gong (2913001) with 148.19mm.

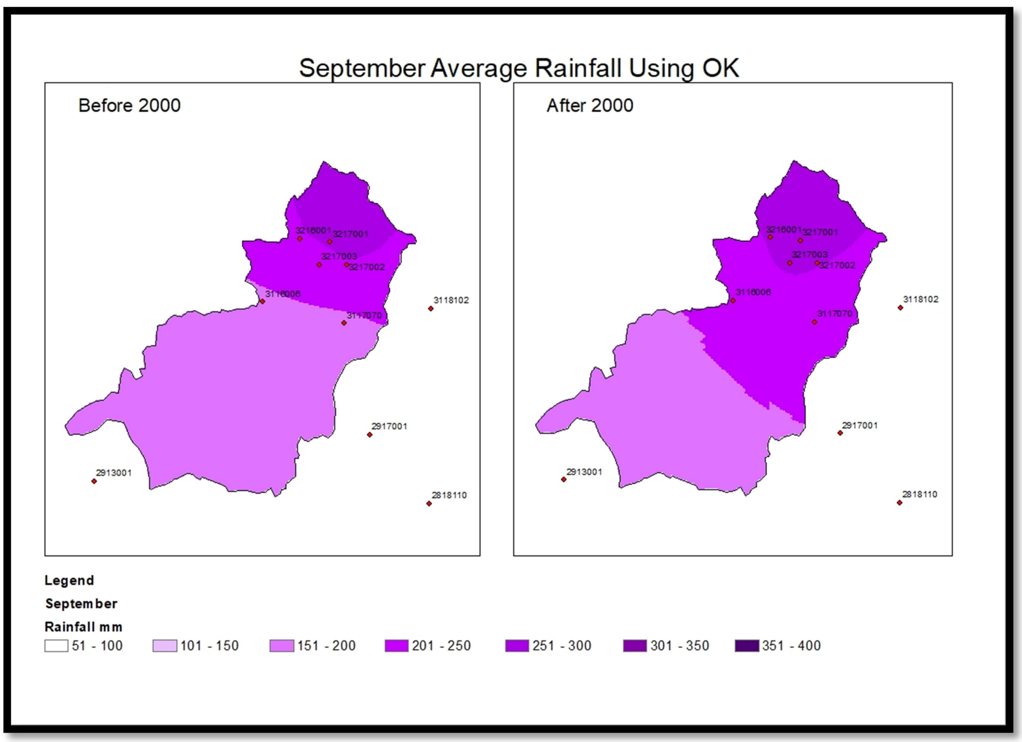

Figure 4.35 September isohyet maps (Before and after 2000)

From table 4.14, the highest rainfall value increased was found in Pusat Penyelidikan JPS Ampang (3117070) with 37.98mm whereas the highest value of rainfall decreased was in P/Kwln P/S Telok Gong (2913001) with 10.67mm. Based on figure 4.36, the trend of September average rainfall was increasing for all stations except for Smk Bandar Tasik Kesuma (2818110), P/Kwln P/S Telok Gong (2913001), and Sek Keb Kampung Lui (3118102).

Table 4.14 September average rainfall before and after 2000

No	**Station ID**	**Name**	**Average Rainfall Value (mm)**		**Difference (mm)**
			Before 2000	**After 2000**	
1	2818110	Smk. Bdr Tasik Kesuma	159.24	155.66	-3.58
2	2913001	P/Kwln P/S Telok Gong	158.86	148.19	-10.67
3	2917001	Setor JPS. Kajang	165.67	202.09	36.42
4	3118102	Sek. Keb. Kg. Lui	218.00	210.94	-7.06
5	3116006	Ldg. Edinburgh Site 2	189.41	215.81	26.41
6	3117070	Pusat Penyelidikan Jps Ampang	188.91	226.89	37.98
7	3216001	Kg. Sg. Tua	246.16	247.22	1.05
8	3217001	Ibu Bekalan Km. 16	251.94	271.94	19.99
9	3217002	Empangan Genting Klang	246.73	247.53	0.80
10	3217003	Ibu Bekalan Km.11	238.96	262.38	23.41
		Total	2063.88	2188.65	124.77

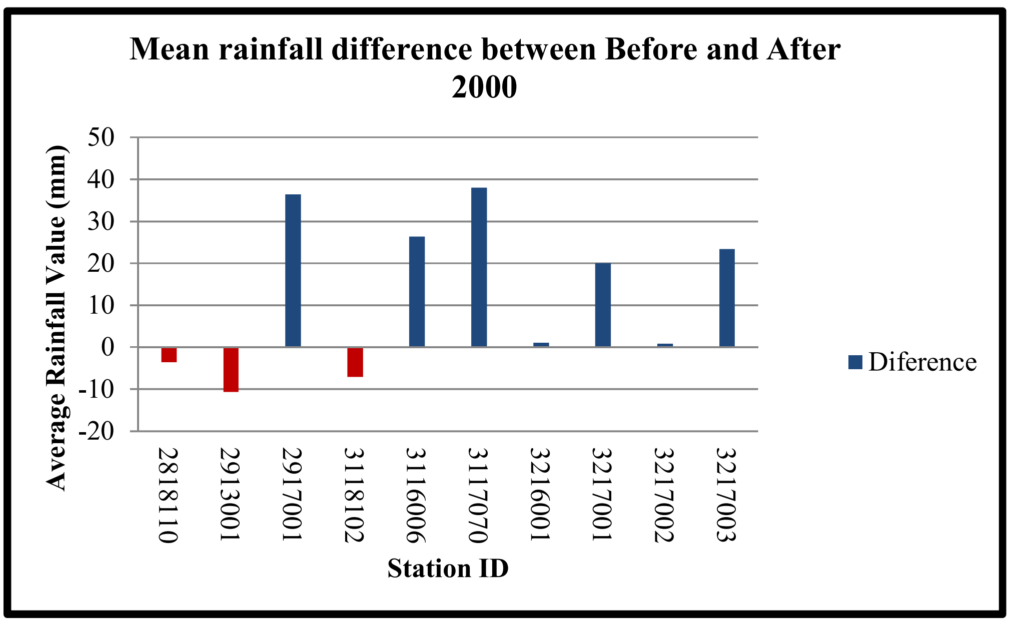

Figure 4.36 Mean September rainfall difference between before and after 2000

4.4.10 October Average Rainfall Before and After 2000

From the figure 4.37, it can be clearly seen that the October average rainfall had been increased after 2000 for the entire basin especially at Ladang Edinburgh Site 2 (3116006). October was second wettest month in Klang river basin. The average rainfall was around 260.80mm. The maximum average rainfall before 2000 was obtained at Empangan Genting Klang (3217002) with 275.41mm. This station was located in Gombak area, Selangor. Meanwhile, the minimum average rainfall before 2000 was obtained at P/Kwln P/S Telok Gong (2913001) with 210.6mm. This station was situated at Telok Gong area, Selangor. On the other hand, the maximum average rainfall after 2000 was found in Ibu Bekalan Km 11 (3217003) with 324.97mm. This station was located in Gombak area, Selangor. While, the minimum average rainfall after 2000 was occurred in Smk Bandar Tasik Kesuma (2818110) with 213.52mm. The station was located at Semenyih area, Selangor.

