DEVELOPMENT OF ISOHYET MAP FOR KUANTAN RIVER BASIN USING KRIGING AND RADIAL BASIS FUNCTIONS METHODS

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ABSTRAK

Curahan adalah parameter iklim yang penting dan kajian mengenai hujan seperti pengenalan corak hujan biasanya terhalang kerana rangkaian tolok hujan yang terhad dan menyebabkan kekurangan data berterusan, dan berlakunya ralat sistematik dan rawak. Untuk mendapatkan pemerhatian yang hilang dalam data, beberapa kaedah interpolasi spasial kini digunakan. Walau bagaimanapun, kekurangan pengetahuan mengenai kesesuaian kaedah ini untuk Lembangan Sungai Kuantan adalah masalah praktikal. Memandangkan masalah ini, salah satu objektif kajian ini adalah perbandingan antara dua kaedah terpilih yang digunakan untuk menganggarkan data hujan yang hilang untuk menentukan kesesuaian mereka di Lembangan Sungai Kuantan. Kaedah yang dikaji ialah kaedah Kriging dan Radial Basis Functions (RBFs). Dalam pendekatan ini, 8 stesen hujan dari Lembangan Sungai Kuantan yang paling kurang sama rata di dalam lembangan dengan data yang paling banyak dipilih. Data hujan diperolehi dari Jabatan Pengairan dan Saliran Malaysia (JPS) dari tahun 1970 hingga 2016. Selepas itu, data bulanan dan tahunan hujan setiap stesen dianggarkan berdasarkan kaedah yang dipilih di atas supaya data sebenar dan data anggaran dapat berbanding dengan menggunakan kaedah silang pengesahan dengan dua statistik diagnostik biasa, termasuk Mean Absolute Error (MAE) dan Root-Mean-Square-Error (RMSE). Hasil keseluruhan kajian menunjukkan bahawa Kaedah RBFs adalah kaedah interpolasi spasial yang paling sesuai untuk menganalisis peta pola hujan bulanan dan tahunan untuk kesan perubahan iklim di Lembangan Sungai Kuantan. Dari segi taburan hujan bermusim, peta pola hujan memperlihatkan bahawa dari bulan November hingga Mac menerima hujan yang lebih tinggi yang mungkin disebabkan oleh kesan monsun timur laut. Sementara itu, dari segi taburan serantau, kawasan-kawasan yang mempunyai tanah yang tinggi dan berdekatan dengan laut biasanya dijangka menerima lebih banyak hujan dibandingkan dengan tanah rendah dan pedalaman. Untuk kesan perubahan iklim, intensiti hujan dan keluasan tempat menerima hujan yang lebih tinggi juga meningkat dengan ketara selama bertahun-tahun. Taburan hujan lebih kurang sama untuk keseluruhan kawasan Kuantan. Perbezaan kedalaman hujan antara tahun 1970 hingga 1999 dengan tahun 2000 hingga 2016 yang tertinggi direkodkan adalah pada musim monsun timur laut di mana kejadian hujan yang lebat berlaku menyebabkan banjir besar.

ABSTRACT

Precipitation is an important climatic parameter and the studies on rainfall such as identification of rainfall pattern are commonly hampered due to limited rain-gauge network in the field and cause lack of continuous data and occurrence of systematic and random errors. To obtain missing observations in data, several spatial interpolation methods are currently used. However, the lack of knowledge on the suitability of these methods for Kuantan River Basin is a practical problem. In view of this problem, one of the objectives of this study is comparing two selected methods used for the estimation of missing rainfall data to determine their suitability in Kuantan River Basin. The methods studied were Kriging and Radial Basis Functions (RBFs) methods. In this approach, 8 rainfall stations from Kuantan River Basin which are most or less evenly distributed in the basin and with the most extensive data were chosen. The rainfall data was obtained from the Department of Irrigation and Drainage Malaysia (DID) from years 1970 until 2016. Subsequently, monthly and annually rainfall data of each station were estimated based on the above selected methods so that actual data and the estimated data can be compared by using cross-validation method with two common diagnostic statistics, include Mean Absolute Error (MAE) and Root-Mean-Square-Error (RMSE). Results in overall of the study show that the RBFs method is the most common spatial interpolation method to analyse monthly and annually rainfall pattern maps for the impact of climate change over Kuantan River Basin. In term of seasonal rainfall distribution, the rainfall pattern maps show that from November to March received higher precipitation which may due to the Northeast monsoon effect. Meanwhile, in term of regional distribution, the areas which high altitudes and near to the open sea usually are projected to receive more precipitation compared to the lowlands and inlands. For the impact of climate change, the rainfall intensity and the areal extent of higher precipitation has also increased significantly over years. The rainfall distributed more evenly over the Kuantan region. The difference of rainfall depth between year 1970 until 1999 and year 2000 until 2016 recorded highest is in the Northeast Monsoon season where extreme precipitation events occur resulting in major floods.

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LIST OF SYMBOLS

P	Average Precipitation
n	Number of Stations
i	Particular Number of Station or Rainfall Point
A	Catchment Area
$z\ (x_i)$	Measured Value
λ_i	An Unknown Weight for the Measured Value
x_0	Prediction Location
N	Number of Measured Values or Number of Values for Estimation
z (x)	Smooth Variation Plus Measurement Error
D	Examining Area
$\varphi\ (\rho)$	Selected Radial Basis Function
ρ	Radial Distance
μ	Bias Value or Lagrangian Multiplier
$E_1(x)$	Exponential Integral Function
Z_i	Measured Value
$\hat{Z}_i$	Estimated Value

LIST OF ABBREVIATIONS

RBFs	Radial Basis Functions
IDW	Inverse Distance Weighted
OK	Ordinary Kriging
GIS	Geographical Information System
NWC	National Weather Centre
IPCC	Intergovernmental Panel on Climate Change
DEMs	Digital Elevation Models
ESRI	Environmental Systems Research Institute
ENVI	Environment for Visualizing Images
MRE	Mean Relative Error
MAE	Mean Absolute Error
RMSE	Root-Mean-Square-Error
LP	Local Polynomial Interpolation
GP	Global Polynomial Interpolation
UK	Universal Kriging
SRMSE	Standardized Root Mean Square Error
CK	Cokriging
OCK	Ordinary Cokriging
KED	Kriging with External Drift
S	Spline
TR	Topo to Raster
G	Goodness of Prediction Measure
AC	Accuracy
R	Pearson correlation coefficient
TPS	Thin Plate Spline
CRS	Completely Regularized Spline
GAP	South-eastern Anatolia Project
DID	Department of Irrigation and Drainage Malaysia

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Malaysia is a country located at the southeast of Asia region which is encompassed by four countries, those are Thailand, Indonesia, Brunei and Singapore. The total land area of Malaysia is about 330,803 km^2 and 0.37% of this land area is made up of water such as lakes, rivers or other internal waters. Besides that, the land of the country is surrounded by coastal areas such as Strait of Malacca, South China Sea and Sulu Sea with a total coastline of 4,675 km approximately. South China Sea has separated Malaysia into two distinct parts, Peninsular Malaysia and East Malaysia.

Due to the reason that situated near to the equator, Malaysia is considered as typical tropical country and has been received rainfall throughout the year. There is two monsoon winds seasons experiences by Malaysia, Southwest Monsoon and Northeast Monsoon. The Southwest Monsoon commences from May to September and the whole country, except for the state of Sabah, normally faces relatively dry weather, also known as dry season. During this monsoon, most of the states in Malaysia receive minimum amount of precipitation as a result of the stable atmospheric conditions in the region and the Sumatran mountain range, which brings about the rain shadow effect while Sabah receives more precipitation due to the tail effect of typhoons in the Philippines. On the other hand, the Northeast Monsoon usually starts from November to March and the east coast of Peninsular Malaysia and western Sarawak are affected by the wet season or rainy season.

Pahang, is one of the states in Malaysia which occupies the vast Pahang River basin, which is enclosed by the Titiwangsa Mountain Range to the west and the eastern highlands to the north. As mentioned earlier, Pahang also faces two monsoon seasons, Southwest Monsoon and Northeast Monsoon. The tropical storms of the Northeast Monsoon brings heavy fall of rain, strong currents and unpredictable storm of the monsoon season that comes in from the South China Sea. Due to the existence of Titiwangsa Mountain Range, which blocks the northeasterly winds, Northeast Monsoon gives significant impact in characterizing the rainfall patterns for eastern part of Peninsula Malaysia (Suhaila *et al.*, 2010). Hence, Pahang river basin will receive high total of precipitation during this season. Sometimes, this incident will and lead to the occurrence of flood at a few low lying areas along the Kuantan River because of overflowing. However, the southwest monsoon brings less rainfall, with sunny and tropical weather up. The seasonal south-west winds blow from Sumatra toward the West Coast of Peninsular Malaysia but are blocked by the Titiwangsa Mountain Range.

Nowadays, the climate of Malaysia is changing in line with global climate change. Climate in Southeast Asia is changing due to global warming both on global and regional scales (Mayowa *et al.*, 2015). Global warming will influence the patterns of precipitation to be change and increasing in occurrences of extreme weather events, such as floods, droughts, and rain-storms (Zhang *et al.*, 2008). Extreme floods and droughts can cause economic and ecological damage, and, in the worst cases, risk lives (Suhaila and Jemain, 2012). Human-caused changes in temperature are also expected to change precipitation patterns (Karl *et al.*, 2009). According to a number of studies, precipitation is forecasted will slightly increase during both the rainy and dry season in the coastal regions of the Peninsular Malaysia (Barr *et al.*, 2007). Subsequently, floods may occur in low areas due to the increasing frequency of extreme precipitation.

The isohyetal method is an alternative method for estimating the mean precipitation over an area by drawing lines of equal precipitation to produce an isohyetal map by using spatial analysis. Isohyetal maps are the contour maps of precipitation while the spatial analysis is a set of techniques used to analyse, compute, visualize, simplify, and theorize the geographic data includes topological, geometric, or geographic properties (Ismail, 2000). Kriging method is one of the geostatistical interpolation techniques that create surfaces incorporating the statistics. This method is not only can used in prediction of surfaces but also error or uncertainty surfaces. On the other hand, Radial Basis Functions (RBFs) method is a deterministic interpolation method that used to create the smooth interpolated surfaces from a large number of sample data points but the method does not have standard errors associated with it.

1.2 PROBLEM STATEMENT

Rainfall is the main source of water supply. Generally, the time and space distribution characteristics are one of the main reasons that composed of the temporal and spatial distribution characteristics. The rainfall in actual situation is distinctly variable in different time and space even in same climate zone and river basin. Besides that, rainfall is significantly different in term of longitude and latitude, water system (reservoir, rivers, lakes), the run of the mountains, slope aspect and altitude change, especially in the mountain plateau. The rainfall spatial distribution of certain basin has the obvious differences, particularly in the dry regions.

In addition, rainfall data is played an important role in hydrological investigations and environment studies. This data can be used to calculate runoff, identify the rainfall pattern, forecast and resolve the meteorological disaster such as rainstorm, floods and drought. However, the rain-gauge network is usually limited in the field and cause occurrence of missing data, systematic and random errors (Adhikary *et al.*, 2017). Hence, specific methods are needed for the area where lack of rain gauge station.

Spatial interpolation method is one of the methods to estimate a missing or new date point which is in the range of a series of known isolated points and indicate visually the spatial pattern of rainfall. Interpolation techniques consist of two distinct group, which are deterministic and geostatistical. Deterministic interpolation methods used on known points to create surfaces, according to the degree of similarity or smoothing, such as Inverse Distance Weighted (IDW) and Radial Basis Functions (RBF) methods. However, geostatistical interpolation methods like Kriging method, are used to estimate the value of an unknown point utilizing the statistical properties of neighboring known points and taking the spatial autocorrelation among known points into consideration (Apaydin *et al.*, 2004).

1.3 OBJECTIVES OF STUDY

The objectives of the study are:

i. To develop isohyet maps for Kuantan River Basin using Kriging and Radial Basis Functions (RBFs) methods.

ii. To evaluate and identify the most optimum spatial interpolation method for rainfall distribution in Kuantan River Basin.

iii. To analyse monthly and annually rainfall pattern maps that developed from the optimum spatial interpolation method for the impact of climate change over Kuantan River Basin.

1.4 SCOPES OF STUDY

The scope of this study includes determination of monthly and annually rainfall pattern and comparison of isohyets map between Kriging method and Radial Basis method. The selected area for this study is Kuantan River Basin. For the analysis, 47 years starting from 1970 until 2016 rainfall data from Department of Irrigation and Drainage's rainfall stations in Kuantan River Basin were used to analyse by using Geographical Information System (GIS) software (ArcGIS 10.2) to produce isohyets maps with Kriging and Radial Basis Functions methods. After the isohyets maps are produced, the performances of the Kriging and Radial Basis methods will be compared and analysed by using cross-validation method. Hence, the most optimum spatial interpolation methods will be selected for the analysis of monthly and annually rainfall pattern maps for the impact of climate change over Kuantan River Basin.

1.5 SIGNIFICANT OF STUDY

The main reason to produce the isohyets map for Kuantan River Basin is the lack of rain gauge station. As a result, rainfall data are generally accessible from a limited number of stations. These limitations increase the need of using suitable spatial estimation methods to obtain the rainfall pattern and generate rainfall isohyet map. Subsequently, it can help in meteorological forecasting and hydrological analyses, for example, water budget analysis, flood modelling, climate change studies, drought management, irrigation scheduling, and water management.

CHAPTER 2

LITERATURE REVIEW

2.1 HYDROLOGICAL CYCLE

The hydrological cycle also refer as hydrologic cycle or, water cycle which describing the movement of water on, above and below the surface of the Earth continuously. Water is always changing states between liquid, vapour, and ice, with these processes happening in the blink of an eye and over millions of years. The hydrological cycle included the processes of precipitation, infiltration, surface runoff, percolation, groundwater flow, evaporation, and transpiration (DID, 2009). The hydrologic cycle in which water leaves the atmosphere and falls to earth as precipitation where it enters surface waters or percolates into the water table and groundwater and eventually is taken back into the atmosphere by transpiration and evaporation to begin the cycle again.

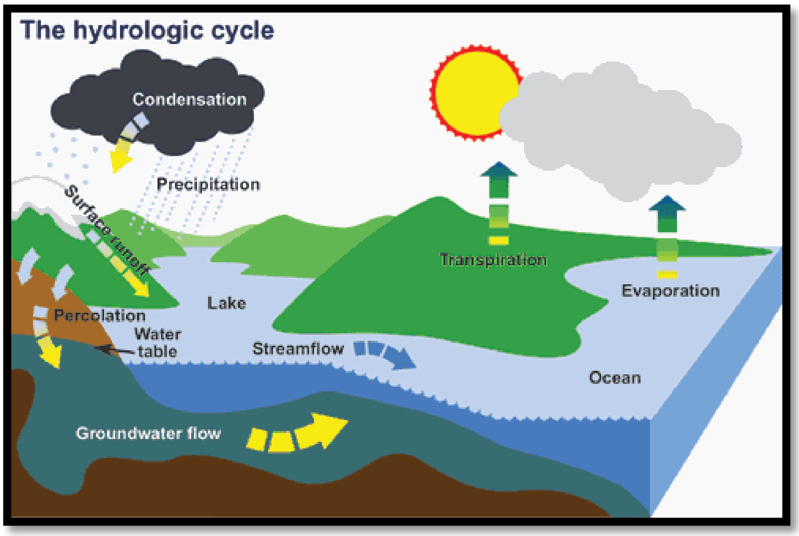


Figure 2.1 Hydrologic Cycle

Source: https://www.canada.ca

2.2 HYDROLOGICAL VARIABLES

Hydrological is a science that can only built on observations and measurements (Wood, 1998). Hydrological measurements are not only important for the interpretation of water quality data, but also for water resource management. Moreover, variations in hydrological conditions have also significant effects on water quality.

2.2.1 Precipitation

Precipitation represents the water amount falling on the land surface from the atmosphere in the form of rain, snow and hail. The precipitation in the form of liquid commonly known as rainfall is caused by the adiabatic cooling and subsequent condensation of water vapour by the lifting mechanism of the air parcel. Precipitation can be categorized into the three categories, consist of, cyclonic precipitation, convective precipitation, and orographic precipitation (Dandekar and Sharma, 2013).

Amount of rainfall can be measured by rain gauges, that can give the amount in depth units over a particular accumulation period, generally the period is 24 hours. In addition, rain intensity which also refers as rain rate, is another hydrological variable in term of precipitation, yet, the measurements of rain intensity are not common and only carry out for the important meteorological stations.

Figure 2.2 Thundershowers over Yellowstone Lake, Montana, USA
Source: https://water.usgs.gov

2.2.2 Evapotranspiration

Generally, evapotranspiration consists of two process, evaporation and transpiration, which transfers water from the ground surface to the atmosphere by converting from liquid to gaseous state. Evaporation defines the water loss from ground surface through surface water bodies, soil moisture and vegetation surfaces. However, the term of transpiration defines to the process of water vapour to the atmosphere during photosynthesis of plants. The water transfer from soil through plant roots to the small openings in the leaves, called, stomata, where the water escapes to the atmosphere (Dandekar and Sharma, 2013).

Evapotranspiration is a complex process depending upon the energy balance, prevailing wind, and relative humidity; availability of moisture is the limiting factor. A major concept to understand evapotranspiration is potential evapotranspiration. Potential evapotranspiration refers to the amount of water have been evapotranspired when the moisture supply is not limited.

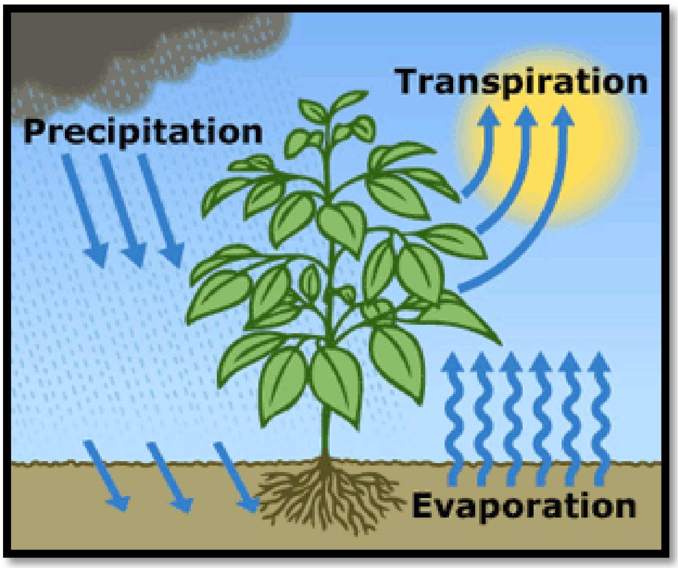


Figure 2.3 Evapotranspiration
Source: http://www.salinitymanagement.org

2.2.3 Infiltration

Conceptually, infiltration is the process that the water from precipitation dissolved into the soil through the ground surface. The infiltration rate is a measure of the rate at which water absorbed into soil from the surface. It is measured in inches per hour or millimetres per hour. The maximum rate at which a given soil can absorb water is its infiltration capacity. The rate decreases when the soil becomes saturated and surface ponding and overland flow occurs when the rate beyond the infiltration capacity. Infiltration rate is depend on the surface vegetation, soil properties such as hydraulic conductivity and porosity, and land management, slope and geomorphic location (Jones, 1997).

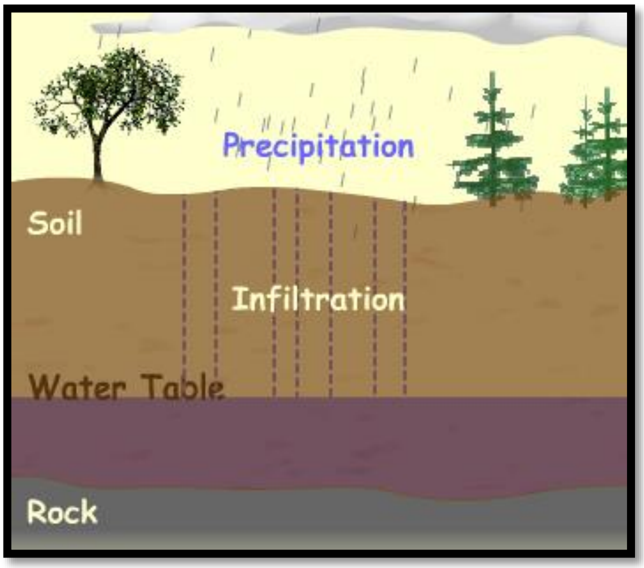


Figure 2.4 Infiltration
Source: http://techalive.mtu.edu

2.2.4 Groundwater

Predominantly, groundwater also named as "aquifer" which used to describe a water-bearing body of soil or rock. Groundwater is relatively abundant and estimated that makes up about 98.97% of all liquid freshwater on earth (Younger, 2009) . The groundwater movement is constantly happening beneath the ground, possibly very slowly but steady, and this movement can be described as "seeping".

The groundwater is absorbed from the land surface into soil via infiltration and then stored in the saturated zone of the ground. The top layer of the saturated zone of soil is called the unsaturated zone. The soil in this zone are not completely saturated with water. Moreover, capillary fringe, where situated just above the water table, is the zone that the water is held above the water table by capillarity. The groundwater also interacts with the surface water based on topography, although it is sitting deep below the ground (Schwalbaum, 1997).

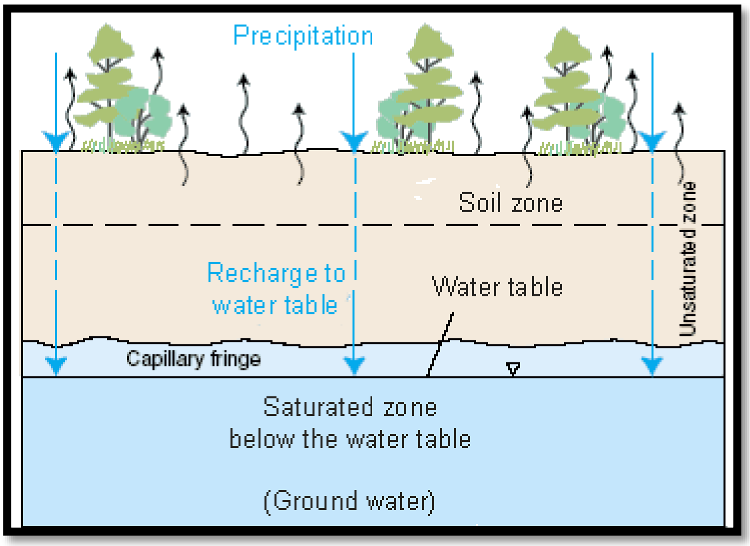


Figure 2.5 Grounwater

Source: https://water.usgs.gov

2.2.5 Humidity

Humidity is the amount of water vapour that present in the atmosphere. It is usually indicating the probability of precipitation, fog, or dew. There are three types of humidity, including absolute humidity, relative humidity and specific humidity (Guldbeck, 1995). Absolute humidity defined as the quantity of water vapour in a given volume of air and expressed in gram per cubic meter or grams per kilogram while relative humidity is the water content of air expressed as a percent which measures the current absolute humidity relative to the maximum for that temperature. Lastly, specific humidity refers to the ratio of the mass of water vapour to the total mass of the moist air parcel. The tools that usually used to measure humidity is sling psychrometer.

2.3 TYPES OF PRECIPITATION

To begin the precipitation process, the moist air mass should condense. This occurs when the air is cooled so that it is saturated with the same amount of moisture. This is generally accomplished by lifting of the air mass to higher altitudes.

There are three type of lifting mechanisms in precipitation. The type of precipitation is based on the way in which air is cooled and condensed to cause precipitation. There are frontal precipitation, orographic precipitation, and convective precipitation (Dandekar and Sharma, 2013).

2.3.1 Frontal Precipitation

Frontal precipitation also called as cyclonic precipitation occurs when masses of air with different characteristic in temperature, density, and moisture. As the less dense warmer air meets colder air. The warmer air is forced to rise over the heavier, colder air and becomes saturated. Finally, this processes cause condensation, formation of cloud and precipitation (Chapman, 1998). In turn, precipitation can enhance the temperature and moisture contrast along a frontal boundary. Passing weather fronts cause sudden changes in general temperature, humidity and pressure in the air at ground level.

There are two types of frontal precipitation, cold fronts and warm fronts. Cold fronts is the transition zone where a cold dry stable air mass is displacing a warm, moist unstable air mass (Pidwirny, 2017). This occurs when cold air is denser than warm air, resulting it undercuts and pushes the warm air vertically ahead of it as it moves. The slope of the cold air with a cold front is very steep, thus the air is rapidly pushed up. As a result, strong to severe thunderstorms may happen if there is available of ample moisture and instability.

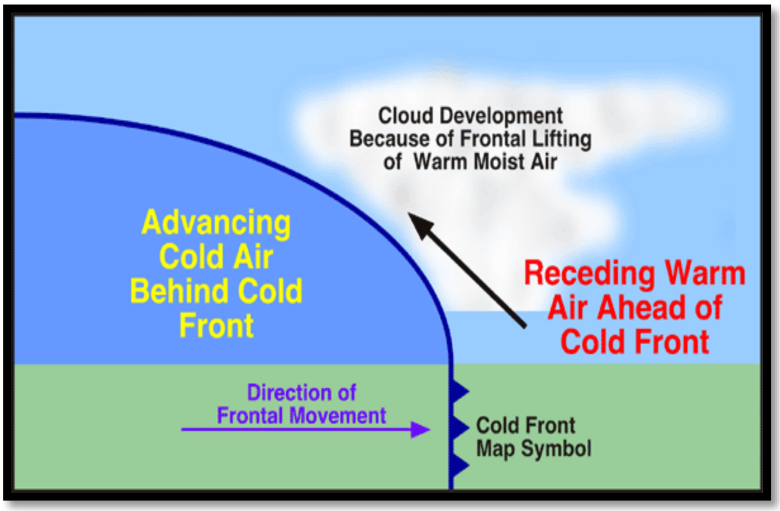


Figure 2.6 Cold fronts

Source: http://www.physicalgeography.net

Warm fronts is the transition zone where a cold dry air mass has been displaced warm moist air mass (Pidwirny, 2017). It is different from cold front, the warm moist air mass will rise over the cold dry air mass at the surface because of the density is lesser. This allows clouds lifting and formation of the warm front. The slope of the cold and warm air in a warm front is flatter than a cold front. Thence, thunderstorms are mostly to form as a cold front as compare to warm front.

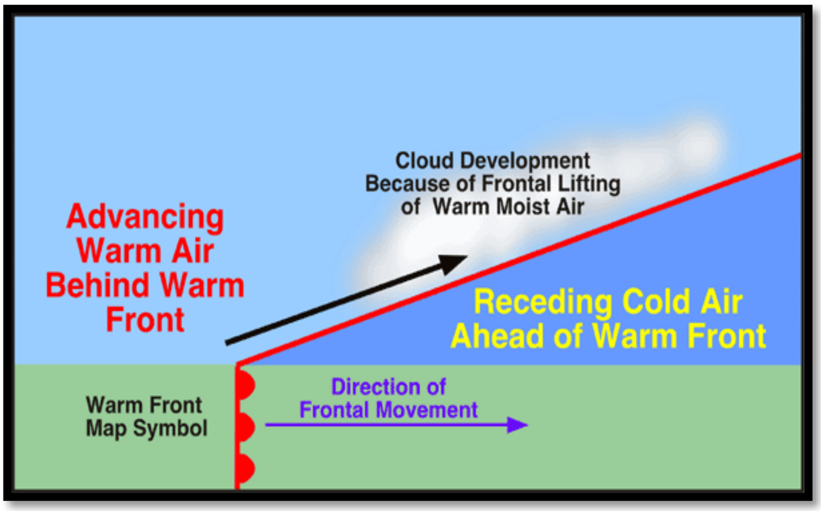


Figure 2.7   Warm fronts

Source: http://www.physicalgeography.net

2.3.2 Orographic Precipitation

Orographic precipitation occurs where the air mass is forced to uplift due to the presence of a topographic obstruction (Pidwirny, 2017). It means that, the warm moist air is forced to rise by large mountains when moving across the ocean. The water vapour in the air start to condense and form of water droplets when the air become cooler due to temperature reduction in a high elevation. As a result formation of cloud and occurrence of precipitation on the windward side of the mountain and then the air is dry and rises over top the mountain. The air start to sink downwards as it collects moisture and warm by the ground as it moves back down the mountain (Chapman, 1998). This side of the mountain is called the leeward side. It receives very little precipitation and this area called as rain shadow.

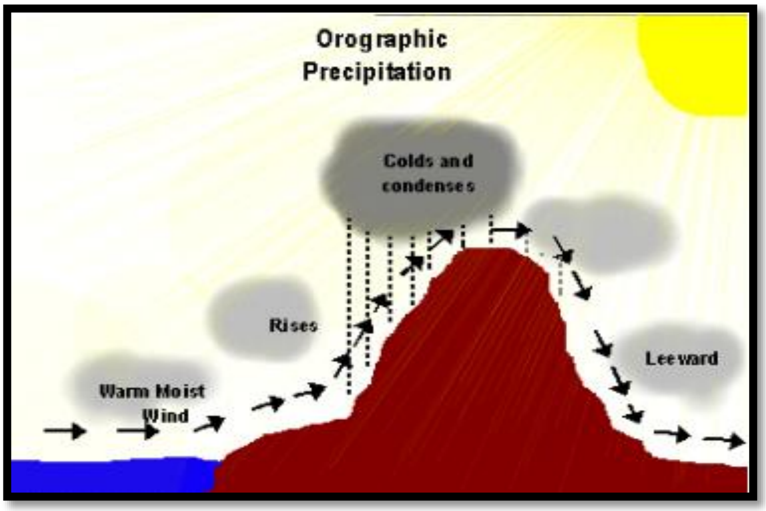


Figure 2.8 Orographic precipitation
Source: http://www.indiana.edu

2.3.3 Convective Precipitation

Convectional precipitation results from the heating of the earth's surface. It is associated with hot climates, mostly occurs in the tropics (Suhaila and Jemain, 2009). The warm ground heats the moist air over it. As the air warms, the air molecules begin to move further apart and are becoming less dense. Thus, the air is being lighter and rises rapidly into the atmosphere. As the air rises, it meets the colder air in denser surroundings (Dandekar and Sharma, 2013). Therefore, water vapour in the air condenses into clouds and precipitation. This type of rainfall is usually associated with rainfall on single wet days.

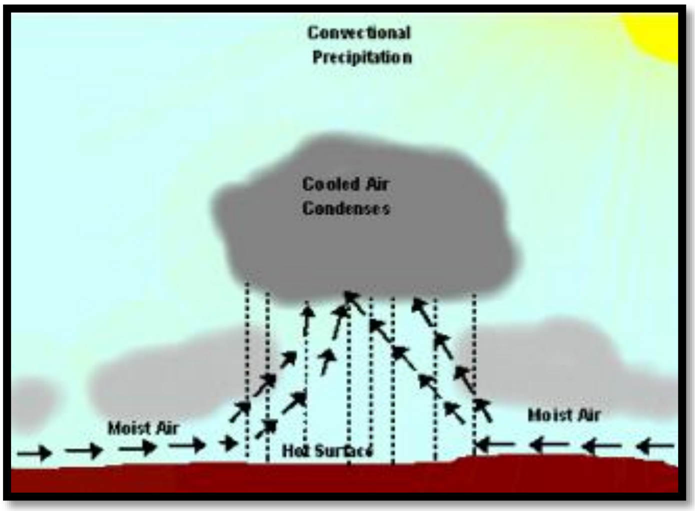


Figure 2.9 Convective precipitation
Source: http://www.indiana.edu

2.4 FACTORS AFFECTING PRECIPITATION

The amount and pattern of precipitation is different and variable in different areas of the Earth's surface. Precipitation significantly different in term of latitude. The areas where near the equator are receive more precipitation than in the temperature zones and Polar Regions. In spite of that, the areas near the Equator occur more evaporation due to the higher temperature.

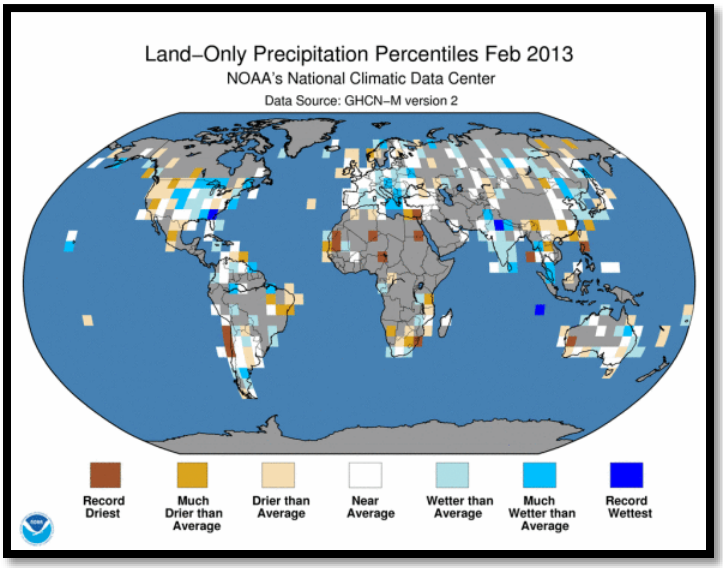


Figure 2.10 Land-only precipitation percentiles, February, 2013.
Source: U.S. National Oceanic and Atmospheric Administration

Besides that, the amount of precipitation received is depends on the altitude or topography. Usually, the high areas will received more precipitation to the low areas (Tekolla, 2010). For instance, when winds blow from the sea toward coastal mountains, they are forced to rise. The rising air cools and its water vapour condenses which from clouds. Hence, the precipitation will falls on the windward side of the mountains, the side where the wind blows, whereas land on the leeward side of the mountains is in rain shadow and receive less precipitation.

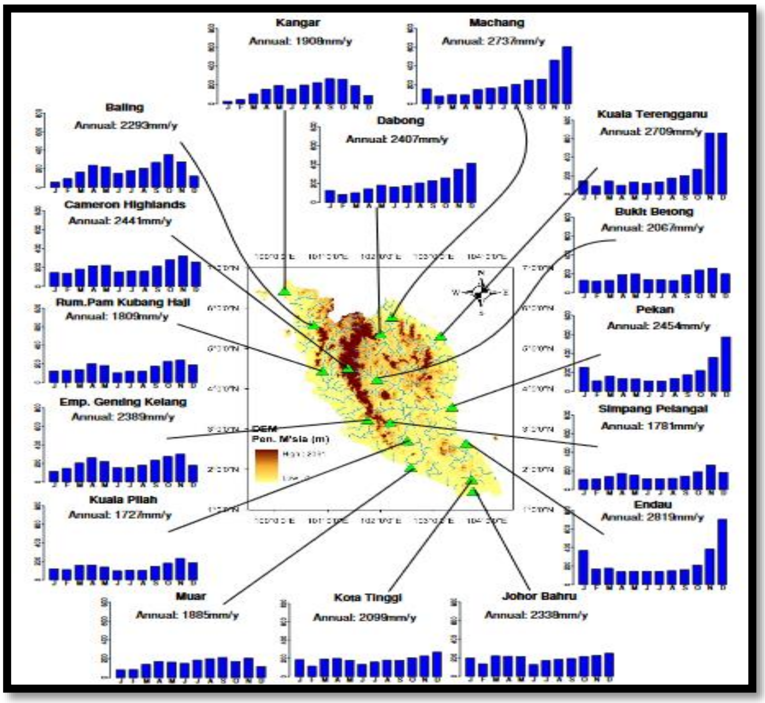


Figure 2.11 Mean monthly and annual rainfall at sixteen selected stations in Peninsular Malaysia. The background map displays the orography of the area.

Source: Wong *et al.* (2009).

Furthermore, the precipitation is mainly influenced by prevailing winds. Prevailing winds defined the winds from the direction that is predominant at a particular place or season. The weather patterns depend on the movement of huge air masses. Air masses are moved from place to place by prevailing winds. Consequently, the amount of precipitation will affected by the amount of water vapour in the air mass influence. In general, the prevailing wind flow is south-westerly and light, usually it is below 7.72 m/s in Malaysia (Othman, 2010).

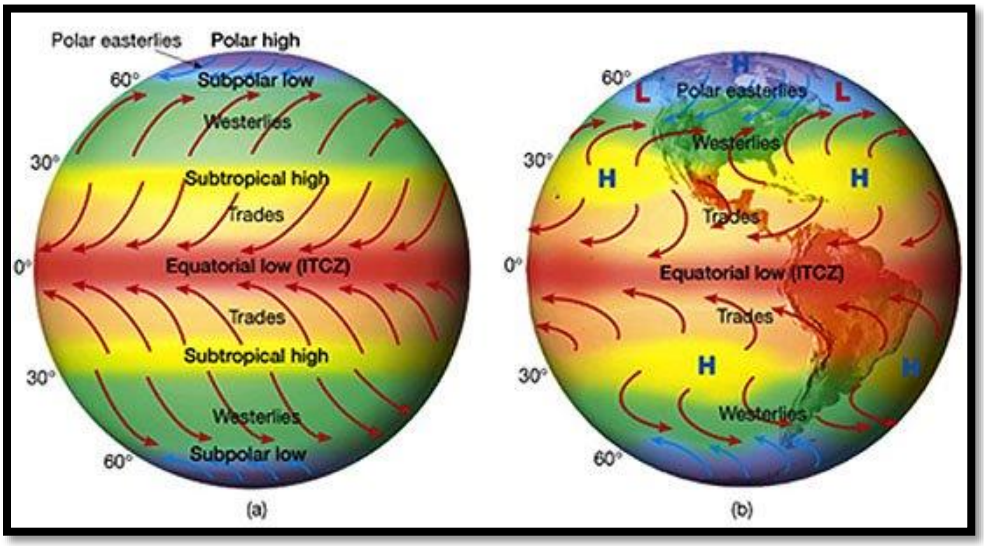


Figure 2.12 The global circulation cells dominate the prevailing winds at a given latitude.

Source: https://wxornotbg.com

A change in seasonal wind, which means winds that blow only during certain seasons, can also affect the precipitation. In general, seasonal winds are same with the sea and land breezes. Sea and land breezes over a vast region that change direction with the season are called monsoons. During daytime, the vertical expansion of air has been heating over the more rapidly heated land (Barry and Chorley, 2003). Hence, the sea breeze blows inland from the sea and gets warmer and more humid. The high amount of precipitation will be produced as the humid air rises over the land, while the amount of precipitation will decrease as the land breeze blows from the land to the sea. This is because the air over the sea is warmer and the winds blow off the land at night.