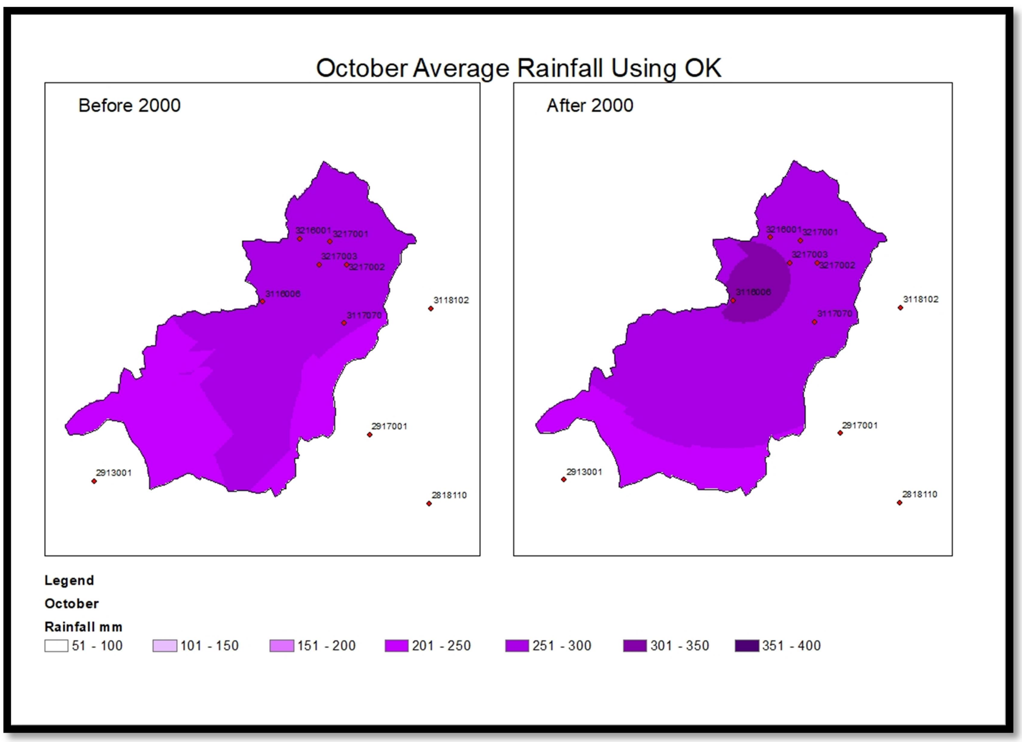

Figure 4.37 October isohyet maps (Before and after 2000)

From table 4.15, the highest rainfall value increased was found in Pusat Penyelidikan JPS Ampang (3117070) with 62.55mm whereas the highest value of rainfall decreased was in Setor JPS Kajang (2917001) with 2.45mm. Based on figure 4.38, the trend of October average rainfall was increasing for all stations except for Setor JPS Kajang (2917001).

Table 4.15 October average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	After 2000	
1	2818110	Smk. Bdr Tasik Kesuma	211.31	213.52	2.21
2	2913001	P/Kwln P/S Telok Gong	210.60	218.23	7.63
3	2917001	Setor JPS. Kajang	228.32	225.87	-2.45
4	3118102	Sek. Keb. Kg. Lui	240.80	249.61	8.81
5	3116006	Ldg. Edinburgh Site 2	262.79	312.61	49.81
6	3117070	Pusat Penyelidikan Jps Ampang	250.62	313.18	62.55
7	3216001	Kg. Sg. Tua	269.47	279.47	10.00
8	3217001	Ibu Bekalan Km. 16	274.09	276.68	2.59
9	3217002	Empangan Genting Klang	275.41	305.82	30.41
10	3217003	Ibu Bekalan Km.11	272.65	324.97	52.32
		Total	2496.06	2719.95	223.89

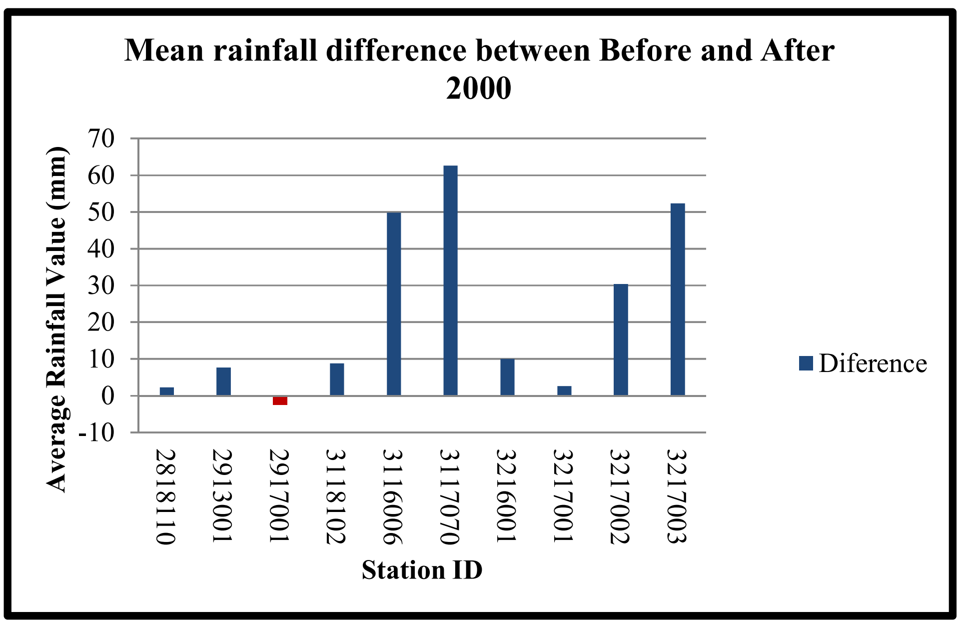

Figure 4.38 Mean October rainfall difference between before and after 2000

4.4.11 November Average Rainfall Before and After 2000

From the figure 4.39, it can be clearly seen that November average rainfall had been increased dramatically after 2000 for the entire basin except at the lowest part of the catchment. November was the wettest month in Klang river basin. The average rainfall was around 297.24mm. The maximum average rainfall before 2000 was obtained at Ladang Edinburgh Site 2 (3116006) with 291.97mm. This station was located in Kepong area and was closer to the federal territory of Kuala Lumpur. Meanwhile, the minimum average rainfall before 2000 was obtained at Ibu Bekalan Km. 11 (3217003) with 213.29mm. This station was situated at Gombak area, Selangor. On the other hand, the maximum average rainfall after 2000 was found in Pusat Penyelidikan JPS Ampang (3117070) with 373.74mm. This station was located in Ampang area, Kuala Lumpur. While, the minimum average rainfall after 2000 was occurred in P/Kwln P/S Telok Gong (2913001) with 262.58mm. The station was located at Telok Gong area, Selangor.

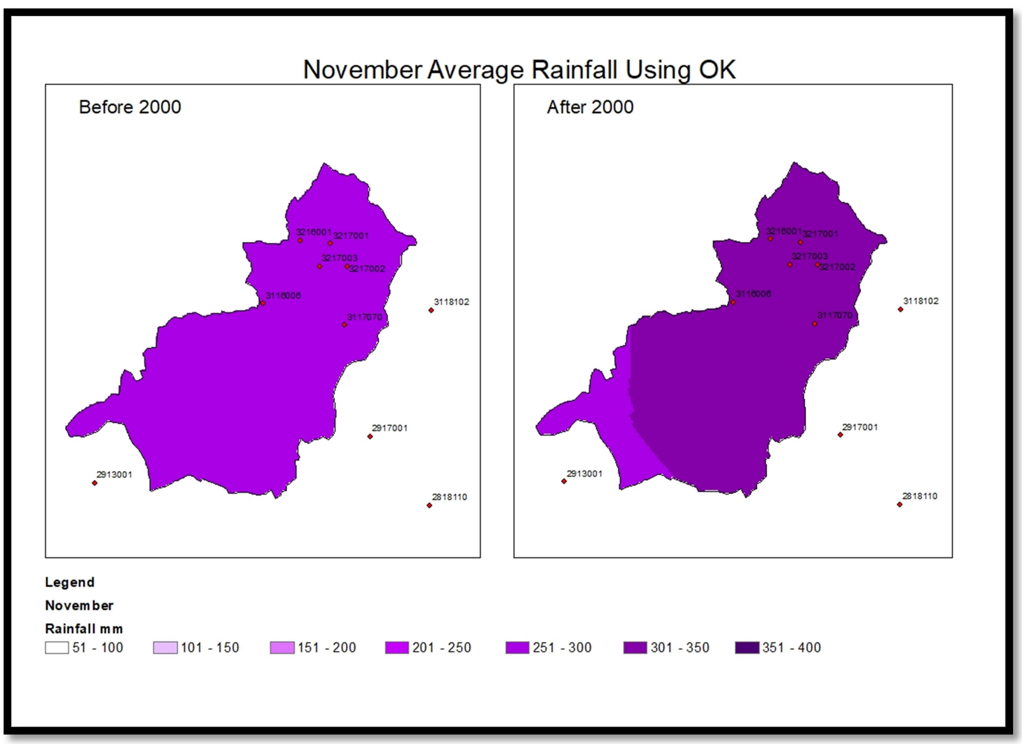

Figure 4.39 November isohyet maps (Before and after 2000)

From table 4.16, the highest rainfall value increased was found in Ibu Bekalan Km. 11 (3217003) with 125mm whereas the highest value of rainfall decreased was in P/Kwln P/S Telok Gong (2913001) with 16.76mm. Based on figure 4.40, the trend of November average rainfall was increasing for all stations except for P/Kwln P/S Telok Gong (2913001).