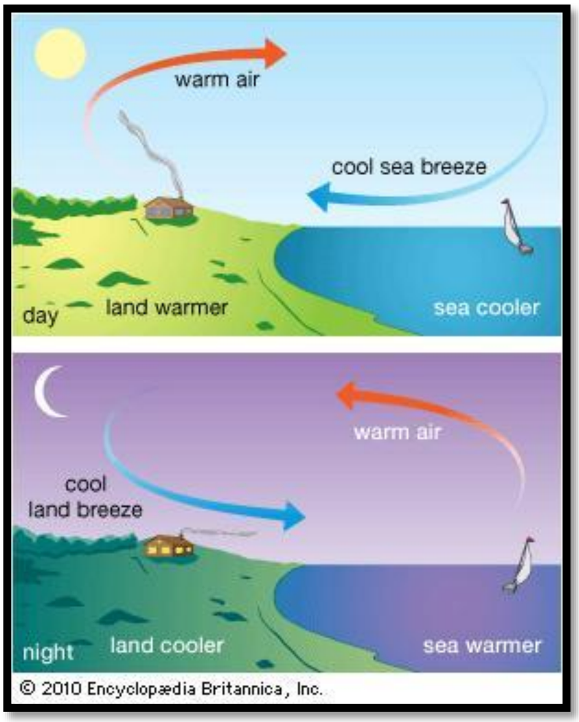


Figure 2.13 The paths of a typical sea breeze (day) and land breeze (night).
Source: www.britannica.com

2.5 PRECIPITATION MEASUREMENTS

Commonly, one of the instrument that used by meteorologists and hydrologists to measure rainfall rate in a certain period of time is rain gauges. Rain gauges are also known as udometer, pluviometer and ombrometer. There are three types of devices used to measure the precipitation, those are rain gauges, radar observations and satellite observations (Dandekar and Sharma, 2013). The rain gauges that have been widely used are non-recording type rain gauges, recording type rain gauges and automatic radio-reporting rain gauges.

2.5.1 Non-Recording Type Rain Gauge

Non-recording type rain gauge is a type of rain gauge that commonly used by meteorological department. It consists of a cylindrical vessel 127mm in diameter with a base enlarged to 210mm diameter. At its top section, funnel is provided with circular brass rim which is 127mm exactly so that it can fit into vessel well. This funnel shank is inserted in the neck of a receiving bottle which is 75 to 100mm high from the base section and thinner than the cylinder, placed into it to receive rainfall.

A Receiving bottle has capacity of 100mm and during heavy rainfall, amount of rain is frequently exceeded, so the reading should be measured 3 to 4 times in a day. Water contained in this receiving bottle is measured by a graduated measuring glass with an accuracy up to 0. 1mm. For uniformity the rainfall is measured every day at 8:30Am IST and is recorded as rainfall of the day. Proper care, maintenance and inspection of rain gauge especially during dry weather is necessary to keep the instrument free form dust and dirt, so that the readings are accurate (Dandekar and Sharma, 2013).

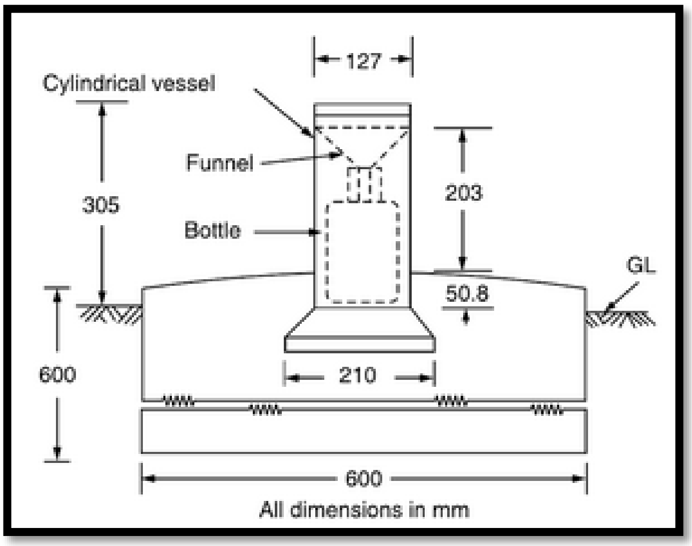


Figure 2.14 Non-recording type rain gauge
Source: Dandekar and Sharma (2013)

2.5.2 Recording Type Rain Gauges

There are three types of recording rain gauges:

i. Weighing Bucket Type Rain Gauge

Weighing bucket type rain gauge is the most common self-recording rain gauge. It consists of a receiver bucket supported by a spring or lever balance or some other weighing mechanism. The movement of bucket depend on its increasing weight is transmitted to a pen which traces record or some marking on a clock driven chart. This instrument provides a plot, named mass curve which represents the total rainfall values with respect to the elapsed time.

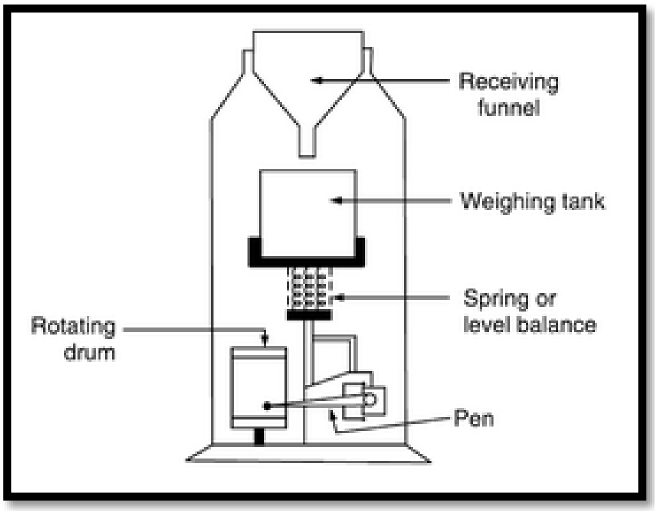


Figure 2.15 Weighing bucket type rain gauge
Source: Dandekar and Sharma (2013)

ii. Tipping Bucket Type Rain Gauge

Tipping bucket type rain gauge consists of 30 cm in diameter of circular rain gauge that attached with a funnel. A pair of tipping buckets is pivoted under this funnel such that when any bucket receives 0.25mm of precipitation.

The bucket’s movement which actuates an electric circuit causing the movement of pen to mark on clock driven revolving drum which carries a recorded sheet. This type of rain gauges is used to record the rainfall intensity.

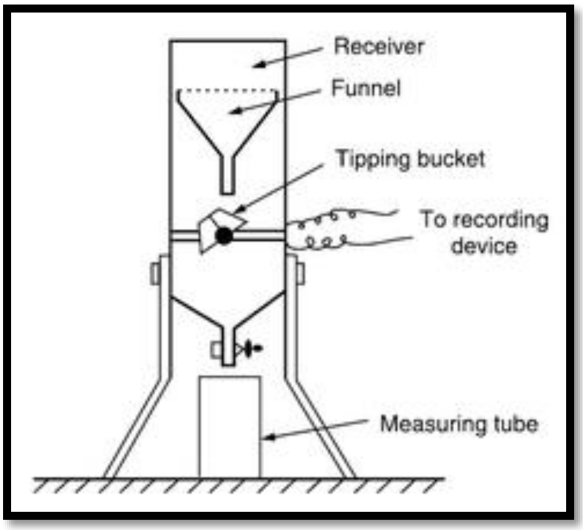


Figure 2.16 Tipping bucket type rain gauge
Source: Dandekar and Sharma (2013)

iii. Floating or Syphon Type Rain Gauge

This type of rain gauge is same work of weighing bucket rain gauge. The rainfall is received by a funnel then delivered into float chamber. The float raises as the water level rises in the chamber. The movement of float is being recorded by a pen moving on a recording drum actuated by a clock-work drum.

When water in the chamber is getting full, the syphon will come into operation and release the water outwards through the connecting pipe, and so all water is drained out. The curve drawn using this data is called mass curve of rain fall.

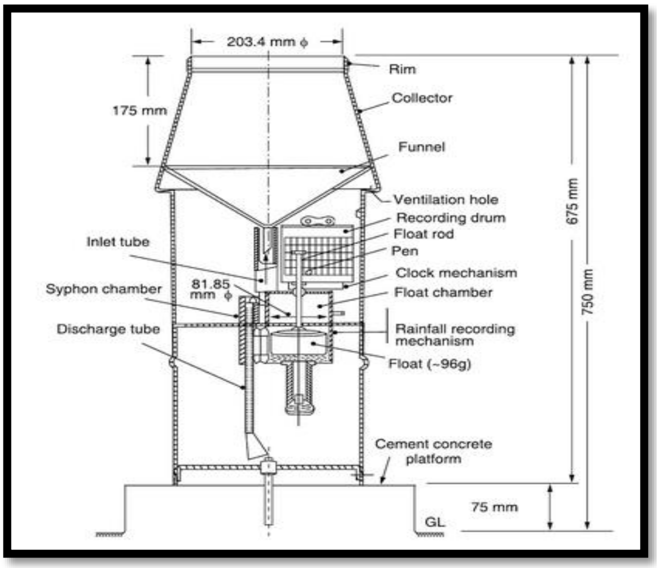


Figure 2.17 Syphon type rain gauge

Source: Dandekar and Sharma (2013)

2.5.3 Automatic Radio-Reporting Rain Gauges

The automatic radio-reporting rain gauges has been developed the India Meteorological Department at Pune, India. Normally, these gauges has been installed at mountainous areas to collect the data of rainfall automatically and controlled by telemetry technique and allocated in real time system. The data is collected by using remote sensors in the real time system. After that, the data is transferred and used almost simultaneously in the computer system for the use of reservoir operation and flood forecasting.

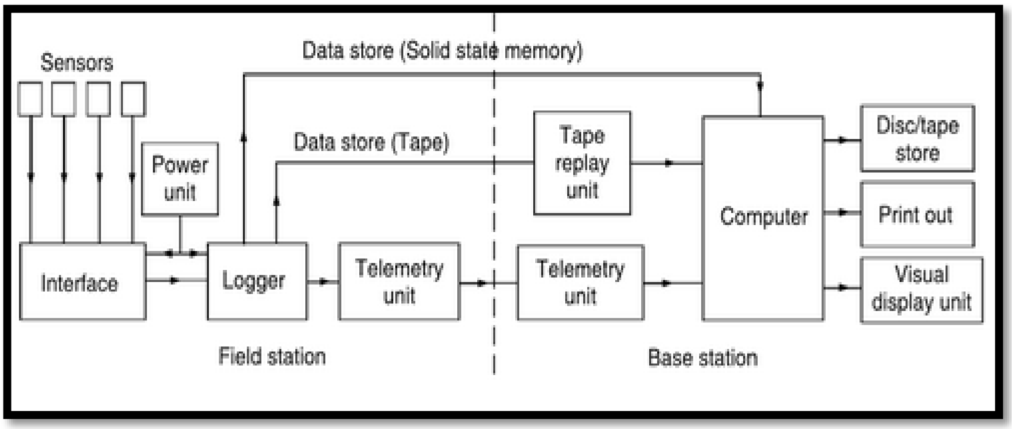


Figure 2.18 Elements of automatic weather station
Source: Dandekar and Sharma (2013)

2.5.4 Radar Observations

Radar is an electronic system that generates electromagnetic waves in the transmitter, radiates them into space via antenna, and then receives the scattered signal returning from the target (Fukao and Hamazu, 2013). Normally, radars are applied in the storm mechanics study, such as areal extent determination, and also in the orientation assessment and rainstorm movement. The rainfall is reflected by radar signals and these are beneficial in storm magnitude determination and its distribution of areal. The range of the radar is of the order of 50 – 60 km.

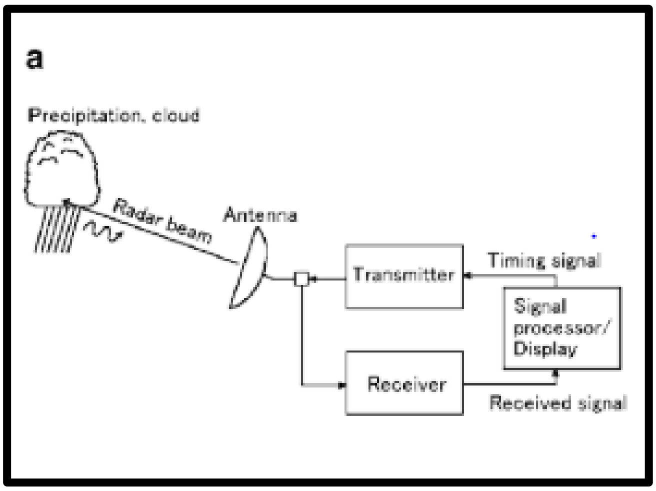


Figure 2.19 Conceptual diagrams of meteorological radar

Source: Fukao and Hamazu (2013)

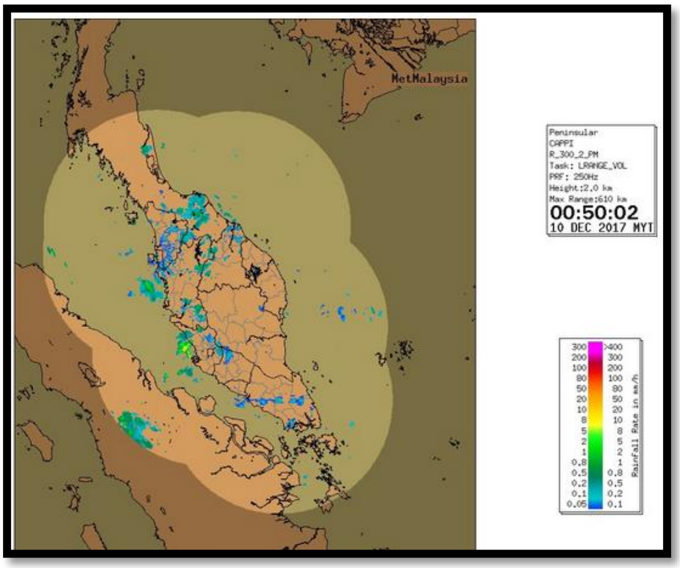


Figure 2.20 Radar Observation in Peninsular Malaysia on 10th December 2017.

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

2.5.5 Satellite Observations

Nowadays, weather satellites have been commonly used in the precipitation assessment and so the large convective storms or frontal storm areas can be simply determined by using the techniques of remote sensing and the imagery of satellite (Dandekar and Sharma, 2013).

In Malaysia, the hydrological network consists of principal and secondary stations. Principal stations are permanent or fixed stations and are equipped with self-recording gauge. Whereas, the secondary stations are short-term or project station which is subjected to review after continuous operation for 5 to 10 years. They are equipped with either manual gauges or self-recording gauges but may have the equal priority to principal stations for data processing and analysis (DID, 2009). Furthermore, the National Weather Centre (NWC) was established on 15 June 1997 and located in the Head Office in Petaling Jaya, Malaysia. The most significant responsibility of NWC is to provide all types of public weather forecasting services for the public and mass media. NWS also issued the severe weather warnings, for instance, thunderstorm warning, heavy rainfall and strong wind warning over land areas.

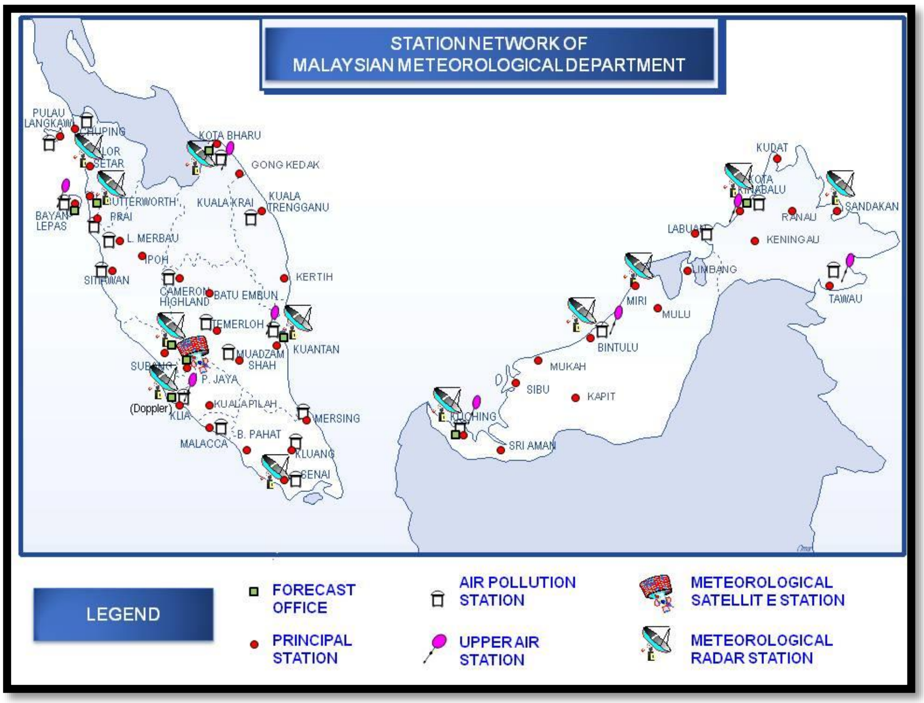


Figure 2.21 Station network of Malaysian Meteorological Department

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

2.6 AREAL ESTIMATION OF PRECIPITATION

Generally, for hydrological analysis, knowledge is required of the areal estimation of precipitation which refers to estimate the total precipitation and its distribution within a basin or watershed. The areal estimation of precipitation is required for various purposes, including, rainfall pattern determination, flood forecasting, hydrology modelling and water resources planning purposes. The following methods are used to estimate the average rainfall over an area:

i. Arithmetic Average

ii. Theissen Polygons

iii. Isohyetal Method

2.6.1 Arithmetic Average Method

This arithmetic average method calculates areal precipitation using the arithmetic mean of all the point or areal measurements considered in the analysis. This method usually measured in the area where provides a satisfactory estimate for a relatively uniform rain. However it is not suitable for mountainous regions or if the rain gauges are no uniformly distributed and the catchment of individual gauge vary widely from the mean.

$$\bar{P} = \frac{1}{n}\sum_{i=1}^{n} P_i \qquad 2.1$$

Where P is average precipitation over the catchment area, n is number of stations, and i is particular number of station.

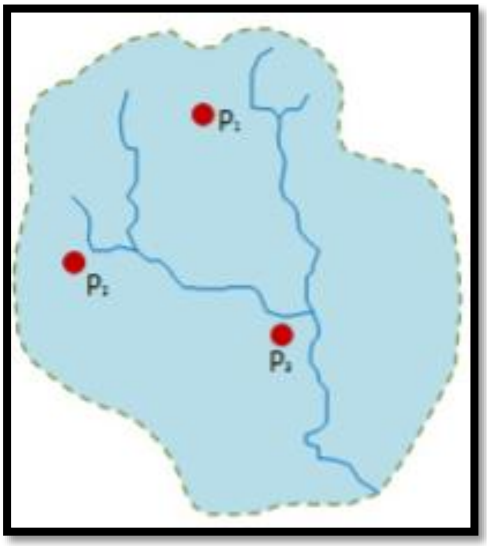


Figure 2.22 Arithmetic average method
Source: http://www.met.gov.my

2.6.2 Theissen Polygons Method

Theissen polygons method is a graphical method that used to calculate the station weights according to the catchment areas of each measurement station in the Theissen polygon network. To obtain the areal average precipitation, individual weights are multiplied by the station observation and then summed up the values. The assumption of this method is that every one of the rain gauge does not obtain the same weight as in the arithmetic method and any point in the basin receives the same amount of rainfall as that measured at the nearest rain gauge station. Hence, for this method, rainfall data which recorded at a gauge can be applied to any point at a distance halfway to the next station in any direction. In this method, the area of influence under each rain gauge station is determined by drawing perpendicular bisectors to the sides of triangles by joining the stations with straight lines to form the polygons (Mishra and Singh, 2003). The following steps are used to form the polygons:

i. Draw lines joining adjacent gages.
ii. Draw perpendicular bisectors to the lines created in step (i).
iii. Extend the lines created in step (ii) in both directions to form representative areas for gages.
iv. Compute representative area for each gage.
v. Compute the areal average by using the following equation:

$$\bar{P} = \frac{1}{A}\sum_{i=1}^{n} A_i P_i \qquad 2.2$$

Where P is average precipitation over the catchment area, n is number of stations, i is particular number of station and A is the catchment area.