Table 4.16 November average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	After 2000	
1	2818110	Smk. Bdr Tasik Kesuma	247.61	296.93	49.32
2	2913001	P/Kwln P/S Telok Gong	279.34	262.58	-16.76
3	2917001	Setor JPS. Kajang	272.84	346.28	73.44
4	3118102	Sek. Keb. Kg. Lui	281.77	342.62	60.85
5	3116006	Ldg. Edinburgh Site 2	291.97	352.09	60.12
6	3117070	Pusat Penyelidikan Jps Ampang	257.09	373.74	116.65
7	3216001	Kg. Sg. Tua	263.39	314.85	51.46
8	3217001	Ibu Bekalan Km. 16	274.99	342.21	67.21
9	3217002	Empangan Genting Klang	256.23	336.63	80.40
10	3217003	Ibu Bekalan Km.11	213.29	338.29	125.00
		Total	2683.52	3306.21	667.69

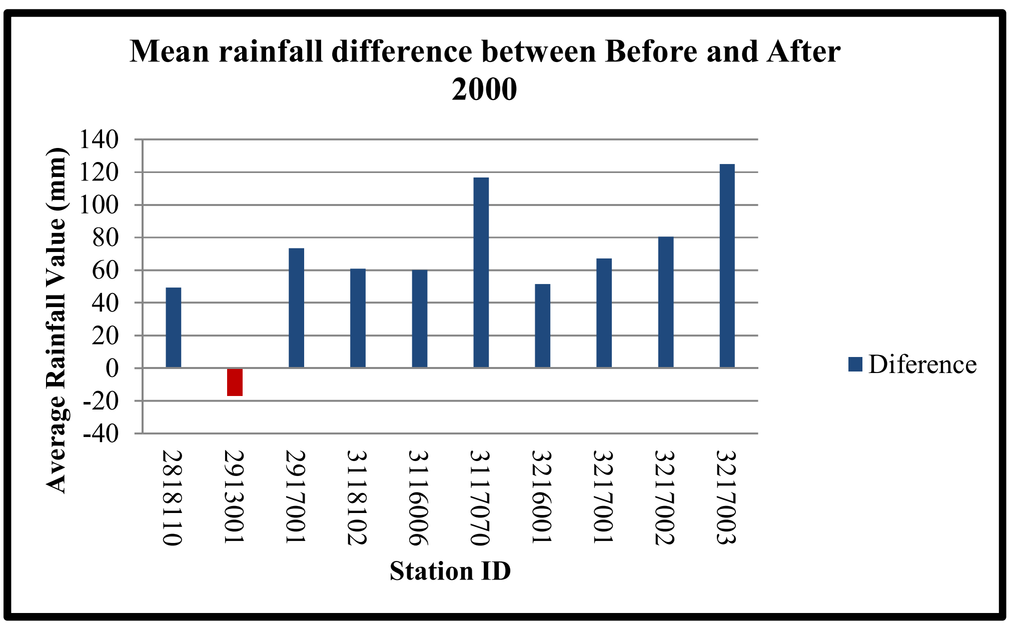

Figure 4.40 Mean November rainfall difference between before and after 2000

4.4.12 December Average Rainfall Before and After 2000

From the figure 4.41, it can be clearly seen that December average rainfall had been increased after 2000 for almost the entire basin except at the upper part of the catchment. The average rainfall was around 190.34mm. The maximum average rainfall before 2000 was obtained at P/Kwln P/S Telok Gong (2913001) with 212.66mm. This station was located in Telok Gong area, Selangor. Meanwhile, the minimum average rainfall before 2000 was obtained at Ibu Bekalan Km. 11 (3217003) with 145.50mm. This station was situated at Gombak area, Selangor. On the other hand, the maximum average rainfall after 2000 was found in Ladang Edinburgh Site 2 (3116006) with 264.97mm. This station was located in Kepong area and was closer to the federal territory of Kuala Lumpur. While, the minimum average rainfall after 2000 was occurred in Ibu Bekalan Km. 11 (3217003) with 158.47mm. The station was located at Gombak area, Selangor.

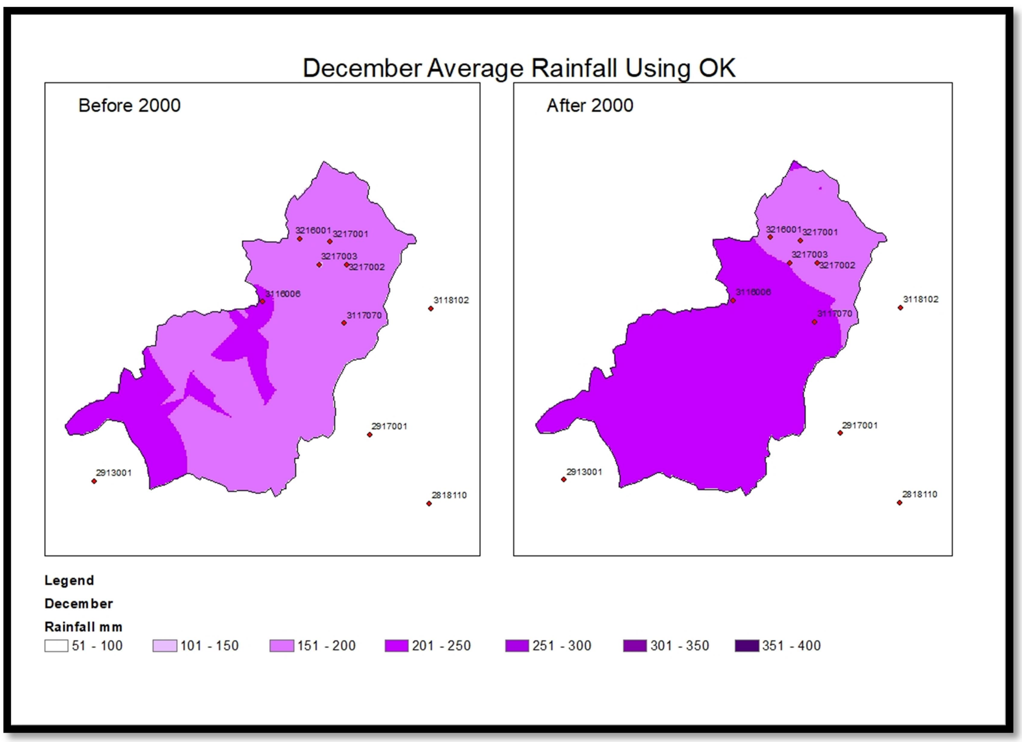

Figure 4.41 December isohyet maps (Before and after 2000)

From table 4.17, the highest rainfall value increased was found in Ibu Bekalan Km. 11 (3217003) with 59.64mm whereas the highest value of rainfall decreased was in Sek Keb Kampung Lui (3118102) with 35.93mm. Based on figure 4.42, the trend of November average rainfall was increasing for all stations except for P/Kwln P/S Telok Gong (2913001), Sek Keb Kampung Lui (3118102) and Ibu Bekalan Km. 16 (3217001).

Table 4.17 December average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	After 2000	
1	2818110	Smk. Bdr Tasik Kesuma	156.25	163.28	7.04
2	2913001	P/Kwln P/S Telok Gong	212.66	208.59	-4.07
3	2917001	Setor JPS. Kajang	209.96	213.47	3.52
4	3118102	Sek. Keb. Kg. Lui	205.86	169.93	-35.93
5	3116006	Ldg. Edinburgh Site 2	208.95	264.97	56.02
6	3117070	Pusat Penyelidikan Jps Ampang	184.96	219.68	34.72
7	3216001	Kg. Sg. Tua	187.22	190.90	3.68
8	3217001	Ibu Bekalan Km. 16	159.42	158.47	-0.95
9	3217002	Empangan Genting Klang	162.00	179.58	17.59
10	3217003	Ibu Bekalan Km.11	145.50	205.15	59.64
		Total	1832.78	1974.02	141.24

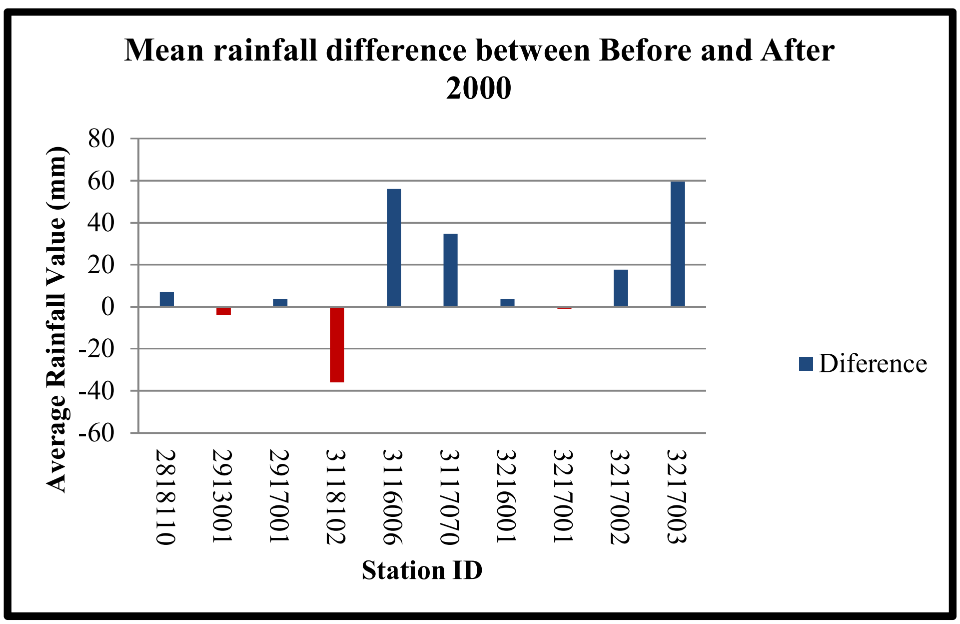

Figure 4.42 Mean December rainfall difference between before and after 2000

4.4.13 Annually Average Rainfall Before and After 2000

From the figure 4.43, it can be clearly seen that the annual average rainfall after 2000 was increasing for the entire Klang river basin especially at the middle part of the catchment. The annual average rainfall was around 2303.35mm. The maximum annual average rainfall before 2000 was occurred at Ibu Bekalan Km.16 (3217001) with 2372.53mm. This station was located in Gombak area, Selangor. Meanwhile, the minimum annual average rainfall before 2000 was obtained at Smk Bandar Tasik Kesuma (2818110) with 1839.12mm. This station was at Semenyih area, Selangor. On the other hand, the maximum annual average rainfall after 2000 was occurred at Ladang Edinburgh Site 2 (3116006) with 2936.97 mm. This station was located in Kepong which was closer to the Kuala Lumpur. While, the minimum annually average rainfall was obtained at P/Kwln P/S Telok Gong (2913001) with 1799.90mm. This station was situated in Klang area, Selangor.

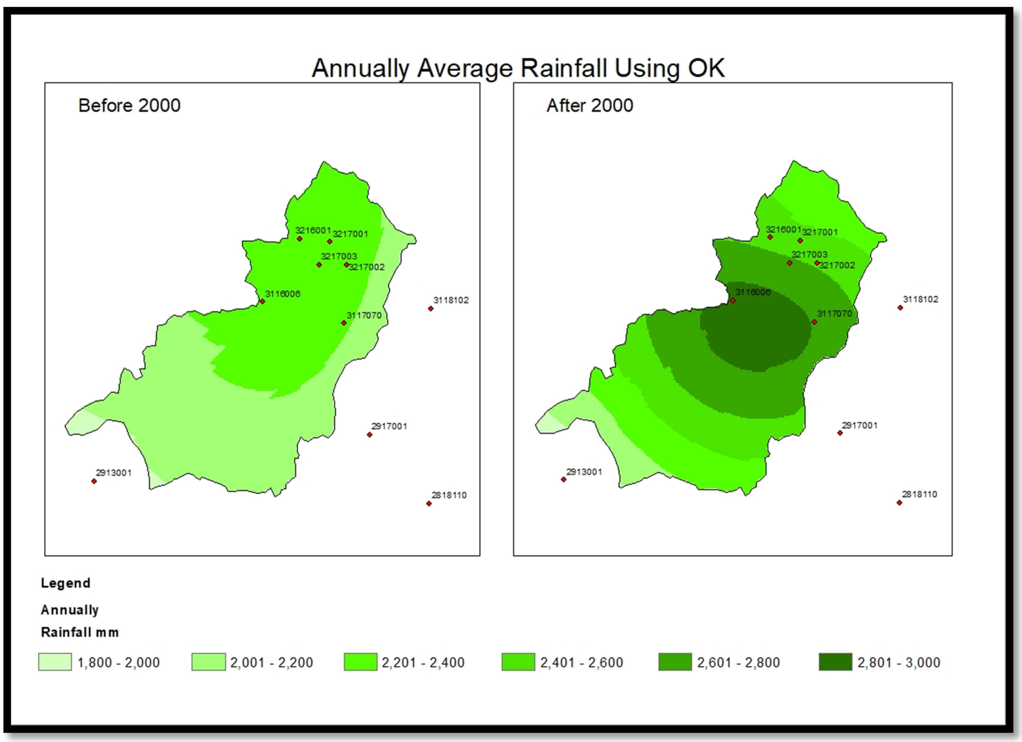

Figure 4.43 Annually isohyet maps before and after 2000

From table 4.18, the highest rainfall increased was found in Ladang Edinburgh Site 2 (3116006) with 643.38mm whereas the highest value of rainfall decreased was in P/Kwln P/S Telok Gong (2913001) with 114.37mm. Based on figure 4.44, the trend of annual average rainfall was increasing for all stations except at P/Kwln P/S Telok Gong (2913001). The rainfall at P/Kwln P/S Telok Gong (2913001) was decreased around 114.37mm.

Table 4.18 Annual average rainfall before and after 2000

No	Station ID	Name	Average Rainfall Value (mm)		Difference (mm)
			Before 2000	After 2000	
1	2818110	Smk. Bdr Tasik Kesuma	1839.12	1997.69	158.58
2	2913001	P/Kwln P/S Telok Gong	1914.27	1799.90	-114.37
3	2917001	Setor JPS. Kajang	2078.48	2421.65	343.17
4	3118102	Sek. Keb. Kg. Lui	1973.39	2370.00	396.61
5	3116006	Ldg. Edinburgh Site 2	2293.59	2936.97	643.38
6	3117070	Pusat Penyelidikan Jps Ampang	2281.64	2850.04	568.40
7	3216001	Kg. Sg. Tua	2368.16	2472.34	104.80
8	3217001	Ibu Bekalan Km. 16	2372.53	2389.96	17.42
9	3217002	Empangan Genting Klang	2224.52	2593.25	368.73
10	3217003	Ibu Bekalan Km.11	2207.10	2682.29	475.19
		Total	21552.81	24514.10	2961.28

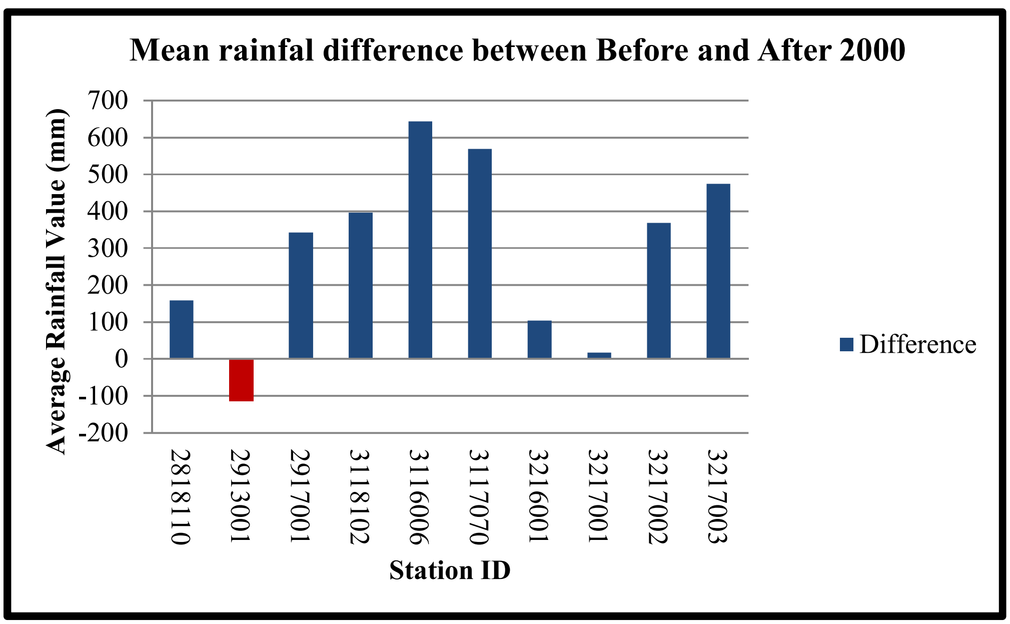

Figure 4.44 Mean annually rainfall difference between before and after 2000

4.4.14 Driest and Wettest Area

Through the observation of the monthly and annually isohyet maps, the driest area in the Klang river basin was found in Klang area, Selangor. It was the lower part of catchment basin. The average rainfall around that area did not increase much. P/Kwln P/S Telok Gong was the only rain gauge station located at that area. From table 4.19, the average rainfall value in P/Kwln P/S Telok Gong was decreased for most of the months and also for annual. For instance, the average rainfall was drop at February, March, July, August, September, November and December. This proven reduction in rainfall intensity was occurred over Klang area, Selangor. This was the best evidence to show that Klang area had been drier compare to the 20 century in response to global warming. The unusual dry season in Klang area had caused water shortage problem frequently.