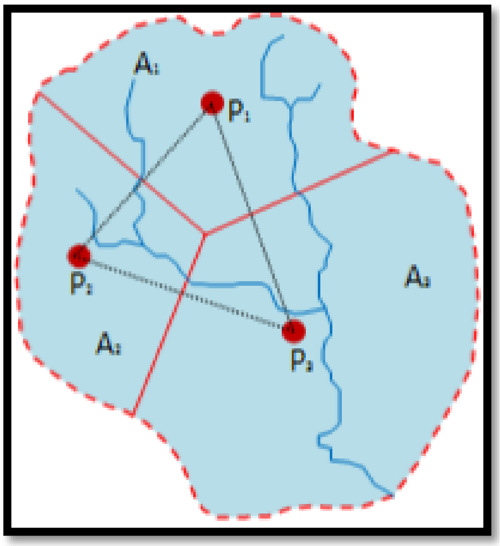


Figure 2.23 Theissen polygons method

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

2.6.3 Isohyetal Method

Isohyetal method is another graphical method that involves drawing estimated lines of equal rainfall over an area based on point measurements. Rainfall data that obtained in the particular period are plotted on the scale map and contours of equal precipitation depth (isohyets) (Mishra and Singh, 2003). The areal rainfall is determined by the average precipitation between isohyets, multiplied by its area and then dividing the sum of these products by the total area. This method can be used for the non-linear distribution and outliers detecting. Although it is least subjective but laborious. Moreover, Isohyetal method is the most accurate method of averaging precipitation over an area when used by an experienced analyst.

$$\bar{P} = \frac{1}{A}\sum_{i=1}^{n} A_i P_i \qquad 2.3$$

Where P is average precipitation over the catchment area, n is number of stations, i is particular number of station and A is the catchment area.

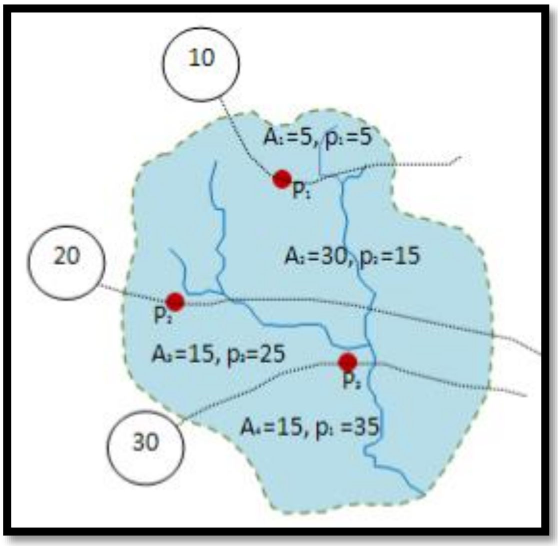


Figure 2.24 Isohyetal method

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

2.7 MONSOON

The broad climate region formed by Malaysia has a tropical climate that is consistently hot, with high and frequent rainfall. Locally, however, the climate is modified by the presence of mountains that may shield some areas from the monsoon winds that bring rain. In general, there are two peaks in the rainfall pattern over the year, with the heaviest rains falling March through May and between September and November.

Generally, monthly and annually precipitations happen throughout Malaysia is greatly affected by the monsoon. The effect of monsoon forming a hydrological cycle depended on the northeast monsoon, the southwest monsoon and two transition periods (Barr *et al.*, 2007). The northeast monsoon winds blow from China and the North Pacific during November through March, bringing moist air and rain. From April through September, the southwest monsoon winds blow from Australia. The dry winds from the Australian deserts produce a mostly dry season from May through September, although Indian Ocean breezes continue to bring some rain. Thence, the Northeast Monsoon influence is relatively stronger and contributes more rainfall over all regions than the Southwest Monsoon (Wong *et al.*, 2016). In addition, April and October form two short transition seasons between the monsoons with light and variable winds and high humidity (Wong *et al.*, 2009) and occurrence of convective rainfall due to high temperature at the lowlands (Tekolla, 2010). During these transition seasons, the west coast is generally wetter than the east coast (Suhaila *et al.*, 2010).

Malaysia is no exception due to its annual experience with flood during the monsoon season. River discharge will increase during monsoon seasons, particularly in Northeast Monsoon Season (Tekolla, 2010). This monsoon season will occur in the East Coast of Pahang state and cause flooding. Thence, flood that occurred on December 2014 was one of the worst floods that ever hit the East Coast of Peninsular Malaysia that consist of Pahang, Terengganu and Kelantan. According to Utusan Online (2014), Pahang major flood started on mid-December and end on mid-January 2015 that provide a lot of precipitation to Pahang River Basin which indirectly caused the overflow of Pahang River, resulted on flood event.

Figure 2.25 Monsoon flood in Kampung Tebing Tinggi, Jerantut, Pahang.
Source: Utusan Online (2014)

2.8 CLIMATE CHANGE

Climate change defines a change in the statistical distribution of weather conditions when that change continue over multiple decades or longer. Consequently, climate used to measure the average pattern of variation in temperature, humidity, atmospheric pressure, wind speed, precipitation and other meteorological variables in a given region over long periods of time (Krishnamurthy, 2017). Nowadays, climate change has been generally acknowledged as the most critical environmental issues that the world will face. The climate of Malaysia is changing in line with global climate change.

Based on previous study, climate in Southeast Asia is changing due to global warming both on global and regional scales (Mayowa *et al.*, 2015). The global warming of the past 50 years is due primarily to human-induced increases in heat-trapping gases. The effect of global warming situation included the changing of precipitation patterns increasing in occurrences of extreme weather events, such as floods, droughts, and rain-storms (Zhang *et al.*, 2008). Extreme floods and droughts can cause economic and ecological damage, and, in the worst cases, risk lives (Suhaila and Jemain, 2012). Human "fingerprints" also have been identified in many other aspects of the climate system, including changes in ocean heat content, precipitation, atmospheric moisture, and Arctic sea ice (13 U.S. government departments and agencies, 2009).

The climate change is predicted that it will influence water resources, public health, agriculture, energy, infrastructure and other sectors. The most significant impact given by climate change is on hydrological events especially in changing rainfall patterns. Human-caused changes in temperature are also expected to change precipitation patterns (Karl *et al.*, 2009). Changing rainfall patterns may face issues on water management with greater fluctuation in water supply over time and space. Besides that, a number of studies forecasted that precipitation will slightly increase during both the rainy and dry season in the coastal regions of the Peninsular Malaysia (Barr *et al.*, 2007). However, the increase in temperature will increase the rate of evaporation of water so that the increase in rainfall will not lead to an increase in the amount of water available for consumption. Subsequently, floods may occur in low areas due to the increasing frequency of extreme precipitation.

According to Intergovernmental Panel on Climate Change (IPCC) (2007), the frequency of heavy precipitation events is projected to increase for most regions during the 21st century and the occurrence of climate change is because of internal processes and external forcing (IPCC, 2007). The external influences include changes in solar radiation and volcanism, occur naturally and contribute to the total natural variability of the climate system. For instance, a decrease in solar activity is thought to have triggered the Little Ice Age between approximately 1650 and 1850, when Greenland was largely cut off by ice from 1410 to the 1720s and glaciers advanced in the Alps (National

Aeronautics and Space Administration, NASA, 2001). Other external changes, such as the change in composition of the atmosphere that began with the industrial revolution, are the result of human activity.

On the other hand, internal processes is present on all time scales. The internal processes are generated by atmospheric processes are known to operate on time scales ranging from essentially instantaneous, such as condensation of water vapour in clouds up to years. Other components of the climate system, such as the ocean and the large ice sheets, tend to operate on longer time scales. These components produce internal processes of their own accord and also integrate variability from the rapidly varying atmosphere (Hasselmann, 1976).

2.9 SPATIAL ANALYSIS

A set of techniques, spatial analysis is used to analyse, compute, visualize, simplify, and theorize the geographic data includes topological, geometric, or geographic properties (Ismail, 2000). The purpose of spatial analysis is to identify pattern, simultaneously, to construct models, if possible by gaining an understanding of process. Several techniques of spatial analysis have been classified into five categories, include measurement, transformations and interpolation methods, descriptive analysis, location optimization, hypothesis testing.

2.9.1 Measurement

Simple numerical values, measurements are describing the geographic data aspects. The measurements consist of the simple properties of objects, for instance, distance, length, shape, area, slope and aspect.

2.9.2 Transformations Methods

This method is a simple method of spatial analysis by using geometric, arithmetic, or logical rules to change data sets. By combining or comparing them, the new data sets can be obtained and finally the new insights formed. Moreover, alternating the vector data to raster data or vice versa and creating fields from collections of objects or detecting collections of objects in fields also can be done by transformations method.

2.9.3 Descriptive Analysis

The purpose of the descriptive analysis is to summarize the information briefly contained in a distribution and compare between point distributions with similar characteristics. Besides that, this method also used to describe the basic features of the data in a study. The methods of descriptive analysis are including Gravity centres, Dispersion, Nearest-neighbour, Spatial Autocorrelation and Fragmentation.

2.9.4 Location Optimization

Location optimization technique is used to choose an optimum location routing, location and allocation for the objects by given some determined specification. This technique is commonly applied in the research of market, industry of package delivery, and other applications.

2.9.5 Hypothesis Testing

Hypothesis testing also known as spatial regression. It is a predictive analysis which used to draw inferences from a sample to population. The generalizations about an entire population from the results of a limited sample also can make by this technique. This technique is more emphasize on the reasoning process. In addition, hypothesis testing also help in identifying the pattern of a point according to the information from a sample.

2.10 INTERPOLATION METHODS

Interpolation methods are commonly used to interpolate point of rainfall data and integrate the areal rainfall data. Missing data and the ungagged site are the common problem that usually occurs in hydrology engineering. Hence, this missing data can be made by spatial interpolation of data obtain from other rain gauge stations. Interpolation techniques are divide of two classification, which are deterministic and geostatistical. Deterministic interpolation methods assign values to locations based on the surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface, such as inverse distance weighted method (IDW) and radial basis function method (RBF). However, geostatistical interpolation methods like Kriging method, are based on statistical models that include autocorrelation which means the statistical relationship among the measured points. Therefore, geostatistical techniques not only can create a prediction surface but also provide some measure of the accuracy and certainty of the predictions (Apaydin *et al.*, 2004).

2.10.1 Inverse Distance Weighted Method (IDW)

The IDW function is applied when the set of point's density is high and the extent of local surface variation needed for analysis is able to be capture. By using a combination set of sample points with the linear-weighed, IDW can used to determine the values of cell. The allocation of weight is a function of the distance of an input point from the output cell location. The increasing of the distance between the cell points, the decreasing of the effect of cell has on the output value.

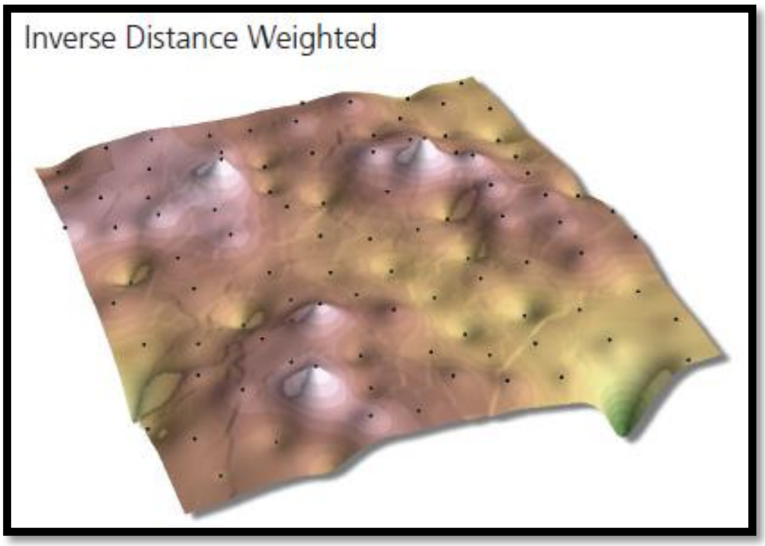


Figure 2.26 Inverse Distance Weighted Method (IDW)
Source: www.esri.com

2.10.2 Spline

Spline is a method used to estimate the values by using a mathematical function which can minimize the entire curvature of surfaces. As a results, a smooth surface is formed which can pass through all the input points accurately. Generally, the surface can be describes as a rubber sheet is bending to pass through all the points. In a meanwhile, the total surface curvature is minimizing. Furthermore, this method also can estimate valleys and ridges in the data. Hence, spline known as the best method to describe the smoothly varying phenomena surfaces.

The variations of spline consist of regularized and tension. The regularized spline is incorporating with three derivative into the calculations of minimization. The first derivative is the slope of the surfaces, second derivatives which represents the rate of change in slope, and third derivative is the rate of change in the second derivative. In the spline calculations, tension spline consists of more points although it use the first and second derivatives only. Normally, the tension spline is creating smoother surfaces than the regularized spline but increasing the time of calculations.

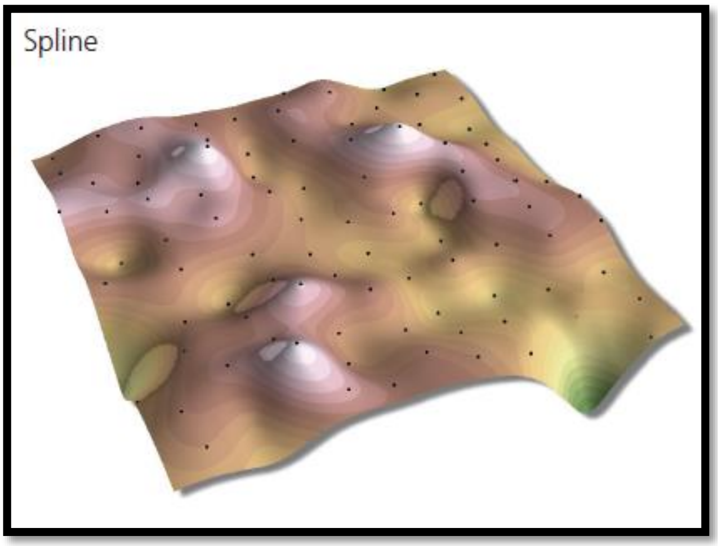


Figure 2.27 Spline
Source: www.esri.com

2.10.3 Kriging

Kriging method is a best method of statistical interpolation which usually used for diverse applications. For example, it is used in the sector of geochemistry, pollution modelling and health science. Conceptually, the assumption made by this method is the direction or distance between sample points which used to reflect a spatial correlation. The spatial correlation is used to explain surface variation. Within a specified radius, a function can be fit into a specified number of points or all points by this method. Eventually, the value of output for each location can be determined. Thence, Kriging is most suitable to be used when the spatially correlated distance or directional bias of the data is determined and is usually used for applications, especially in soil science and geology.

The measure of the relationship in the samples is used to derive the estimated value by using the technique of sophisticated weighted average. This technique is using a search radius which is fixed or variable. The samples range can be exceeded by the generated values of cell, meanwhile, the surface does not pass through samples.

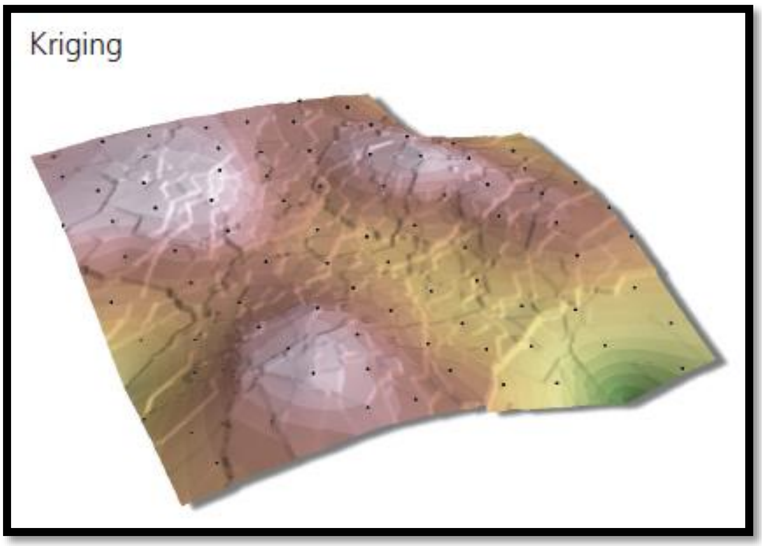


Figure 2.28 Kriging
Source: www.esri.com

2.10.4 PointInterp

Method which similar as IDW, PoinInterp is allowing more control over the neighbourhood of sampling. The influence of a specific sample on the value of interpolated grid cell is according to the sample point whether it is in the neighbourhood of the cell and the distance from the cell being interpolated it is located. The points where located outside the neighbourhood have no influence.

However, inside the neighbourhood, the points' weighed value is calculated using the interpolation of IDW or inverse exponential distance. PoinInterp is interpolating a raster by using the features of point while allowing for different neighbourhoods type. Normally, the neighbourhoods can formed different in shapes like rectangles, circles, irregular polygon, annuluses and wedges.

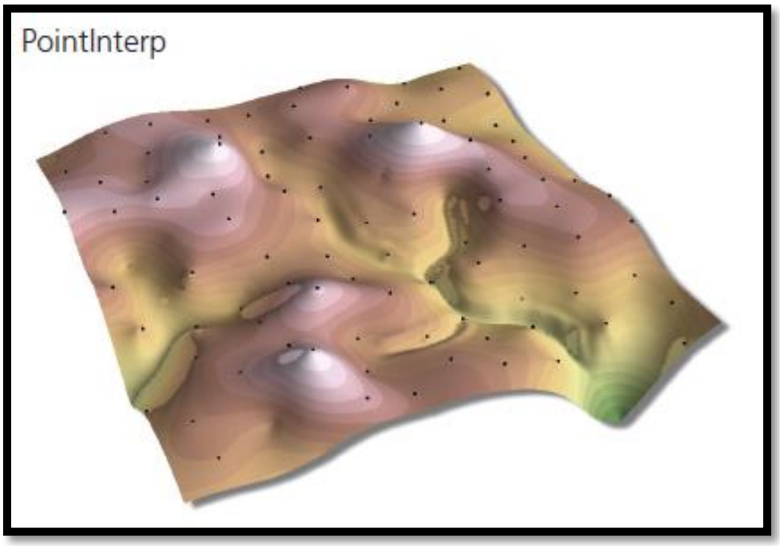


Figure 2.29 PointInterp

Source: www.esri.com

2.10.5 Natural Neighbor

Natural Neighbor is used for both interpolation and extrapolation, and also work for clustered scatter points. This method generally known as the weighted-average method which the basic equation used is similar to the interpolation of IDW. It can handle large datasets of input point efficiently. The local coordinates determine the amount of influence any scatter point will have on the output cells when using this method.