Table 4.19 Mean rainfall difference for station P/Kwln P/S Telok Gong

Period		**Difference between after and before 2000**
Month	January	14.21
	February	-46.11
	March	-4.95
	April	3.39
	May	7.63
	June	2.51
	July	-23.27
	August	-14.58
	September	-10.67
	October	7.63
	November	-16.76
	December	-4.07
Annual		-114.37

On the contrary, the wettest area was found in the Kuala Lumpur area through the maps. It located at the middle of the basin which experienced the highest economic growth in the country. The average rainfall was increased intensely at this area compare to surrounding area. The rain gauge stations located at this area were Ladang Edinburgh Site 2 and Pusat Penyelidikan JPS Ampang. From table 4.20 and 4.21, the average rainfall value was increased for monthly and annually. This showed that Kuala Lumpur received more rain and was wetter than 20 century. This happened because of the urban heat island effect due to the rapid development at the city. The temperature within Kuala Lumpur was higher than the temperature at the surrounding suburban area. Flash floods always happened in Kuala Lumpur after a few hours of heavy rain.

Table 4.20 Mean rainfall difference for station Ladang Edinburgh Site 2

Period		**Difference between after and before 2000**
Month	January	87.31
	February	13.64
	March	13.37
	April	81.17
	May	12.72
	June	9.70
	July	59.36
	August	14.00
	September	26.41
	October	49.81
	November	60.12
	December	56.02
Annual		643.38

Table 4.21 Mean rainfall difference for station Pusat Penyelidikan JPS Ampang

Period		**Difference between after and before 2000**
Month	January	58.01
	February	-36.08
	March	76.62
	April	59.73
	May	29.71
	June	44.38
	July	26.44
	August	21.71
	September	37.98
	October	62.55
	November	116.65
	December	34.72
Annual		568.40

Figure 4.45 and 4.46 depicted the bar chart of mean monthly and annually rainfall difference for station P/Kwln P/S Telok Gong, Ladang Edinburgh Site 2, and Pusat Penyelidikan JPS Ampang. It clearly showed that the average rainfall was increasing for rain gauge station Ladang Edinburgh Site 2 and Pusat Penyelidikan JPS Ampang whereas the average rainfall was decreasing in station P/Kwln P/S Telok Gong.

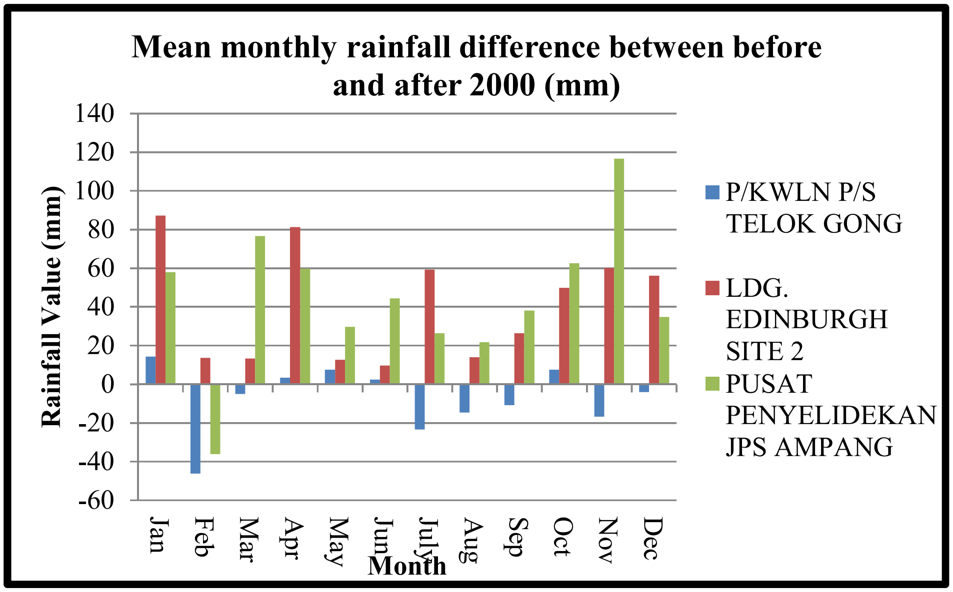

Figure 4.45 Mean monthly rainfall difference between before and after 2000 for selected stations

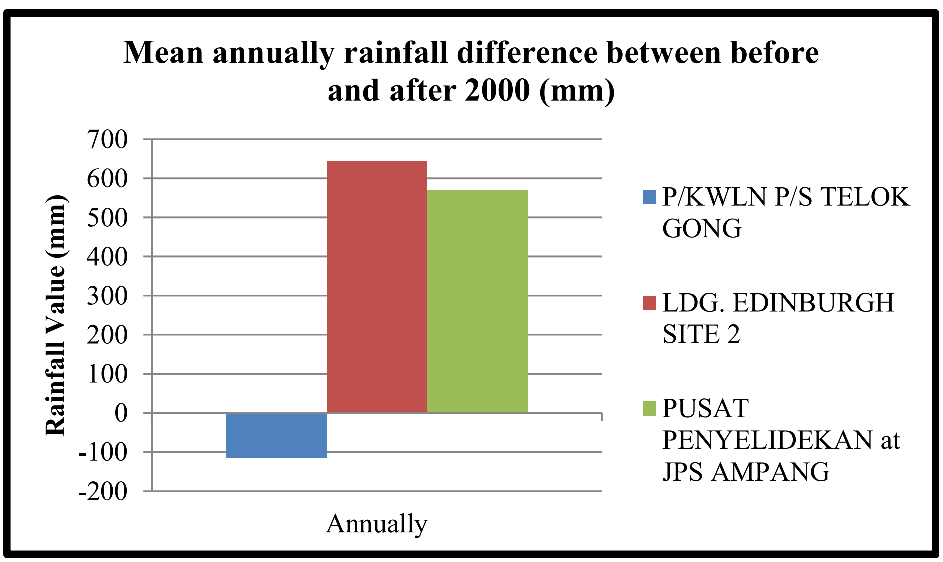

Figure 4.46 Mean annually rainfall difference between before and after 2000 for selected stations

4.4.15 Summary

Climate in Klang river basin can be classify into four different seasons which were northeast monsoon, southwest monsoon and two inter-monsoons. The northeast monsoon started from October to March. The wind was blow down the China Sea and tends to bring more rainfall to Malaysia. However, Klang river basin was situated at the west part of Peninsular Malaysia so it was less influenced by this monsoon. Less rainfall was received compared to the east region of Peninsular Malaysia. This was due the wind had been sheltered or obstructed by the Titiwangsa range. Southwest monsoon began in May until September. This season will affect mostly the weather over the basin. The wind blows across Straits of Malacca. From the isohyet maps, it can be observed that the April, October and November were the wettest months. The average rainfall for wettest season was above 250mm. The maximum rainfall was occurred in November. Driest months in the basin were January, June and July. For driest season, the average rainfall was below 150mm. The minimum rainfall was occurred in January. The amount of rainfall was increasing for annually isohyet maps for all stations except P/Kwln P/S Telok Gong (2913001).

From the maps and tables above, the dry region was found at the Klang area, Selangor. It was the lowest part of the catchment basin. After 20 century, the average rainfall for this region was decreasing. This means the temperature was rising so the rainfall volume was declining in this region. The scenario was due to the global warming which contributes by human activity and rapid development in Klang river basin. The reduction of rainfall value proven that the concentration of greenhouse gases was increased and caused warming effect to Klang area. This is because the heat radiation was trapped in the atmospheric and these gases blocked the heat to escape into space. Carbon dioxide, chlorofluorocarbon (CFC), methane and nitrous oxides are the gases that contribute the greenhouse effect. For example, burning of fossil fuels will increase the concentration of carbon dioxide.

The rising temperature was expected to result in increased water consumption and energy demand required for cooling in Klang. Furthermore, the rate of water evaporates from the water surface and soil will be increased. However, the rainfall amount was unlikely to increase as much as the evaporation rate. Less water was available in Klang area and made this area become drier compare to previous.

Consequently, drier soil with longer dry period makes the drought more severe. The unusual and prolonged dry season was the biggest challenges in Klang. Water shortage problem always happened in this area.

Besides, the wet region was located at the Kuala Lumpur. It was the capital city of Malaysia. This region was situated at the middle part of Klang river basin. Similar to other metropolitan areas, Kuala Lumpur has the high population density and is surrounding by dense urban structures. From the isohyet maps and tables above, the amount of rainfall had been increased dramatically after 20 century. This is because urban areas usually made of high concentration of buildings and heat absorbs material such as asphalt, concrete and steel. As a result, temperature in the city is warmer than the surrounding rural area and the weather in the city is also altering. The increased heat will promote more rising warm air and produce clouds around the city. This can cause high intensity of rainfall over urban area.

This phenomenon can be called as urban heat island effect. Urban heat island was a phenomenon that associated with human activity and urbanisation. Due to this phenomenon, higher magnitude and frequency of rainfall events had been created around Kuala Lumpur. This effect also had increased the water input in the middle catchment of this basin and lead to the flash floods to occur. Flash flood event happen due to the rapid development in Greater Kuala Lumpur, change the land use and reduction in vegetation covers.

CHAPTER 5

CONCLUSION

5.1 Introduction

The isohyet maps are prepared in monthly and annually using ArcGIS 10.2. Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) techniques are used to generate the rainfall maps. These techniques are frequently used to predict the values of meteorological parameters. The most appropriate method need to be selected in order to get the correct spatial distribution of rainfall for Klang river basin. The accuracy assessment is carried out with the help of ArcGIS Geostatistical Analyst.

Nowadays, climate change has becoming a common issue that was encountered by every country around the world. It gives significant impact to every creature in the world. Wet region will receive more rainfall, dry region will receive less rainfall. The isohyet maps that are produced using the most appropriate method will be used to evaluate the climate assessment at Klang river basin. Thus, accurate isohyet map is important to detect the impact of climate change at a particular area.

5.2 Conclusion

In conclusion, all the objectives of this study were successfully achieved. The monthly and annually isohyet maps for Klang river basin had been created using Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) methods through the aided of ArcGIS Geostatistical Analyst. Then, these two interpolation methods were evaluated through cross validation to determine which interpolator more accurate. From the analysis, Ordinary Kriging performed better in this study so it was selected as the most optimum spatial interpolation for the basin. This is because Inverse Distance Weighting tends to overestimated minimum values and underestimated maximum and standard deviation values. However, the average values generated by these two techniques were close to the raw average value. In addition, MAE, RMSE and G value were chosen as the validation criteria for Klang river basin. From the comparison of validation criteria, it had been noticed that Ordinary Kriging had the smaller MAE and RMSE value. Besides, this method also obtained positive value of G for most of the month and annually. Therefore, Ordinary Kriging method proven had less variation of estimate values, smaller error and greater central tendency than Inverse Distance Weighting.

The isohyet maps developed through Ordinary Kriging (OK) was adopted to evaluate the impact of climate change over Klang river basin. Climate of this basin was divided into northeast monsoon, southwest monsoon and inter-monsoons. It was located at the west part of Peninsular Malaysia so southwest monsoon influenced more the weather of this basin. Moreover, the maximum rainfall happened during the transition period between northeast and southwest monsoons. It can be called as inter-monsoon. Through the analysis, the highest amount of rainfall was received during November. The average rainfall value on wettest season was above 250mm. The minimum rainfall was usually during the two monsoon seasons. January was the month that received the minimum rainfall. For drier season, the average rainfall received was below 150mm. From the annual isohyet map, it can be clearly observed that the average annual rainfall was increasing for the whole basin.

Based on comparison of the isohyet maps, it can be observed that some part of the basin was undergoing some significant changes of rainfall intensity. The hydrological cycle is expected to adopt some alters due to climate change. Dry region will get drier and wet region will get wetter. The dry region was found in Klang area, Selangor. It was located at the lowest part of the basin and less rainfall was received compared to 20 century. This mean that this region becoming hotter now. The heat was blocked by the greenhouse gases so it cannot escape into the space. As the temperature become warmer, the capacity to hold water vapour will also increase. In another words, more evaporation will occur in drier area and soil become drier. Still, the growth of population and industrialization in Klang had increase the demand and pressure of water supply. Water shortage problem may occur during dry period. The warming effect makes the drought more severe. Hence, the weather in this region had become unpredictable and is expected to be more droughts in the future.

Furthermore, the wet region in Klang river basin was situated at the middle part of catchment which was Greater Kuala Lumpur. Rapid urbanisation and development projects had increased the average rainfall dramatically after 20 century. Due to urban heat island effect, temperature in Kuala Lumpur was much warmer than its surrounding rural area. More heat energy was trapped by dark colour roads and dense tall buildings. This effect will reduce human comfortability and increase energy demand for cooling process in buildings. The concentration of greenhouse gases from vehicle, air condition and factory also will be increased. Warmer air will tend to rise and formed more clouds in the atmospheric. This will cause this region to receive more rainfall amount and lead to extreme weather event. For instance, Kuala Lumpur area was always inundated by flood waters after two to three hours of heavy rain. As a result of heavy development had reduced the capacity of river and increased the amount of surface runoff. Thus, hot areas were growing in Kuala Lumpur and more rainfall falls in the city area than rural area.

5.3 Recommendation

According to the result and conclusions obtained, it shows the effective of Geographical Information System (GIS) in generate the rainfall patterns to analyse the climate condition over Klang river basin. However, there are a few subjects that may need to be studied in more details to improve the accuracy of this study.

i. Increase the number of rain gauge stations within the river basin. This can help to increase the accuracy of the generated rainfall pattern map. Increase the number of rain gauge stations can reduce the variance of the estimation error.

ii. The rainfall data must be sufficient. The longer the period of rainfall data, the accurate the result obtained for this study. This can also aid to identify the when an extreme weather event occur in the river basin.

iii. Temperature and evaporation data can be combining with the rainfall data for future study. This can help to improve the assessment of climate in the river basin.

iv. The rain gauge at each station must be maintained regularly. This can avoid missing data and inaccurate reading in the sample. For example, ensure the cleanliness of funnel and debris screen can increase the rainfall accuracy so that more precision isohyet map can be produced.

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APPENDIX A
MONTHLY AVERAGE RAINFALL BEFORE 2000 (1970 – 1999)

Table A1: Monthly Average Rainfall Value Before 2000

No	Station ID	Station Name	Average Rainfall Value Before 2000 (mm)											
			Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1	2818110	Smk. Bdr Tasik Kesuma	79.30	127.86	208.15	195.40	168.77	95.00	128.14	124.59	159.24	211.31	247.61	156.25
2	2913001	P/Kwln P/S Telok Gong	131.70	143.67	142.37	158.40	121.02	101.51	129.06	139.69	158.86	210.60	279.34	212.66
3	2917001	Setor JPS. Kajang	119.87	152.00	225.98	221.80	160.74	124.67	127.20	127.44	165.67	228.32	272.84	209.96
4	3118102	Sek. Keb. Kg. Lui	86.01	149.94	198.92	191.21	239.58	151.38	165.93	152.93	218.00	240.80	281.77	205.86
5	3116006	Ldg. Edinburgh Site 2	129.36	188.45	263.56	272.11	245.43	142.48	125.97	161.69	189.41	262.79	291.97	208.95
6	3117070	Pusat Penyelidikan Jps Ampang	111.36	185.84	193.83	276.54	219.97	138.30	146.82	163.35	188.91	250.62	257.09	184.96
7	3216001	Kg. Sg. Tua	96.74	153.12	190.95	256.25	239.88	170.78	181.61	183.51	246.16	269.47	263.39	187.22
8	3217001	Ibu Bekalan Km. 16	79.00	152.73	201.23	246.88	235.74	154.30	183.33	201.98	251.94	274.09	274.99	159.42
9	3217002	Empangan Genting Klang	94.88	142.46	189.60	245.23	227.23	144.72	133.65	184.11	246.73	275.41	256.23	162.00
10	3217003	Ibu Bekalan Km.11	89.26	145.20	205.98	284.67	235.37	149.65	140.54	169.53	238.96	272.65	213.29	145.50