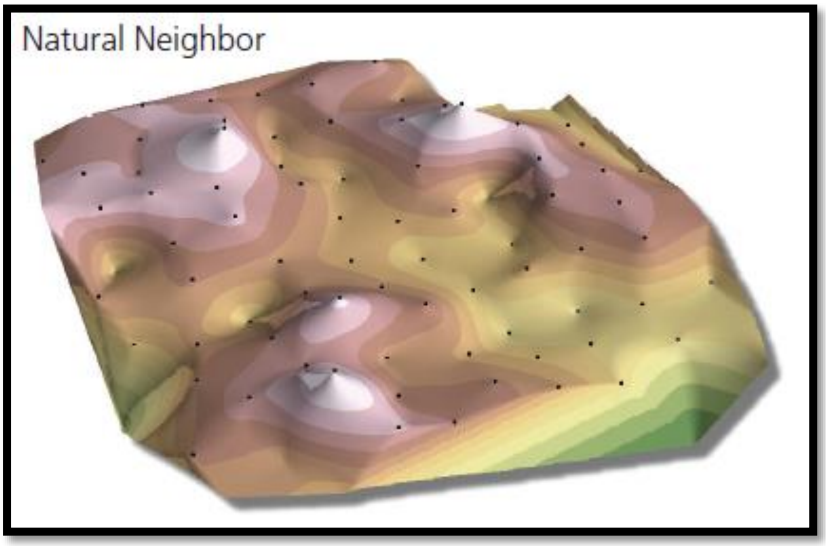


Figure 2.30 Natural Neighbor

Source: www.esri.com

2.10.6 Trend

Least-squares regression fit is used to find the surface that fits the sample points to finds the surface through statistical method, Trend. This method is fit one polynomial equation to the entire surface. This results in a surface that minimizes surface variance in relation to the input values. For every input point, the total differences between the predict values and the actual values such as the variance will be minimize since the surface is constructed. Besides, it can detect the trends of sample data and is similar to natural phenomena which is typically vary smoothly although this method known as the inexact interpolator that the points of inputs is rarely passing through by the resulting surface.

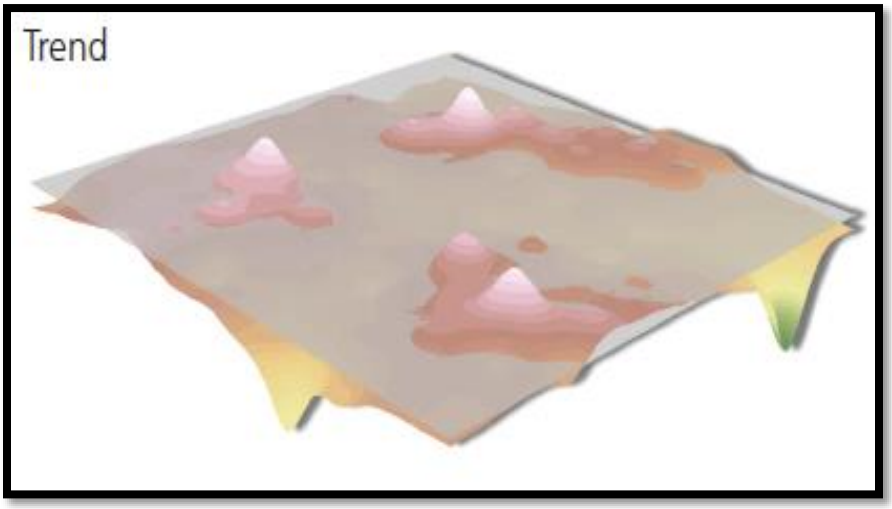


Figure 2.31 Trend

Source: www.esri.com

2.10.7 Radial Basis Functions

Exact interpolation techniques define the surface that interpolates by the method of Radial Basis Functions (RBFs) must pass through each estimated value of sample. This method consists of five different basis functions, Thin-plate spline, Completely regularized spline, Tension spline, Multiquadric function, and Inverse multiquadric function. Each of these basis function has a different shape and can be formed in a different surface of interpolation.

Conceptually, RBFs is similar as a rubber membrane that fits through the estimated values of sample, in a meanwhile the total surface curvature has been minimized. The way of the rubber membrane fits between the values will determined by the selected basis function.

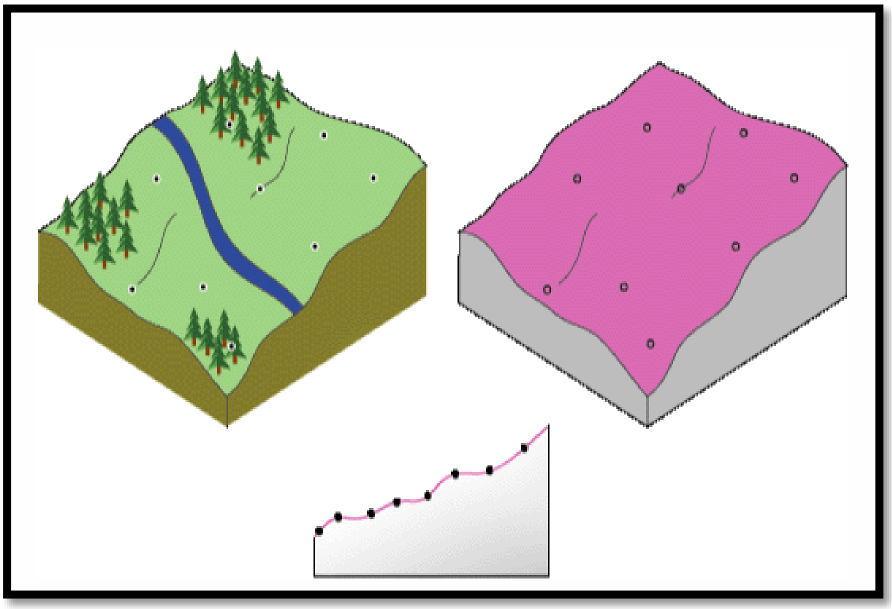


Figure 2.32 Radial Basis Functions (RBFs)

Source: www.esri.com

2.11 RELATED SOFTWARE IN DEVELOPMENT OF ISOHYET MAP

A geographic information system (GIS) can used to visualize, question, analyse, and interpret data for understanding relationships, patterns, and trends. There is numerous of GIS packages and related toolsets which equipped with strong facilities to process and analyse an isohyets map (Smith *et al.*, 2007). There are:

i. ArcGIS 10.5
ii. MATLab
iii. Surfer 8
iv. RiverTools 4.0
v. MapCalc 2.0

2.11.1 ArcGIS 10.5

ArcGIS is a system of geographic information for working with maps and geographic information. In general, tis software is used to create maps, compile geographic data, analyse mapped information, share and discover geographic information, use maps and geographic information in a range of applications, and manage the geographic information in a database.

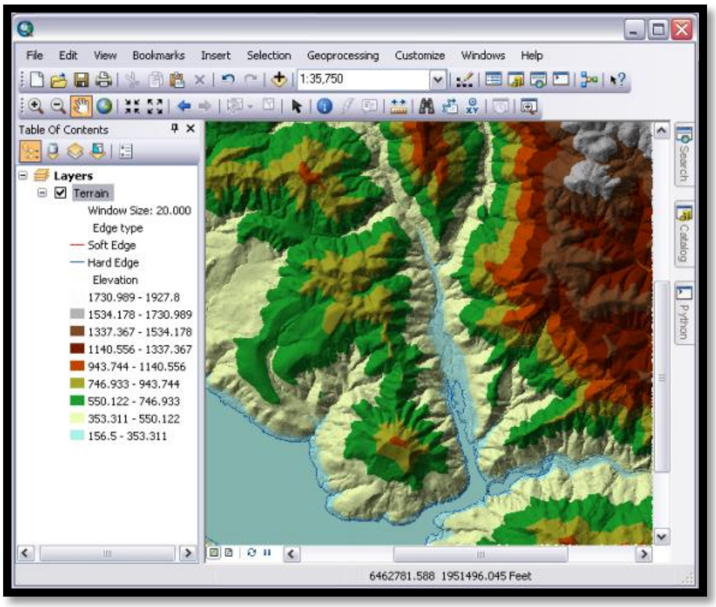


Figure 2.33 Terrain layer in ArcMap

Source: www.desktop.arcgis.com

2.11.2 MATLab

Mapping Toolbox in this program usually is providing algorithms and functions to analyse geographic data and create map. MATLab can combine the geospatial data with the layers of base map from multiple sources in a single map display. Additionally, mapping Toolbox also used to support the 3D data visualization and analysis, for instance, digital terrain, bathymetry, and other gridded-data products. This program also provides a numerous of functions for visualizing the terrain data and adding annotations like the lines of contour.

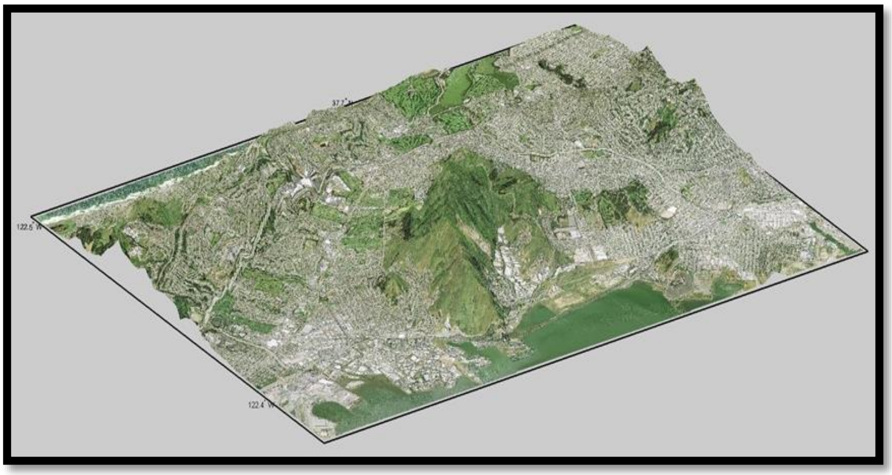


Figure 2.34 A composite 3D map of San Francisco created with functions in Mapping Toolbox.

Source: www.mathworks.com

2.11.3 Surfer 8

Surfer is a program runs under Microsoft Windows for contouring and mapping of 3D surface. This program can convert the data quickly and easily into outstanding results such as contour, surface, wireframe, vector, image, shaded relief, and post maps. Virtually all the maps' aspects are customizing to produce exactly the presentation required. The publication quality maps can be produced in a quicker and easier way.

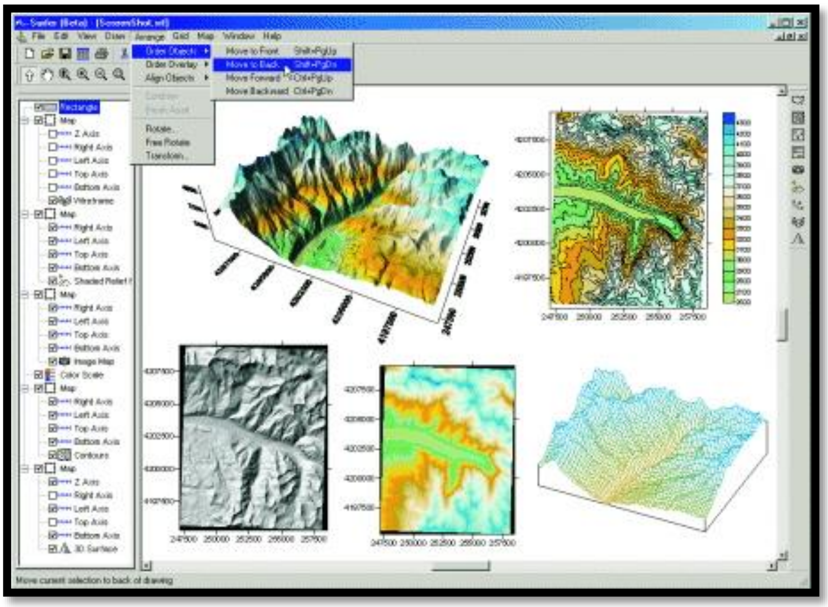


Figure 2.35 Surfer easily creates a multitude of map types to visualize the data.
Source: www.ssg-surfer.com

2.11.4 RiverTools 4.0

A user-friendly GIS application, RiverTools 4.0 can used to analyse and visualize the digital terrain, watersheds and river networks. The most powerful features of this program is it can be able to extract patterns of drainage network and analyse data of hydrologic from very large DEMs (digital elevation models) rapidly. A comprehensive, start-to-finish analysis of a watershed, sub-basin and river network can be performed by this program in a short time. By using the Earth ellipsoid model, it can also provide measurement of river and basin characteristics accurately, for example, upstream area, channel lengths, elevation drops, slope and curvature. This program can make delineate catchment boundaries easier and calculate numerous basin and sub-basin parameters quicker. Finally, it is importing and exporting data from other GIS applications like ESRI's ArcView and with remote sensing, image processing systems like Environment for Visualizing Images (ENVI).

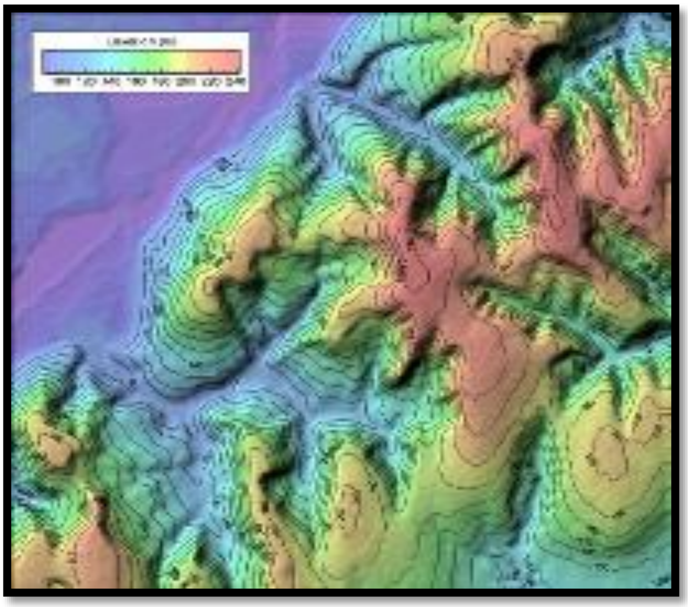


Figure 2.36 Shaded relief with labeled contour line overlay and color bar.
Source: www.rivix.com

2.11.5 MapCalc 2.0

MapCalc 2.0 is a software package with grid-based map analysis. This program is particularly designed to help students for learning the rich range of analysis operations available in the raster domain.

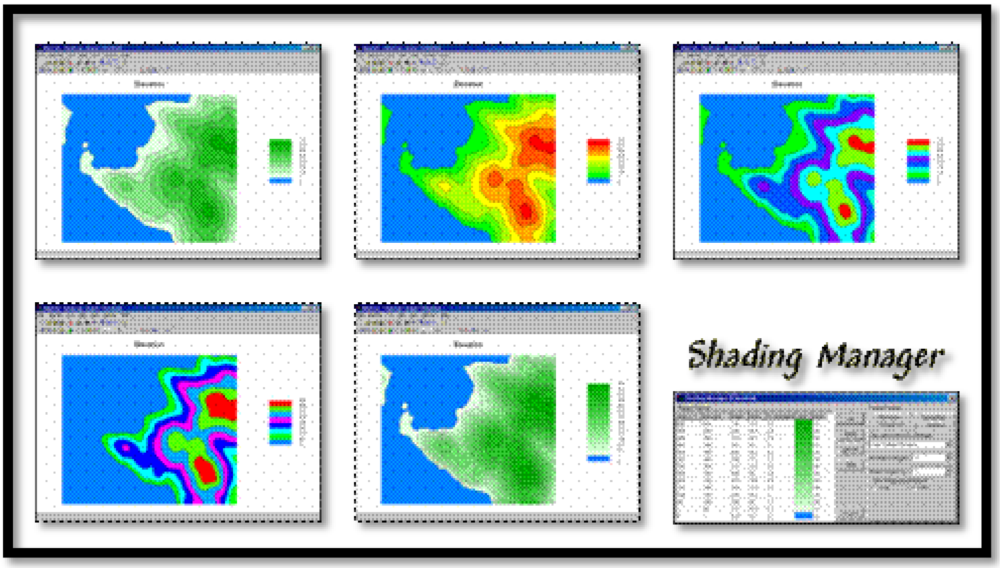


Figure 2.37 Summary of MapCalc Shading Results.
Source: www.innovativegis.com

2.12 CROSS-VALIDATION AND EVALUATION CRITERIA

The cross-validation is one of the most widely used techniques to examine the estimation of different spatial interpolation methods and to determine the accuracy of model predictions in unknown areas. Generally, an independent validation set is used to compare predicted values with real values and to assess the accuracy of predictions. In a cross-validation procedure, one data point is remove from the data sample at a time. An estimated value for this point is interpolated by using all the other data points. This procedure is repeated until a value is estimated for all the original data points (Terry and Goff, 2012).

The validation criteria that commonly used for comparison between the spatial interpolation methods are Mean Relative Error (MRE), Mean Absolute Error (MAE) and Root-Mean-Square Error (RMSE) (Hao and Chang, 2013). The MRE gives an indication whether the model is, on average, producing estimates that are overestimating or underestimating the observed value. However, MAE is used to measure the average magnitude of the errors in a set of predictions. MRE and MAE should be close to zero in a well-adapted model. Furthermore, RMSE is a quadratic scoring rule that used to measure the average precision of the prediction and should be as small as possible. RMSE is useful when large errors are particularly undesirable since it gives a relatively high weight to large errors. Hence, the best-performed model not only will be the one with the smallest value of RMSE and MAE but also obtains MRE that closest to zero (Nadiah *et al.*, 2014). This would suggest that the predictions are impartial and close to the respective real values.

2.13 RELATED STUDIES USING SPATIAL INTERPOLATION METHODS FOR RAINFALL DATA

There are several studies that using spatial interpolation methods not only for analysis rainfall pattern, but also identification of climate change. Besides, comparison between spatial interpolation methods on rainfall data also as a popular topic for the studies. For instances:

i. Variability of rainfall in Peninsular Malaysia
ii. Spatial interpolation of monthly precipitation in Selangor, Malaysia – Comparison and evaluation of methods

iii. Comparison of Spatial Interpolation Methods for Precipitation in Ningxia, China
iv. Analysis and Study on Space Variation Laws of Rainfall of Yuanyang Hani Terrace
v. Cokriging for enhanced spatial interpolation of rainfall in two Australian catchments
vi. Comparison of spatial interpolation methods for rainfall data over Sri Lanka
vii. Comparison on the methods for spatial interpolation of the annual average precipitation in the Loess Plateau region
viii. Comparison of spatial interpolation methods for daily meteorological elements
ix. Assessment Of The Changes Of Climate In Bangladesh Using Geospatial Interpolation Of Climatic Variables
x. Spatial interpolation techniques for climate data in the GAP region in Turkey

2.13.1 Variability of rainfall in Peninsular Malaysia

This study presents the variability of rainfall over Peninsular Malaysia. The authors analysed and quantified the spatial patterns and time-variability of rainfall in Peninsular on monthly, yearly and monsoon temporal scales. The overview of rainfall pattern is obtained from 16 point data sources for this study. The results led to choosing three different regions, such as the east coast, inland and west coast regions. However, the southern and northern regions were not chosen in the study because of a lack in significant monthly and yearly periodical changes in the harmonic analysis during preliminary study. For detailed analysis, Shepard's angular distance weighting interpolation scheme was applied to the station data to produce daily rainfall field on a 0.05 degree resolution grids for the period 1971 till 2006 in Peninsular Malaysia.

The conclusions that can be drawn from this study are the spatial variability of monthly rainfall in the east coast region was the lowest among the three regions. The spatial distribution is more uniform although this region received higher amounts of monthly rainfall. This is attributed to the relatively flat landscape on this region. In the inland region, two rainfall maxima were observed in the monthly periodical changes and the largest spatial variability occurs in February, which is the month with the smallest amount of rainfall. The last region studied was the west coast region, showed a relatively higher interquartile range and the larger spatial rainfall variation in mean monthly rainfall. In short, there was no significant trend found in the rainfall spatial variability of the three different regions in peninsular Malaysia (Wong et al., 2009).

2.13.2 Spatial interpolation of monthly precipitation in Selangor, Malaysia – Comparison and evaluation of methods

For this study, there are 5 GIS-based spatial interpolation methods such as Inverse Distance Weighted (IDW), Local Polynomial Interpolation (LP), Global Polynomial Interpolation (GP), Ordinary Kriging (OK), Universal Kriging (UK) were compare to determine their suitability for estimating mean monthly precipitation,. The rainfall data was obtained at nearly 21 rain gauges in Selangor. This study was constructed in two parts. The first part is the presentation of precipitation network in Selangor while the second part presents the methodological of the analysis and the results obtained from the evaluation method. In this study, the cross-validation method is used to assess which method gives the best interpolation.