APPENDIX B
MONTHLY AVERAGE RAINFALL AFTER 2000 (2000 – 2016)

Table B1: Monthly Average Rainfall Value After 2000

No	Station ID	Station Name	Average Rainfall Value After 2000 (mm)											
			Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	2818110	Smk. Bdr Tasik Kesuma	80.85	107.52	165.83	266.68	159.35	107.61	125.97	137.00	155.66	213.52	296.93	163.28
2	2913001	P/Kwln P/S Telok Gong	145.91	97.56	137.41	161.79	128.66	104.03	105.79	125.11	148.19	218.23	262.58	208.59
3	2917001	Setor JPS. Kajang	170.69	175.44	244.50	308.42	197.79	118.13	128.95	184.41	202.09	225.87	346.28	213.47
4	3118102	Sek. Keb. Kg. Lui	122.65	142.80	209.56	284.21	213.25	139.26	156.78	211.14	210.94	249.61	342.62	169.93
5	3116006	Ldg. Edinburgh Site 2	216.68	202.09	276.93	353.28	258.15	152.18	185.32	175.68	215.81	312.61	352.09	264.97
6	3117070	Pusat Penyelidikan Jps Ampang	169.37	149.76	270.46	336.27	249.68	182.68	173.26	185.07	226.89	313.18	373.74	219.68
7	3216001	Kg. Sg. Tua	119.10	125.38	210.35	263.31	236.50	173.15	173.41	169.94	247.22	279.47	314.85	190.90
8	3217001	Ibu Bekalan Km. 16	108.33	118.29	173.21	232.94	236.47	171.66	186.21	159.25	271.94	276.68	342.21	158.47
9	3217002	Empangan Genting Klang	110.44	124.26	209.47	274.53	272.12	191.68	184.94	201.30	247.53	305.82	336.63	179.58
10	3217003	Ibu Bekalan Km.11	114.18	146.03	232.09	282.21	250.65	196.59	176.94	178.78	262.38	324.97	338.29	205.15

APPENDIX C
ANNUALLY AVERAGE RAINFALL BEFORE 2000 (1970 – 1999)

Table C1: Annually Average Rainfall Value Before 2000

No	Station ID	Station Name	Average Rainfall Value Before 2000 (mm)
1	2818110	Smk. Bdr Tasik Kesuma	1839.12
2	2913001	P/Kwln P/S Telok Gong	1914.27
3	2917001	Setor JPS. Kajang	2078.48
4	3118102	Sek. Keb. Kg. Lui	1973.39
5	3116006	Ldg. Edinburgh Site 2	2293.59
6	3117070	Pusat Penyelidikan Jps Ampang	2281.64
7	3216001	Kg. Sg. Tua	2368.16
8	3217001	Ibu Bekalan Km. 16	2372.53
9	3217002	Empangan Genting Klang	2224.52
10	3217003	Ibu Bekalan Km.11	2207.10

APPENDIX D
ANNUALLY AVERAGE RAINFALL AFTER 2000 (2000 – 2016)

Table D1: Annually Average Rainfall Value After 2000

No	Station ID	Station Name	Average Rainfall Value After 2000 (mm)
1	2818110	Smk. Bdr Tasik Kesuma	1997.69
2	2913001	P/Kwln P/S Telok Gong	1799.90
3	2917001	Setor JPS. Kajang	2421.65
4	3118102	Sek. Keb. Kg. Lui	2370.00
5	3116006	Ldg. Edinburgh Site 2	2936.97
6	3117070	Pusat Penyelidikan Jps Ampang	2850.04
7	3216001	Kg. Sg. Tua	2472.34
8	3217001	Ibu Bekalan Km. 16	2389.96
9	3217002	Empangan Genting Klang	2593.25
10	3217003	Ibu Bekalan Km.11	2682.29

APPENDIX E
CROSS VALIDATION IDW MONTHLY BEFORE 2000 (1970 – 1999)

Table E1: Predicted Monthly Average Rainfall Value Before 2000 Using IDW

No	Station ID	Station Name	Predicted Average Rainfall Value Before 2000 (mm)											
			Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1	2818110	Smk. Bdr Tasik Kesuma	109.89	156.13	212.81	232.78	194.62	135.46	139.84	148.60	192.18	243.05	268.73	196.66
2	2913001	P/Kwln P/S Telok Gong	102.26	158.61	213.37	247.54	219.09	140.90	145.35	162.26	208.15	254.32	263.76	182.75
3	2917001	Setor JPS. Kajang	94.98	152.59	203.80	233.11	210.43	130.73	144.14	155.61	198.87	243.98	259.01	175.56
4	3118102	Sek. Keb. Kg. Lui	100.54	158.46	202.83	254.78	219.31	142.17	146.48	169.20	215.81	259.25	257.68	175.08
5	3116006	Ldg. Edinburgh Site 2	95.37	154.15	197.38	256.91	226.89	149.61	155.32	174.35	228.88	263.89	251.94	171.06
6	3117070	Pusat Penyelidikan Jps Ampang	96.70	151.95	206.79	248.62	228.07	147.06	147.83	171.74	227.69	263.74	258.42	174.48
7	3216001	Kg. Sg. Tua	89.91	152.36	205.33	261.07	233.31	149.31	155.67	182.20	238.03	270.64	251.58	160.62
8	3217001	Ibu Bekalan Km. 16	94.84	149.03	198.55	263.04	233.04	152.46	148.75	176.13	238.75	270.57	243.70	165.33
9	3217002	Empangan Genting Klang	89.72	153.62	203.52	262.87	233.84	151.69	160.66	180.65	236.65	268.85	249.79	162.76
10	3217003	Ibu Bekalan Km.11	92.26	153.17	198.20	249.86	232.76	153.00	162.50	186.95	241.01	270.46	266.78	171.16

APPENDIX F
CROSS VALIDATION IDW MONTHLY AFTER 2000 (2000 – 2016)

Table F1: Predicted Monthly Average Rainfall Value After 2000 Using IDW

No	Station ID	Station Name	Predicted Average Rainfall Value After 2000 (mm)											
			Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	2818110	Smk. Bdr Tasik Kesuma	154.65	158.07	233.41	296.55	217.26	142.82	150.13	183.50	216.45	257.82	343.34	205.85
2	2913001	P/Kwln P/S Telok Gong	143.52	149.57	228.45	296.06	232.73	158.82	166.55	177.64	226.00	281.00	340.28	203.68
3	2917001	Setor JPS. Kajang	124.96	133.52	211.07	285.46	216.01	150.88	158.36	169.99	209.15	269.16	330.97	190.43
4	3118102	Sek. Keb. Kg. Lui	136.96	141.17	226.95	290.45	241.25	171.30	171.14	179.26	235.43	291.33	343.54	198.97
5	3116006	Ldg. Edinburgh Site 2	125.25	134.99	219.15	277.54	241.07	176.79	173.12	178.00	244.61	293.55	337.66	192.88
6	3117070	Pusat Penyelidikan Jps Ampang	129.44	142.23	218.48	281.30	243.06	170.57	173.62	183.16	239.99	290.34	337.19	194.66
7	3216001	Kg. Sg. Tua	121.16	136.38	210.19	268.93	246.47	180.49	180.75	174.32	257.44	299.70	341.64	187.86
8	3217001	Ibu Bekalan Km. 16	119.52	136.15	221.97	279.02	252.20	185.78	177.63	183.64	250.01	305.00	333.43	195.68
9	3217002	Empangan Genting Klang	121.27	136.04	212.23	269.32	241.90	179.45	178.41	172.02	256.88	297.57	340.60	188.89
10	3217003	Ibu Bekalan Km.11	120.53	128.07	203.28	264.57	247.67	176.33	181.07	177.05	252.10	288.53	336.58	180.92