The conclusion that can be made from this study is OK and UK are considered as the most optimal methods for interpolating mean monthly precipitation in Selangor. This is due to the Diagnostic Statistic indicated that OK and UK has the smallest Root Mean Square Error (RMSE) and Standardized Root Mean Square Error (SRMSE) (Nadiah *et al.*, 2014).

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

The aim of this study was to find an optimal interpolation scheme for precipitation in Ningxia where located in northwest of China. In this study, six schemes and three models for IDW, GP, LP, Radial Basis Functions (RBFs), Kriging and Cokriging (CK): Cokriging Spherical, Cokriging Exponential, Cokriging Gaussian, , have been used to analyse the annual mean precipitation of 20 years in Ningxia, China after exploring the rainfall data. The cross-validation was used as the criterion to evaluate the accuracy of the methods. In conclusion, the best method that obtained from this study were CK, while the performance of the IDW is the worst. Gaussian model is the best method as compared with three types of model in CK (Hao and Chang, 2013).

2.13.4 Analysis and Study on Space Variation Laws of Rainfall of Yuanyang Hani Terrace

This study was to analyse and research the space variation laws of rainfall of Yuanyang Hani terrace. The monthly average rainfall in this area was measured from 2001 to 2010 of the four typical meteorological sites, included Kakou, Xiaoshujing, Xinjie and 073. The datasets were analysed by using IDW, OK, RBF and the most neighboring method. Lastly, the actual observation data were compared with the analysed results through cross-validation, drawn rainfall isoline maps by utilizing surfer software. In conclusion, the results showed that results of Kriging interpolation method was mostly close to variation laws of actual measured data among the several interpolation methods and Kriging's interpolation effect was the best, second was the RBF interpolation method. Meanwhile, the rainfall of Hani terrace took on strong spatial variability according to the interpolation analysis (Wei *et al.*, 2011).

2.13.5 Cokriging for enhanced spatial interpolation of rainfall in two Australian catchments

In this study, the objective is to evaluate three geostatistical interpolation methods, OK, Ordinary cokriging (OCK), Kriging with an external drift (KED), and two deterministic interpolation methods, IDW and RBF. These interpolation methods were used to enhance spatial interpolation of monthly rainfall in the Middle Yarra River catchment and the Ovens River catchment in Victoria, Australia. The rainfall data used for analysis was obtained from the existing rain gauge stations. In addition, cross validation was assessed for the prediction performances of the adopted interpolation methods. From the result, it's showed that the geostatistical methods perform better than the deterministic methods for spatial interpolation of rainfall. Especially for the OCK method, it is found to be the best interpolator to estimate spatial rainfall distribution in both the catchments with the lowest prediction error between the observed and estimated monthly rainfall. Therefore, this study proved that the use of geostatistical interpolation methods can significantly enhance the estimation of rainfall over a catchment (Adhikary *et al.*, 2017).

2.13.6 Comparison of spatial interpolation methods for rainfall data over Sri Lanka

This study aimed to compare the various interpolation techniques and finalized to estimate the missing or not measured data in precipitation observations. This is because of the network of the precipitation measuring stations is limited in Sri Lanka and the available data are insufficient to characterize the highly variable precipitation and its spatial distribution. For this study, five common interpolation techniques were used for some comparison such as IDW, OK, UK, Spline (S) and Topo to Raster (TR). These techniques also used to assess against monthly total rainfall and annual total rainfall of about 300 rain gauge stations in Sri Lake. The accuracy of each method was assessed by the SRMSE, Mean Absolute Error (MAE) and Goodness of Prediction Measure (G). Quantitative assessment was done and there were considerable differences among the five interpolation methods.

In this study, Kriging interpolation methods have the better performances out of five methods. Furthermore, OK and UK techniques were obtained the minimum SRMSE and MAE values in the error matrices. Overall, the OK and UK techniques consider as the most suitable for spatial interpolation methods of rainfall data over Sri Lanka according to the SRMSE, MAE and G values (Wijemannage *et al.*, 2016).

2.13.7 Comparison on the methods for spatial interpolation of the annual average precipitation in the Loess Plateau region

The datasets of daily precipitation in 57 years (1957-2013) were obtained from 85 meteorological stations in the Loess Plateau region, China. Then, the datasets of this study had been conducted by three different spatial interpolation methods, consist of IDW, OK and RBF to analyse the spatial variation of annual average precipitation regionally. Meanwhile, the MAE, RMSE, the accuracy (AC) and the Pearson correlation coefficient (R) were compared among the interpolation results in order to quantify the effects different interpolation methods on spatial variation of the annual average precipitation. In this study, the MAE and RMSE of the IDW and the RBF showed higher values than the OK. However, the comparison of the four semi-variagram models, such as Circular, Spherical, Exponential and Gaussian for the OK indicated that the circular model had the lowest MAE and the highest accuracy, while the MAE of exponential model was the highest. In conclusion, comparing the validation between the training data and the test results of the different spatial interpolation methods, the circular model of the OK method was the best one for obtaining accurate spatial interpolation of annual average precipitation in the Loess Plateau region (Y *et al.*, 2015).

2.13.8 Comparison of spatial interpolation methods for daily meteorological elements

This study was constructed to evaluate the methods of IDW, CK and thin plate spline (TPS) in interpolating the average meteorological elements which consist of maximum and minimum air temperature, precipitation and sunshine hours. The observation data was obtained at the 15th day per month from 1951-2005 from 559 meteorological stations in China. From the results of the RMSE for the precipitation in winter interpolated by TPS was the smallest, while the RMSE for the precipitation in summer interpolated by IDW was the smallest. The R2 between the observed and predicted precipitation in winter interpolated by CK was the highest. Due the reason that TPS had also the smallest values of RMSEs for the maximum and minimum air temperature and the sunshine hours in a year. Hence, it was suggested that TPS could be the optimal spatial interpolation method in interpolating and rasterizing the daily meteorological elements in China (XJ *et al.*, 2010).

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

For this study, the climate data, included daily maximum and minimum temperature and daily rainfall were obtained from different climate stations of Bangladesh for consecutive years from 1951 till 2010. This study is to determine the most suitable geospatial interpolation technique, such as IDW, Kriging and Local Polynomial interpolation methods, which can be used to monitor the changes in climatic parameters in an efficient way. From the analysis, the Kriging method was found as the most suitable geospatial interpolation method. The monsoon rainfall was observed to be increased and dry season rainfall to be decreased respectively giving the evidence of climate change. In conclusion, the authors recommended that results of the study may assist in selecting the suitable method of interpolation which can be used for analysing the climate variables in Bangladesh among the long range of available tools (Saha and Islam, 2015).

2.13.10 Spatial interpolation techniques for climate data in the GAP region in Turkey

In this study, six spatial interpolation techniques, consisted of IDW, GP, LP, Comletely Regularized Spline (CRS), Kriging and CK with four sub-types, were evaluated to determine the best spatial distribution of six different climate parameters, such as solar radiation, sunshine duration, temperature, relative humidity, wind speed and rainfall. The study area was located in the region of the South-eastern Anatolia Project (GAP) of Turkey. According to the RMSE values of predictions made using measured values from year of 1971 to 1999, simple CK yielded the best results for temperature, solar radiation, relative humidity, wind speed, while completely regularized spline for sunshine duration and rainfall (Apaydin *et al.*, 2004).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The isohyetal method is an alternative method for estimating the mean precipitation over an area by drawing lines of equal precipitation. Isohyet maps are the contour maps of precipitation. Each isohyet indicates the contour line of equal precipitation along its length on a topographic map. In this method, value of precipitation are plotted at the respective rainfall stations on a suitable base map, and isohyets are drawn to create an isohyet map.

Generally, the isohyet maps consider as a most accurate spatial distribution of precipitation. The isohyetal method is widely applied by the agencies of government in numerous countries for areal estimation of precipitation. Thence, the need of having good judgment in drawing the isohyets and in assigning the proper mean rainfall values to the area between them are important to obtain the best results in constructing the isohyet maps.

3.2 FLOW CHART OF THE STUDY

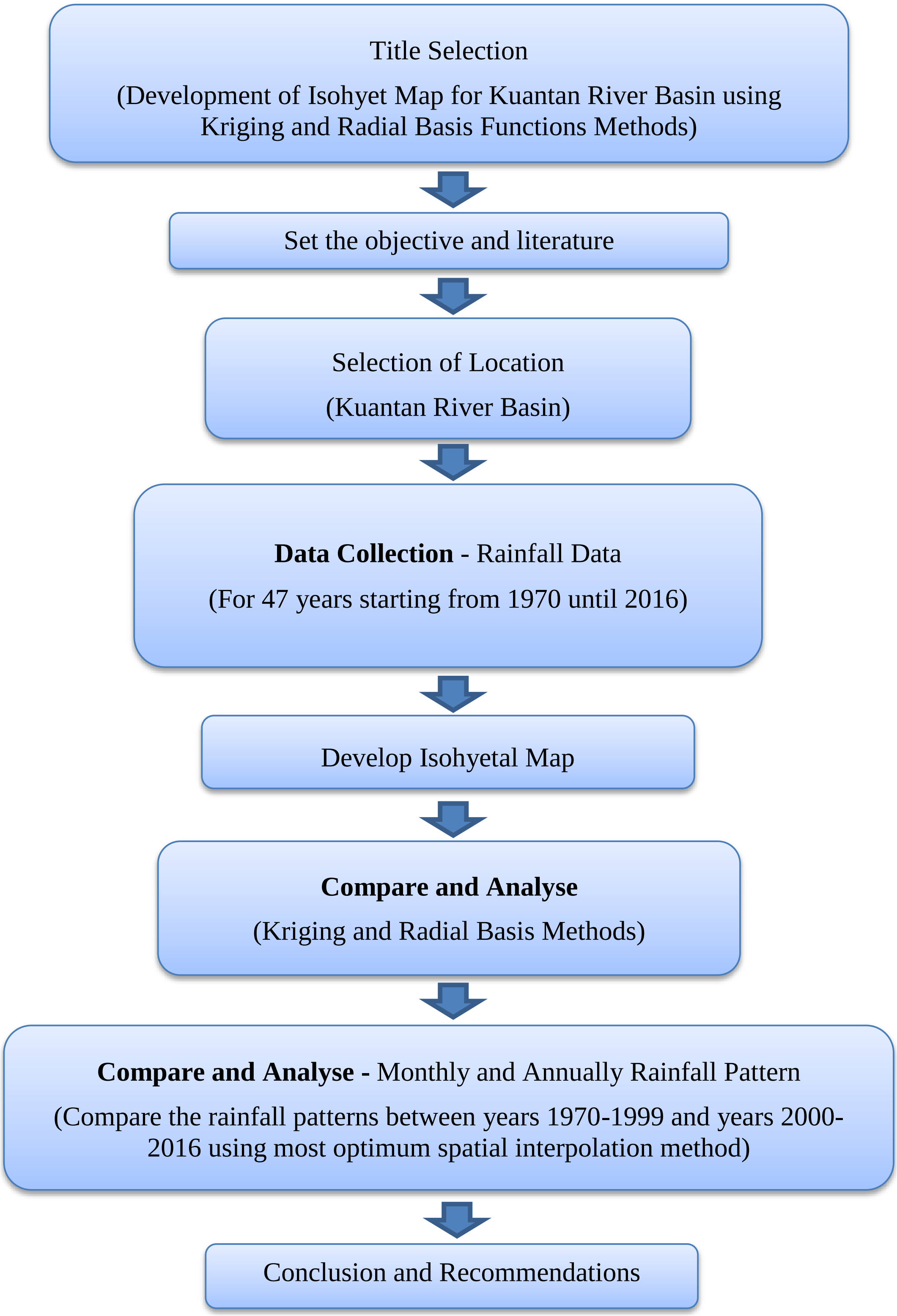


Figure 3.1 Flow chart of the study

3.3 STUDY AREA

The area of the study is Kuantan, the state capital of Pahang, Malaysia. It is located in the east is the South China Sea with a coastline of 56 km (35 miles). In the west are Maran and Jerantut Districts, north is the Terengganu State and in the south is the Pekan District. Kuantan has 6 mukim that are Ulu Kuantan, Ulu Lepar, Kuala Kuantan, Sungai Karang, Beserah and Penur. Furthermore, Kuantan River Basin consists of eight rainfall stations. These rainfall stations are located in JKR. Gambang (station no. 3731018), Paya Besar (station no. 3732020), Kg. Sg. Soi (station no. 3732021), Ranc. Pam Paya Pinang (station no. 3832015), Pej. JPS. N. Pahang (station no. 3833002), Sg. Lembing PCCL Mill (station no. 3930012), Ladang Nada (station no. 3931013) and Ladang Kuala Reman (station no. 3931014). The coordinates of each station refer to Appendix A.

Figure 3.2 Map of Kuantan River Basin

Source: http://pdtkuantan.pahang.gov.my

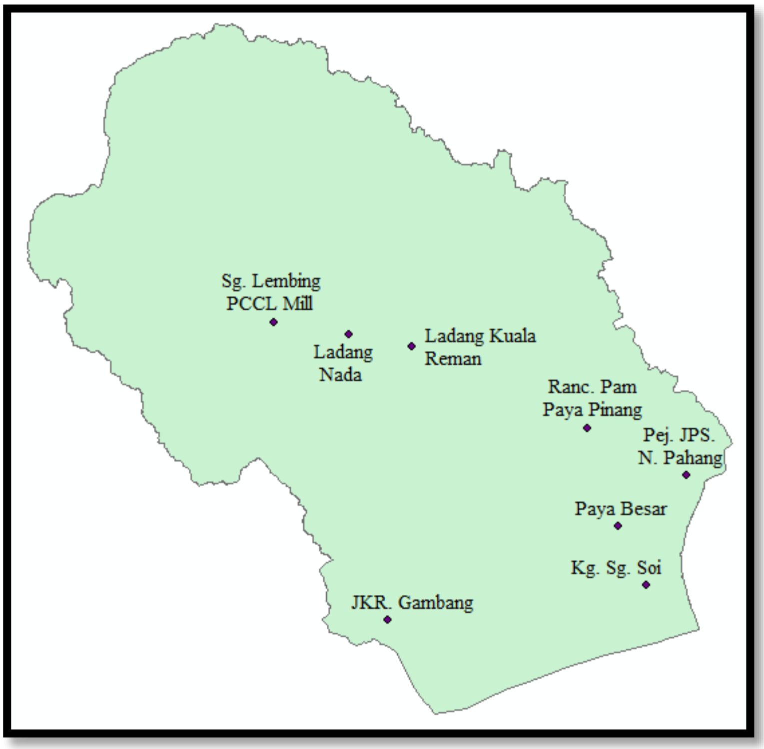


Figure 3.3 Location of rainfall stations

Source: http://pdtkuantan.pahang.gov.my

3.4 DATA COLLECTION

There are two main data used to develop isohyet map:

i. Monthly and Annually Rainfall data

ii. Maps

3.4.1 Rainfall Data

Rainfall Data is obtain from Department of Irrigation and Drainage Malaysia (DID). The data is collected from all the rainfall gauging stations in Kuantan starting from year 1970 until year 2016.

To develop isohyet maps, the missing data that more than 20 percentage in a month will be filtered out and the maximum and the minimum rainfall at every mukim in Kuantan should be extracted from rainfall data. Then, all the monthly and annually data was collected and analysed. Hence, the relationship between rainfall and the elevation were investigated. Kriging and Radial Basis Functions methods is used for isohyets maps development and mean precipitation determination.

3.4.2 Maps

The maps of Kuantan is obtain from Jabatan Ukur dan Pemetaan Malaysia, JUPEM and the map of digitized in Geographical Information System (GIS) to developed an isohyets map of Kuantan River Basin.

3.5 SOFTWARE

Geographic Information Systems (GIS) is a computer system of hardware, software, and people to collect, store, analyse, manipulate, model, visualize, and disseminating information of spatial or geographical data, usually in a map (Ismail, 2000). Generally, GIS applications can use to create interactive queries, analyse spatial information, edit data in maps, and present the results of all these operations.

Besides that, GIS can refer to a number of different technologies, processes, and methods. It is attached to many operations and has many applications related to engineering, planning, management, transport or logistics, insurance, telecommunications, and business. For that reason, GIS and location intelligence applications can be the foundation for many location-enabled services that rely on analysis and visualization.

Nowadays, this application is commonly used in hydrology and to hydrologists in the scientific study and management of water resources. Normally, hydrologists used to generate rainfall patterns in visual formation with a combination of characteristics of rainfall data. Consequently, it can be used to facilitate the process of analysis and forecasting rainfall.

3.6 KRIGING METHOD

Kriging method is one of the geostatistical interpolation techniques that create surfaces incorporating the statistics. In this method, semivariogram plays an important role in the analysis of geostatistical data (Gunarathna *et al.*, 2016). It is not only can used in prediction of surfaces but also error or uncertainty surfaces by taking into account the spatial autocorrelation in data to create mathematical models of spatial correlation structures commonly expressed by variograms. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface.

The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modelling, creating the surface, and exploring a variance surface. Kriging is most appropriate used when there is a spatially correlated distance or directional bias in the data. Kriging weights the surrounding measured values to derive a prediction for an unmeasured location. The general formula for both interpolators is formed as a weighted sum of the data:

$$\widehat{Z}\,(x_0) = \sum_{i=1}^{N} \lambda_i \, z(x_i) \qquad 3.1$$

Where z (x_i) = the measured value at the i^{th} location, λ_i = an unknown weight for the measured value at the i^{th} location, x_0 = the prediction location and N = the number of measured values.

Kriging method is categorized into two different tasks, which are quantifying the spatial structure of the data and producing a prediction. Quantifying the structure also refers as variography, is where to fit a spatial-dependence model to the data. In general, this method uses the fitted model from variography, spatial data configuration and values of the measured sample points around the prediction location to make a prediction for an unknown value for a specific location (Johnston *et al.*, 2001).

There are two commonly used kriging methods, ordinary and universal. Especially, ordinary Kriging (OK) is the most general and widely used of the Kriging methods and is the default (Smith *et al.* , 2018). It assumes the constant mean is unknown. This is a reasonable assumption unless there is a scientific reason to reject it. Hence, ordinary Kriging is used for this study. It uses a geostatistical model of reality and makes the following assumption:

$$\widehat{Z}\,(x) = \mu + z(x), \qquad x \in D \qquad 3.2$$

Where μ is an unknown constant, $z(x)$ is a smooth variation plus measurement error (both zero-mean) and D is the examining area.

Whereas, universal Kriging (UK) assumes that there is an overriding trend in the data. For instance, a prevailing wind and it can be modelled by a deterministic function, a polynomial. This polynomial is subtracted from the original measured points, and the autocorrelation is modelled from the random errors. Once the model is fit to the random errors and before making a prediction, the polynomial is added back to the predictions to give meaningful results. Both of ordinary and universal Kriging can use either semivariograms or covariances, use transformations and remove trends, and allow for measurement error (Earls and Dixon, 2007).

3.7 RADIAL BASIS FUNCTIONS METHOD

Radial Basis Functions (RBFs) method is a deterministic interpolation method that the interpolated surface is forced to conform to the sample data points, and the method does not have standard errors associated with it. It provides a general mathematical tool that is able to identify a continuous surface representing the variable behavior.

RBFs are suitable to use in creating smooth surfaces from a large number of data points. The method produces good results for gently varying surfaces such as elevation. Conceptually, it is similar to bending and stretching the predicted surface so that it passes through all of the shape of the surface between the measured points to produce the surfaces. But, the method is not suitable to apply when there is occurring of large changes in the surface values within short distances and when the sample data is prone to measurement error or uncertainty (Johnston *et al.*, 2001).

In Geostatistical Analyst, RBFs are formed over each data location. A RBFs is a function that changes with distance from a location and predicts values that can vary above the maximum or below the minimum of the measured values. There are five different basis functions, thin-plate spline, spline with tension, completely regularized spline, multiquadric function, and inverse multiquadric function. Each of the RBFs has a parameter that controls the smoothness of the surface to minimise the overall curvature of the surface (Karydas *et al.*, 2009). And also, the RBFs estimator can be viewed as a weighted linear function of distance from grid point to data point plus a bias factor, which is given by:

$$\hat{Z}\ (x_0) = \sum_{i=1}^{N} \lambda_i \varphi\ (\|x_i - x_0\|) + \mu \qquad 3.3$$

Where φ (ρ) is the selected radial basis function, ρ is the radial distance from point x_0 to the i^{th} data point x_i (ρ =$\|x_i - x_0\|$) and λ_i are the weights to be estimated together with the bias value μ (or Lagrangian multiplier). These weights are given by the solution of a system of (n + 1) simultaneous linear equations.

In this study, completely regularized spline is used as the radial basis functions, which is given by:

$$E_1(x) = \int_1^{\infty} \frac{e^{-tx}}{t}\ dt \qquad 3.4$$

Where $E_1(x)$ is the exponential integral function. Completely regularized spline is usually better when the range of sample values may not include the extreme changes of the phenomenon being interpolated and the number of sample values is relatively small. In addition, it can create smooth surfaces with estimated values that may fall well outside the sample data range (Smith *et al.*, 2007).

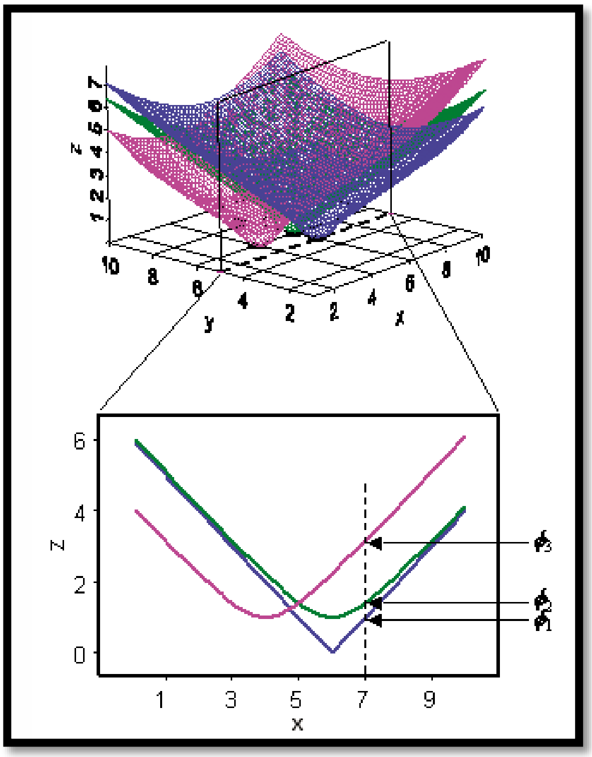


Figure 3.4 RBFs functions for different locations

Source: Johnston *et al.* (2001)

3.8 CROSS-VALIDATION

Commonly, cross-validation is a method used to evaluate the accuracy and performance of interpolation methods. It compares the interpolation methods by removing a known data point from the data sets and estimating the values using the other measured points. Then predicted value at the removed point can be compared with the measured value. This procedure will be carried out for all the measured points. Various evaluation criteria have been used in cross-validation (Hao and Chang, 2013). Two common diagnostic statistics, Mean Absolute Error (MAE) and Root-Mean-Square Error (RMSE), are calculated to assess the accuracy of the interpolation method. MAE estimates the possible range of error estimates while RMSE used to reflect the sensitivity and extremum of estimates by using data of sampling points (Wei *et al.*, 2011). The best interpolation method should yield the smallest MAE and RMSE (Nadiah *et al.*, 2014).

$$MAE = \frac{1}{N}\sum_{i=1}^{n}\left|\hat{Z}_i - Z_i\right| \qquad 3.5$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left(\hat{Z}_i - Z_i\right)^2} \qquad 3.6$$

Where Z_i and $\hat{Z}_i$ are the measured and the estimated value respectively at the rainfall point i (i=1, 2... n); and N is the number of values used for the estimation (Piazza *et al.*, 2015).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter will present the summary of the average monthly and annually rainfall in the form of isohyet maps. The isohyet maps produced from GIS based interpolation techniques (Kriging and Radial Basis Functions methods). Consequently, the accuracy and performance of the spatial interpolation methods also will be evaluated using cross-validation method. After the optimum spatial interpolation method have been selected, the monthly and annually rainfall pattern maps for the impact of climate change over Kuantan River Basin will be discussed.

To determine the average monthly and annually rainfall for Kuantan River Basin, 8 rainfall stations, which are most or less evenly distributed in the basin and with the most extensive data were chosen. In order to analyse the impact climate change over Kuantan River Basin for duration of 47 years, the rainfall data was divided into two time periods, from years 1970 until 1999 and from years 2000 until 2016 by comparing the rainfall patterns.

The precipitation climate in Kuantan is characterized by two rainy seasons associated with the Northeast Monsoon Season from November to March and Southwest Monsoon Season from May to September. Moreover, substantial rainfall also occurs in two transitional periods which normally occur in April and October between the monsoon seasons. During these transition seasons, the west coast is generally wetter than the east coast (Suhaila *et al.*, 2010). In general, the Northeast Monsoon influence is relatively stronger and contributes more rainfall over all regions than the Southwest Monsoon (Wong *et al.*, 2016).

Besides, climate is not only used to measure the average pattern of variation in precipitation, but also in other metrological variables, such as temperature, humidity, atmospheric pressure and wind speed in a given region over long periods of time (Krishnamurthy, 2017). Climate in Southeast Asia is changing due to global warming both on global and regional scales (Mayowa *et al.*, 2015) and one of the effect of global warming is precipitation patterns are forecasted to be change and increase in occurrences of extreme weather events. (Zhang *et al.*, 2008). The most significant impact given by climate change is changing rainfall patterns that precipitation will slightly increase during both the rainy and dry season in the coastal regions of the Peninsular Malaysia (Barr *et al.*, 2007).

4.2 ISOHYET MAPS FOR KUANTAN RIVER BASIN

The isohyet maps generated from ordinary Kriging (OK) and Radial Basis Functions (RBFs) methods were used to visualise the spatial rainfall patterns from years 1970 to 2016 for each 8 stations in Kuantan River Basin. The average rainfall data are recorded in each station (refer Appendix B).

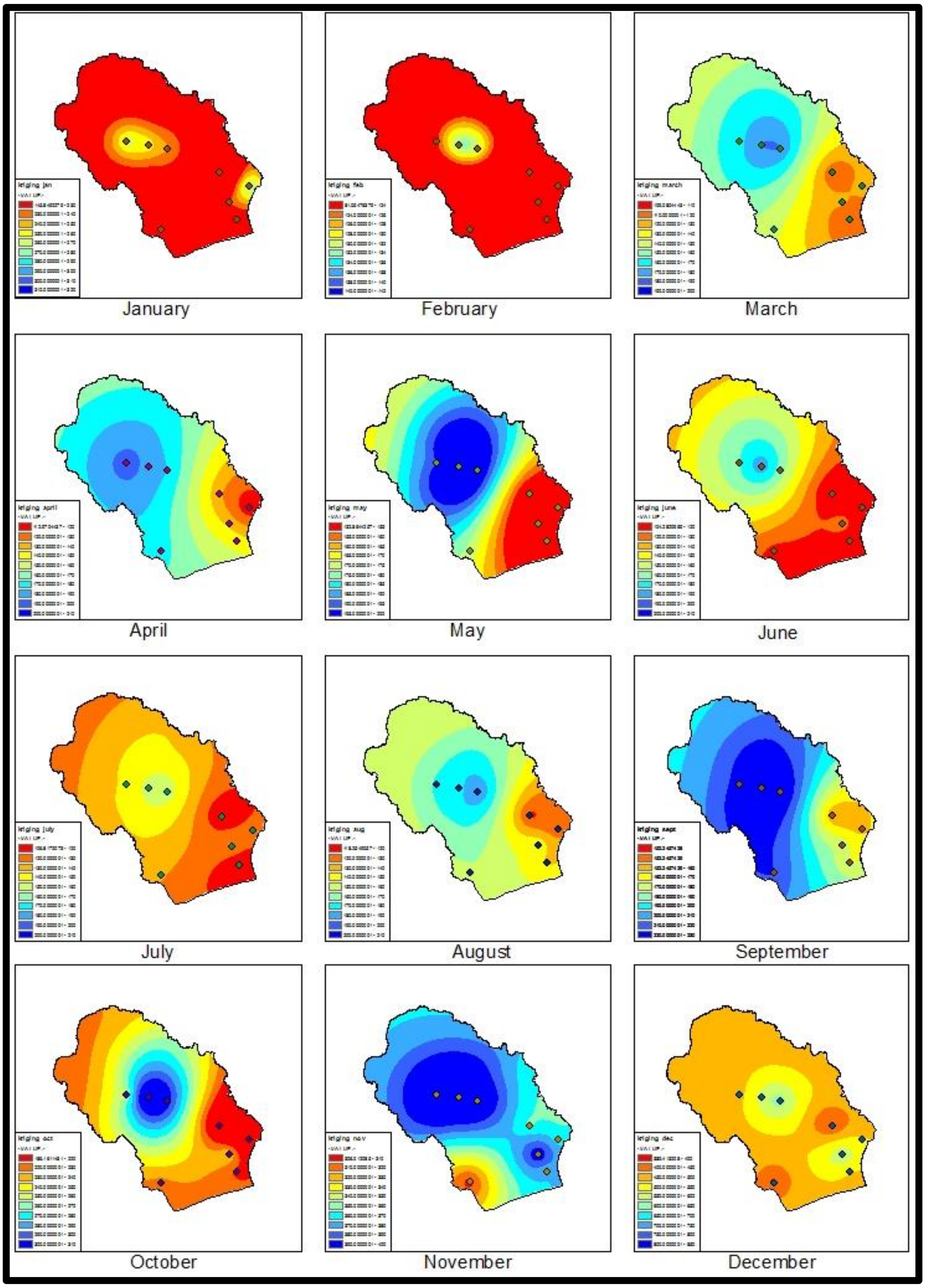


Figure 4.1 Isohyet maps of monthly rainfall (year 1970 until 1999) for Kuantan River Basin using ordinary Kriging (OK) method

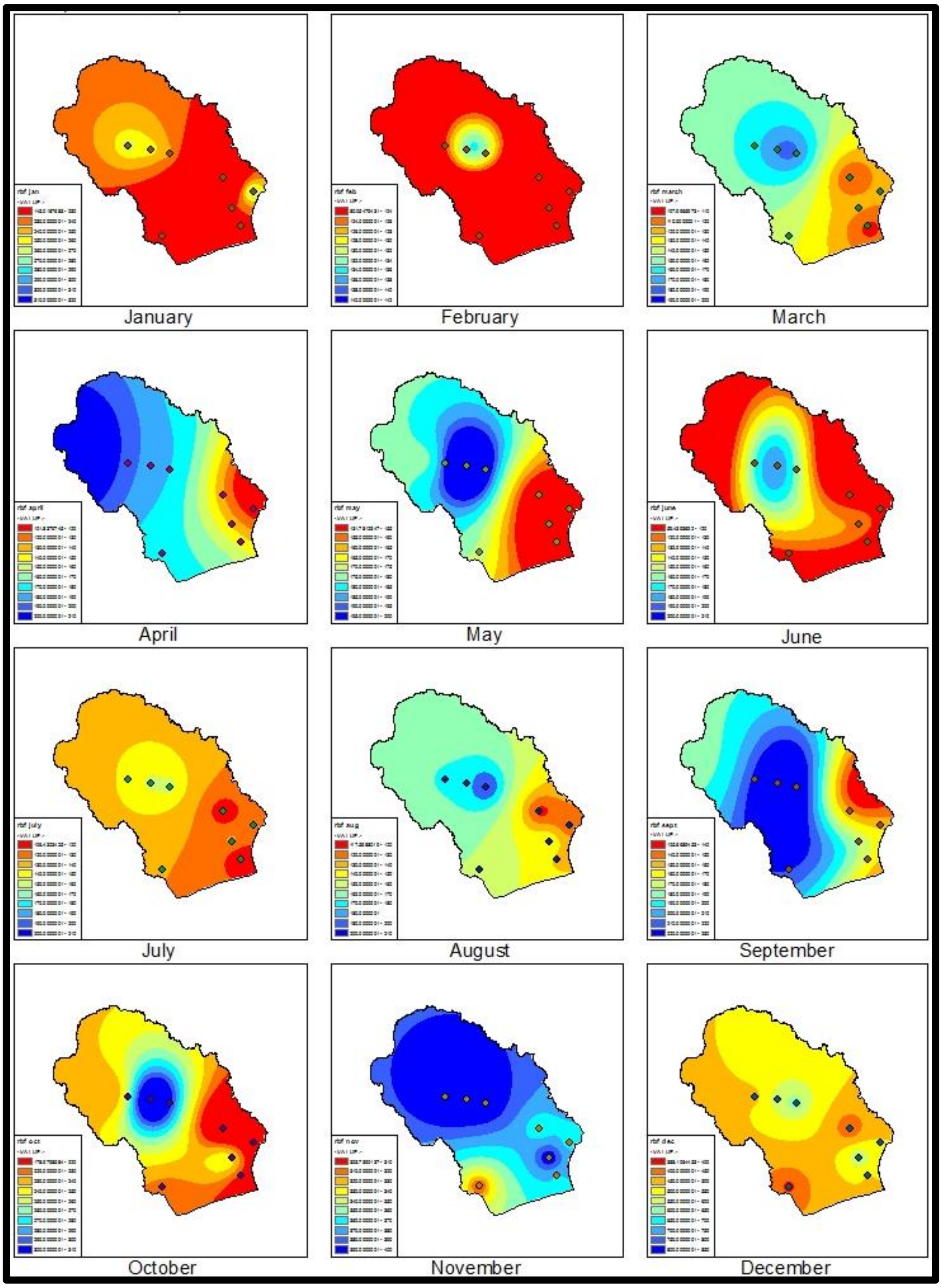


Figure 4.2 Isohyet maps of monthly rainfall (year 1970 until 1999) for Kuantan River Basin using Radial Basis Functions (RBFs) method

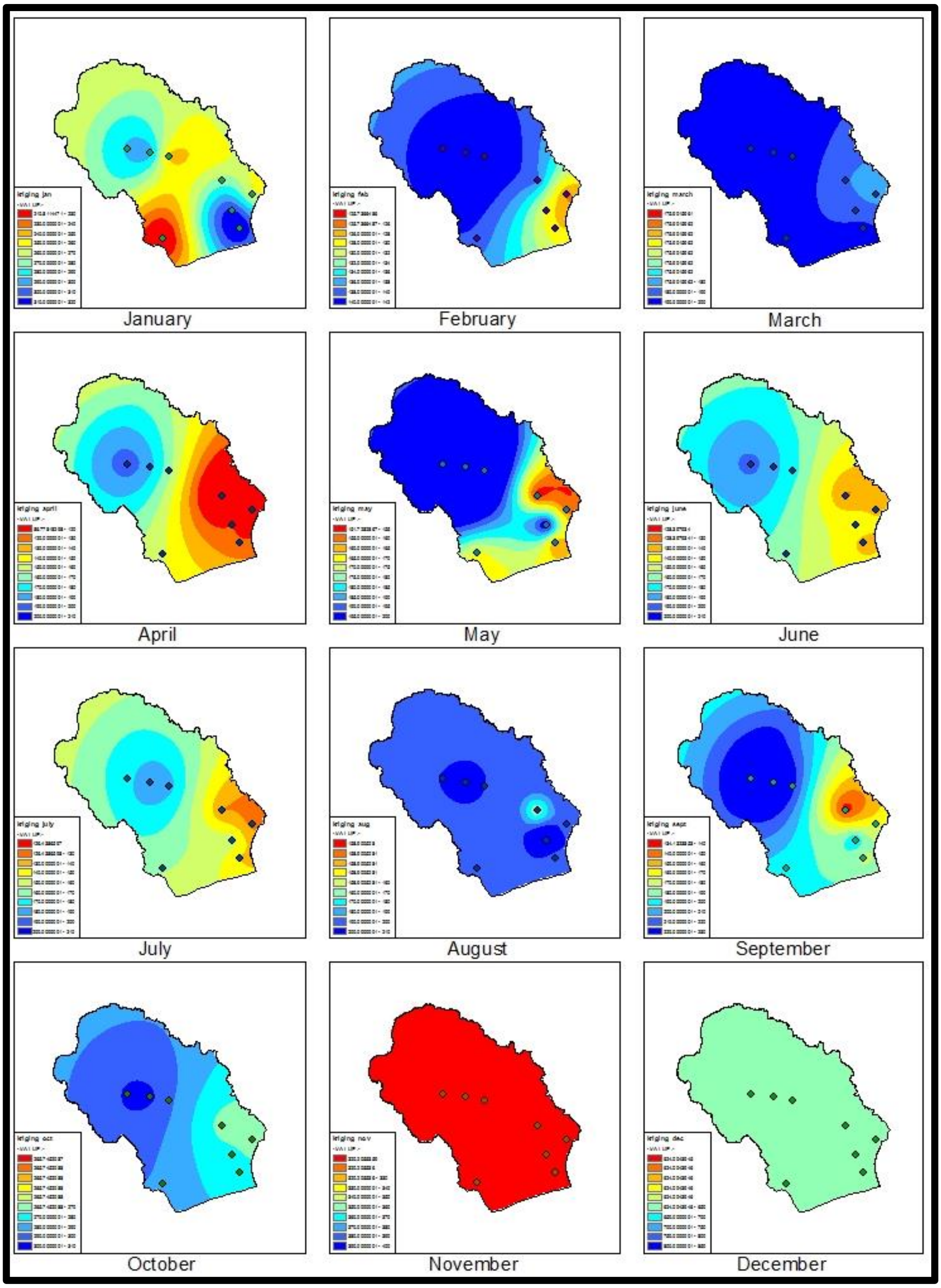


Figure 4.3 Isohyet maps of monthly rainfall (year 2000 until 2016) for Kuantan River Basin using ordinary Kriging (OK) method