APPENDIX G
CROSS VALIDATION IDW ANNUALLY BEFORE AND AFTER 2000

Table D1: Annually Average Rainfall Value Before and After 2000

No	Station ID	Station Name	Annually Average Rainfall Value	
			Before 2000	After 2000
1	2818110	Smk. Bdr Tasik Kesuma	2139.70	2494.28
2	2913001	P/Kwln P/S Telok Gong	2196.62	2567.41
3	2917001	Setor JPS. Kajang	2103.28	2430.58
4	3118102	Sek. Keb. Kg. Lui	2234.20	2596.34
5	3116006	Ldg. Edinburgh Site 2	2252.51	2561.86
6	3117070	Pusat Penyelidikan Jps Ampang	2212.92	2560.15
7	3216001	Kg. Sg. Tua	2274.54	2568.82
8	3217001	Ibu Bekalan Km. 16	2250.94	2606.75
9	3217002	Empangan Genting Klang	2280.80	2560.73
10	3217003	Ibu Bekalan Km.11	2307.94	2516.94

APPENDIX H
CROSS VALIDATION OK MONTHLY BEFORE 2000 (1970 – 1999)

Table H1: Predicted Monthly Average Rainfall Value Before 2000 Using OK

No	Station ID	Station Name	Predicted Average Rainfall Value Before 2000 (mm)											
			Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1	2818110	Smk. Bdr Tasik Kesuma	114.39	149.14	200.60	188.56	131.35	122.68	138.64	128.44	179.19	234.30	273.21	209.56
2	2913001	P/Kwln P/S Telok Gong	114.78	168.26	220.15	230.89	234.13	129.34	143.74	148.33	193.84	288.51	259.68	198.87
3	2917001	Setor JPS. Kajang	99.39	152.04	200.97	227.76	190.96	114.01	138.51	140.09	158.82	216.58	261.04	182.70
4	3118102	Sek. Keb. Kg. Lui	101.16	154.71	196.57	240.35	223.96	125.96	148.35	164.61	205.29	257.29	255.06	177.77
5	3116006	Ldg. Edinburgh Site 2	105.79	155.88	194.00	277.79	205.57	146.55	149.29	170.76	202.82	248.88	260.73	185.48
6	3117070	Pusat Penyelidikan Jps Ampang	104.44	152.75	213.61	248.12	217.30	141.36	146.69	161.06	210.71	263.68	264.60	185.39
7	3216001	Kg. Sg. Tua	91.13	158.10	218.05	265.65	246.87	151.85	145.16	182.97	240.39	275.96	261.97	168.50
8	3217001	Ibu Bekalan Km. 16	92.81	148.51	189.84	256.84	243.91	158.09	145.06	176.93	254.64	277.99	260.52	168.80
9	3217002	Empangan Genting Klang	88.16	156.29	201.84	253.67	238.41	153.55	150.10	176.27	239.40	268.38	264.70	166.88
10	3217003	Ibu Bekalan Km.11	95.77	156.39	200.74	257.93	236.53	152.81	149.01	180.17	238.79	269.91	269.47	174.92

APPENDIX I
CROSS VALIDATION OK MONTHLY AFTER 2000 (2000 – 2016)

Table I1: Predicted Monthly Average Rainfall Value After 2000 Using OK

No	Station ID	Station Name	Predicted Average Rainfall Value After 2000 (mm)											
			Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	2818110	Smk. Bdr Tasik Kesuma	151.27	148.80	223.21	283.64	156.61	94.81	94.37	186.99	189.85	213.92	339.80	198.49
2	2913001	P/Kwln P/S Telok Gong	168.87	164.47	229.03	369.87	221.61	116.73	197.33	169.67	171.43	261.67	348.37	222.06
3	2917001	Setor JPS. Kajang	129.74	130.32	204.27	272.68	189.75	132.11	148.70	158.99	177.45	251.40	321.30	197.97
4	3118102	Sek. Keb. Kg. Lui	133.66	136.04	222.04	276.02	243.02	173.48	204.00	171.80	225.62	284.28	338.69	192.10
5	3116006	Ldg. Edinburgh Site 2	138.69	142.64	220.56	253.44	232.36	182.73	163.65	168.19	234.52	294.75	328.75	196.38
6	3117070	Pusat Penyelidikan Jps Ampang	141.36	157.23	229.99	279.92	231.79	165.23	167.36	178.14	228.62	281.65	339.25	197.42
7	3216001	Kg. Sg. Tua	132.45	144.18	214.10	294.21	263.33	178.29	191.61	184.08	264.37	307.44	347.05	197.98
8	3217001	Ibu Bekalan Km. 16	115.02	126.42	215.58	293.58	254.83	187.36	178.19	190.79	254.03	301.27	336.77	199.40
9	3217002	Empangan Genting Klang	124.43	134.62	214.10	290.83	242.64	180.17	175.71	182.13	257.96	290.70	345.07	196.73
10	3217003	Ibu Bekalan Km.11	127.80	132.45	213.86	284.39	249.18	178.64	182.38	181.81	248.72	294.05	341.68	193.81

APPENDIX J
CROSS VALIDATION OK ANNUALLY BEFORE AND AFTER 2000

Table J1: Annually Average Rainfall Value

No	Station ID	Station Name	Annually Average Rainfall Value (mm)	
			Before 2000	After 2000
1	2818110	Smk. Bdr Tasik Kesuma	1970.60	2213.20
2	2913001	P/Kwln P/S Telok Gong	2138.14	2599.13
3	2917001	Setor JPS. Kajang	2033.47	2388.67
4	3118102	Sek. Keb. Kg. Lui	2156.33	2539.57
5	3116006	Ldg. Edinburgh Site 2	2319.18	2635.15
6	3117070	Pusat Penyelidikan Jps Ampang	2184.79	2690.73
7	3216001	Kg. Sg. Tua	2301.84	2582.82
8	3217001	Ibu Bekalan Km. 16	2255.65	2538.76
9	3217002	Empangan Genting Klang	2260.29	2557.84
10	3217003	Ibu Bekalan Km.11	2313.33	2613.08

APPENDIX K
MONTHLY AVERAGE RAINFALL DIFFERENCE

Table K1: Monthly Average Rainfall Value Difference

No	Station ID	Station Name	Average Rainfall Difference Value (mm)											
			Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	2818110	Smk. Bdr Tasik Kesuma	1.55	-20.34	-42.31	71.28	-9.42	12.61	-2.16	12.41	-3.68	2.21	49.32	7.04
2	2913001	P/Kwln P/S Telok Gong	14.21	-46.11	-4.95	3.39	7.63	2.51	-23.27	-14.58	-10.67	7.63	-16.76	-4.07
3	2917001	Setor JPS. Kajang	50.83	23.44	18.52	86.61	37.05	-6.54	1.76	56.96	36.42	-2.45	73.44	3.52
4	3118102	Sek. Keb. Kg. Lui	36.64	-7.14	10.64	93.00	-26.33	-12.13	-9.15	58.21	-7.06	8.81	60.85	-35.93
5	3116006	Ldg. Edinburgh Site 2	87.31	13.64	13.37	81.17	12.72	9.70	59.36	14.00	26.41	49.81	60.12	56.02
6	3117070	Pusat Penyelidikan Jps Ampang	58.01	-36.08	76.62	59.73	29.71	44.38	26.44	21.72	37.98	62.55	116.65	34.72
7	3216001	Kg. Sg. Tua	22.36	-27.73	19.40	7.06	-3.38	2.37	-8.20	-13.57	1.05	10.00	51.46	3.68
8	3217001	Ibu Bekalan Km. 16	29.33	-34.44	-28.03	-13.94	0.73	17.35	2.88	-42.73	19.99	2.59	67.21	-0.95
9	3217002	Empangan Genting Klang	15.56	-18.20	19.87	29.30	44.89	46.95	51.29	17.19	0.80	30.41	80.40	17.59
10	3217003	Ibu Bekalan Km.11	24.92	0.83	26.11	-2.46	15.28	46.94	36.40	9.25	23.41	52.32	125.00	59.64

APPENDIX L
ANNUALLY AVERAGE RAINFALL DIFFERENCE

Table L1: Annually Average Rainfall Difference Value

No	Station ID	Station Name	Average Rainfall Value (mm)
1	2818110	Smk. Bdr Tasik Kesuma	158.58
2	2913001	P/Kwln P/S Telok Gong	-114.37
3	2917001	Setor JPS. Kajang	343.17
4	3118102	Sek. Keb. Kg. Lui	396.61
5	3116006	Ldg. Edinburgh Site 2	643.38
6	3117070	Pusat Penyelidikan Jps Ampang	568.40
7	3216001	Kg. Sg. Tua	104.18
8	3217001	Ibu Bekalan Km. 16	17.42
9	3217002	Empangan Genting Klang	368.73
10	3217003	Ibu Bekalan Km.11	475.19