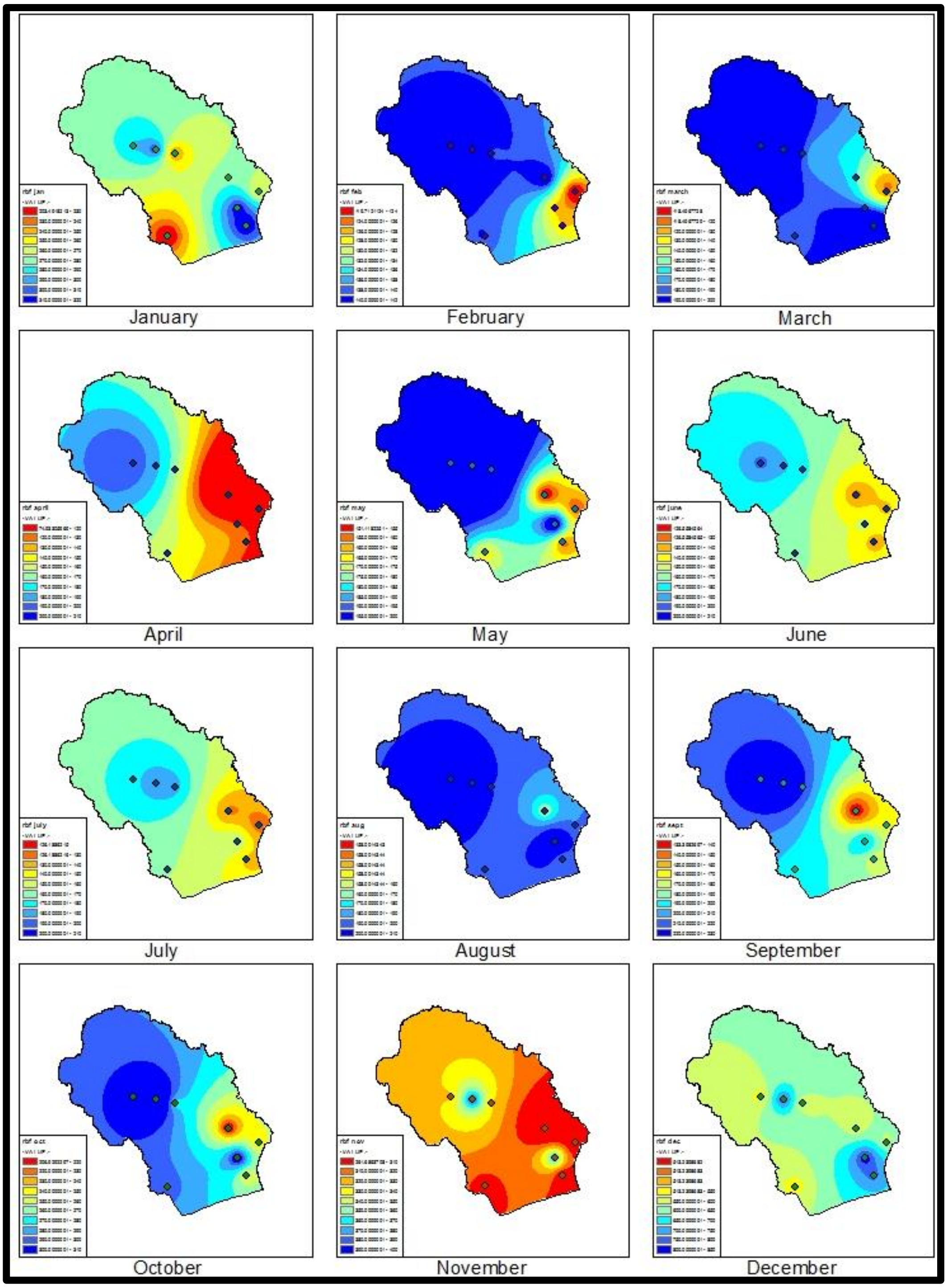


Figure 4.4 Isohyet maps of monthly rainfall (year 2000 until 2016) for Kuantan River Basin using Radial Basis Functions (RBFs) method

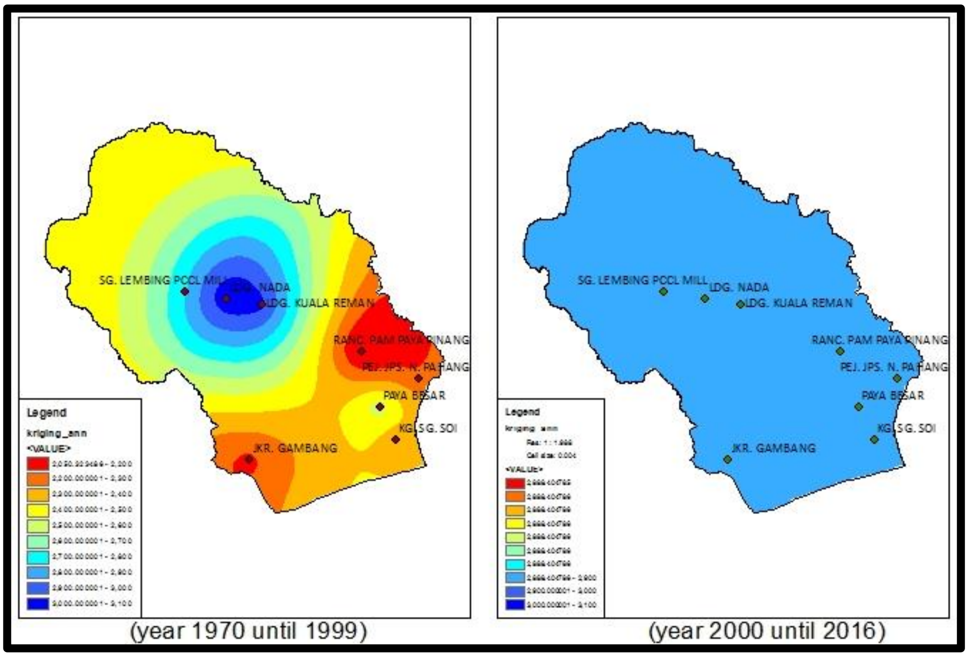


Figure 4.5 Isohyet Maps of annually rainfall from year 1970 until 1999 and from year 2000 until 2016 respectively for Kuantan River Basin using ordinary Kriging (OK) method

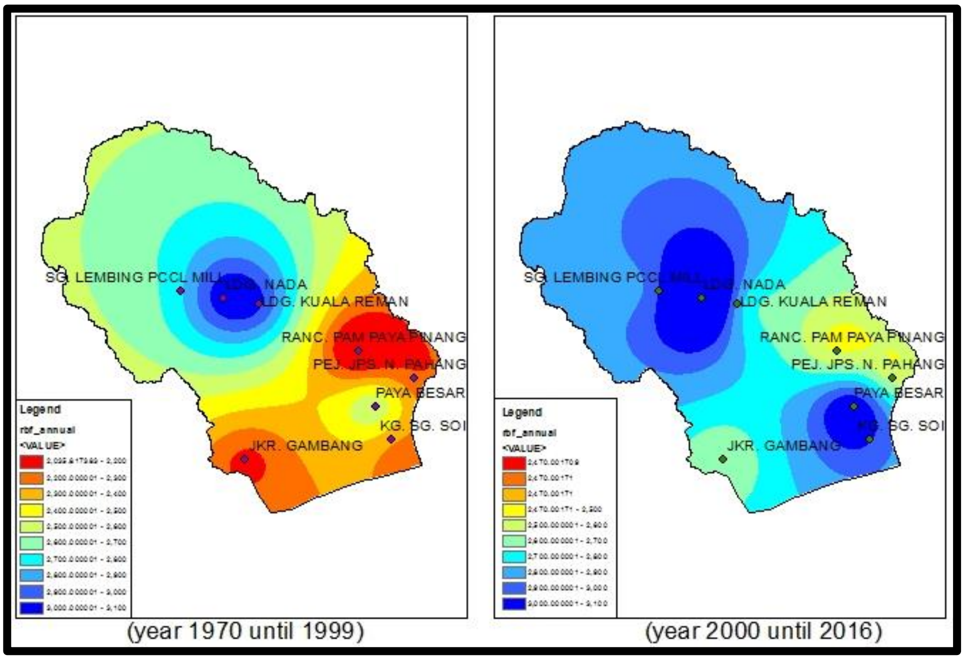
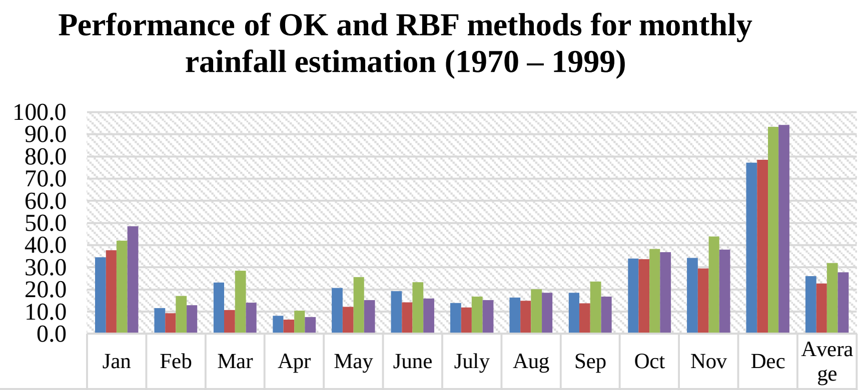


Figure 4.6 Isohyet Maps of annually rainfall from year 1970 until 1999 and from year 2000 until 2016 respectively for Kuantan River Basin using Radial Basis Functions (RBFs) method

4.3 COMPARISON AND VALIDATION OF SPATIAL INTERPOLATION METHOD

In this study, the spatial interpolation methods between ordinary Kriging (OK) and Radial Basis Functions (RBFs) methods will be compared in term of spatial rainfall distributions. Cross-validation was carried out for OK and RBFs with two performance measures including Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) are frequently used to indicate how accurately an interpolator estimates the measured data. An interpolator with smaller values of MAE and RMSE indicate better estimation by the corresponding method. The summary statistics for the interpolation of monthly and annually rainfall estimation shown in Appendix C.

Figure 4.7 presents the graph of different performance measures of the adopted spatial interpolation methods (OK and RBFs) for estimating monthly rainfall from year 1970 to 1999 over the study area. As can be seen from the table, RBFs performs better than OK in overall. The average MAE values for OK and RBFs methods are 25.97 mm and 22.74 mm respectively, while the average RMSE values are 31.92 mm and 27.80 mm respectively.

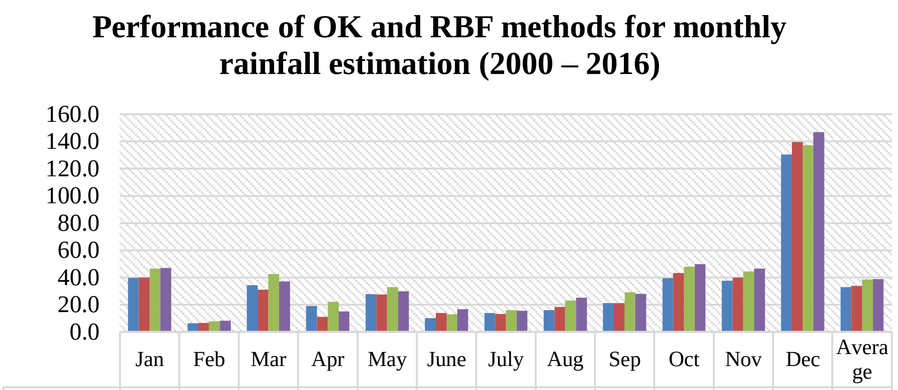


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Avera ge
mae OK	34.6	11.6	23.2	8.1	20.8	19.3	13.9	16.3	18.6	34.0	34.3	77.2	25.97
mae RBF	37.7	9.4	10.7	6.5	12.1	14.2	11.9	14.9	13.8	33.7	29.5	78.5	22.74
rmse OK	42.0	17.1	28.4	10.5	25.7	23.3	16.8	20.1	23.6	38.2	44.0	93.4	31.92
rmse RBF	48.5	12.9	14.0	7.5	15.2	15.9	15.2	18.6	16.8	36.9	38.0	94.2	27.80

Figure 4.7 Performance of different interpolation (OK and RBF) methods for monthly rainfall estimation (1970 – 1999).

Figure 4.8 show the graph of performances of OK and RBFs methods are be matched in strength for year 2000 until 2016. The average MAE values for OK and RBFs methods are 33.02 mm and 33.83 mm respectively, while the average RMSE values are

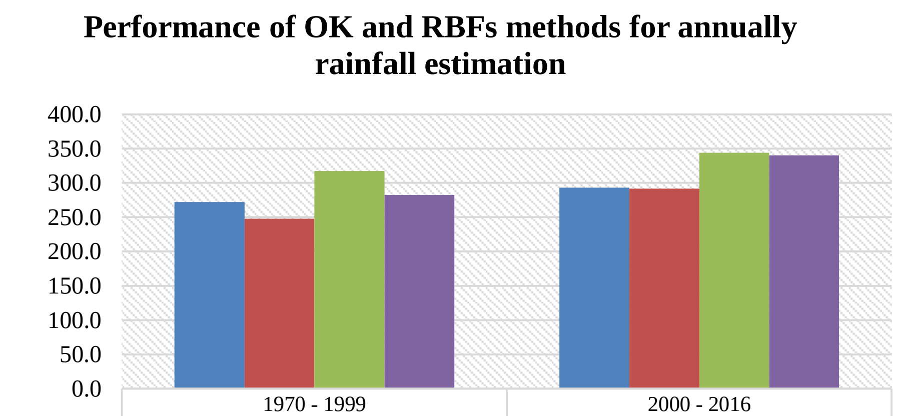
38.58 mm and 38.86 mm respectively. Hence, OK performs slightly better than RBFs for year 2000 until 2016 over the study area.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
mae OK	39.9	6.5	34.2	19.2	27.8	10.2	13.8	16.0	21.2	39.4	37.7	130.4	33.02
mae RBF	40.0	6.7	31.1	11.1	27.5	14.0	13.1	18.4	21.1	43.3	40.1	139.6	33.83
rmse OK	46.5	7.8	42.6	22.1	33.0	13.0	16.1	23.0	29.3	47.9	44.5	137.2	38.58
rmse RBF	47.1	8.4	37.1	15.1	29.9	16.6	15.6	25.1	28.0	49.9	46.6	146.8	38.86

Figure 4.8 Performance of different interpolation (OK and RBF) methods for monthly rainfall estimation (2000 – 2016).

Figure 4.9 shows the graph of performances of OK and RBFs methods for annually rainfall estimation. In this part of evaluation, RBFs method obtains smaller values for both MAE and RMSE than OK method in year 1970 – 1999 and year 2000 – 2016.



	1970 - 1999	2000 - 2016
mae OK	272.2	292.8
mae RBF	247.9	291.7
rmse OK	317.4	343.7
rmse RBF	282.3	340.3

Figure 4.9 Performance of different interpolation (OK and RBFs) methods for annually rainfall estimation.

In short, the RBFs method gives the best results for rainfall estimations in overall over the study area for most of the months and years when considering all the performance measures. This result agrees with the findings by Apaydin et al. (2004) and Piazza et al. (2015). RBFs (completely regularized spline) was especially successful for rainfall interpolation. Therefore, the RBFs method is selected as the most optimum spatial interpolation method for rainfall distribution in Kuantan River Basin and it is used to generate a continuous rainfall dataset of the monthly and annually average rainfall pattern maps.

4.4 COMPARISON OF MONTHLY RAINFALL PATTERN

Figure 4.10 shows the average monthly rainfall for January from years 1970 to 1999 and from years 2000 to 2016 respectively.

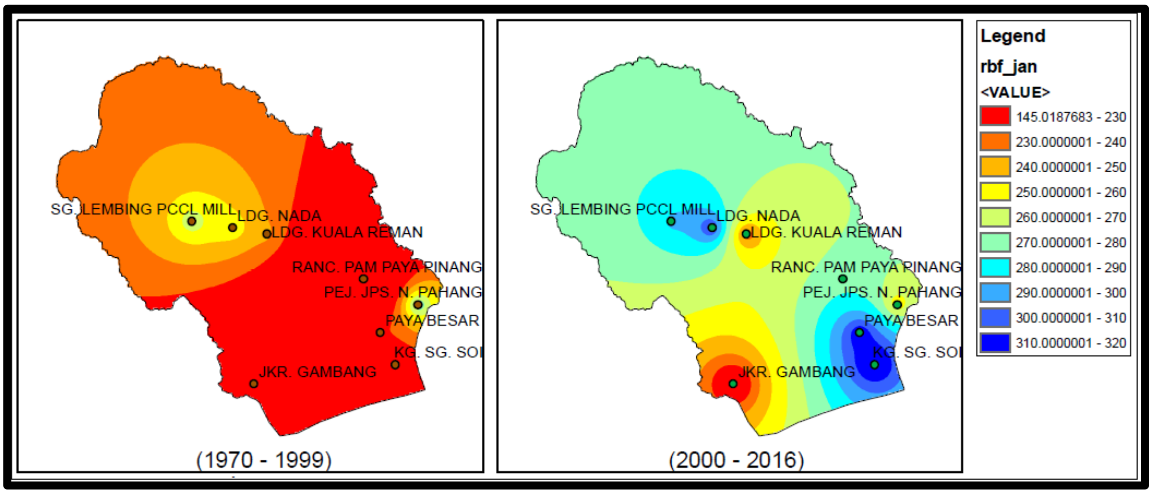


Figure 4.10 Average monthly rainfall for January

From years 1970 to 1999, the maximum average value was obtained at station Pej. JPS. N. Pahang with average value recorded is 274.25 mm while the minimum average value was obtained at station Ranc. Pam Paya Pinang with average value 145.11 mm. In contrast, average value at station Kg. Sg. Soi, 331.20 mm, which was the highest average value whereas the lowest average value obtained by station JKR. Gambang, 203.46 mm from years 2000 until 2016. The amount of precipitation received during this month is much higher than the other months due to the areas is facing Northeast Monsoon, which bring heavy precipitation and contribute more total rainfall depth in East Coast region of Peninsular Malaysia. Obviously, the maps show that Kuantan River Basin receives higher precipitation after year 2000 especially in eastern and highland area.

Figure 4.11 shows the average monthly rainfall for February from years 1970 to 1999 and from years 2000 to 2016 respectively.

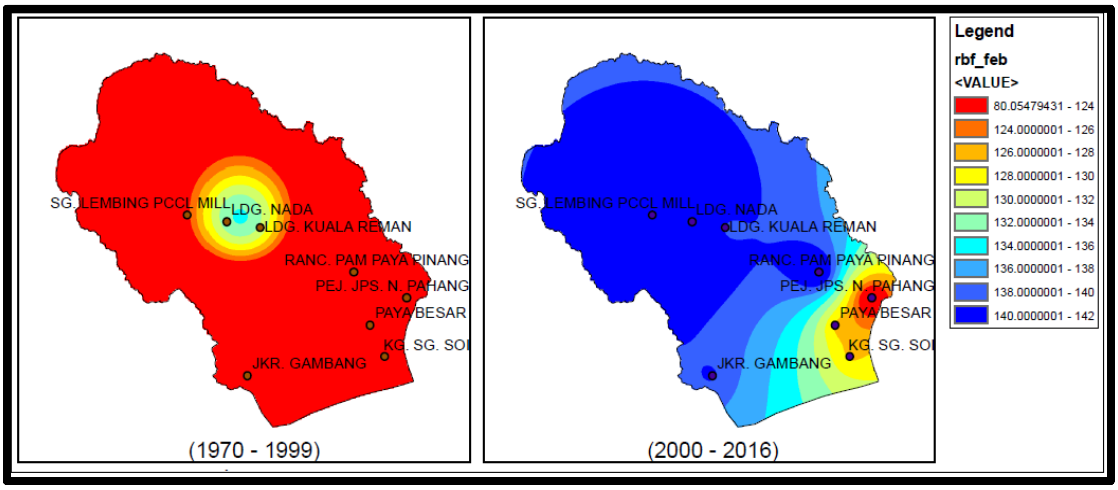


Figure 4.11 Average monthly rainfall for February

In February, Ldg. Nada obtained the maximum average values for years 1970 until 1999 and years 2000 until 2016 with average values recorded 133.24 mm and 150.73 mm respectively. However, the minimum average value from years 1970 to 1999 was obtained at station JKR. Gambang with average value 81.00 mm while the lowest average value from years 2000 until 2016 was obtained by station Pej. JPS. N. Pahang, 119.78 mm. Kuantan experienced hot and dry conditions in this month due to the area was encroaching towards the end of Northeast Monsoon Season. But, as can be seen from the map, the areal extent of higher precipitation had been increased after year 2000.

Figure 4.12 shows the average monthly rainfall for March from years 1970 to 1999 and from years 2000 to 2016 respectively.

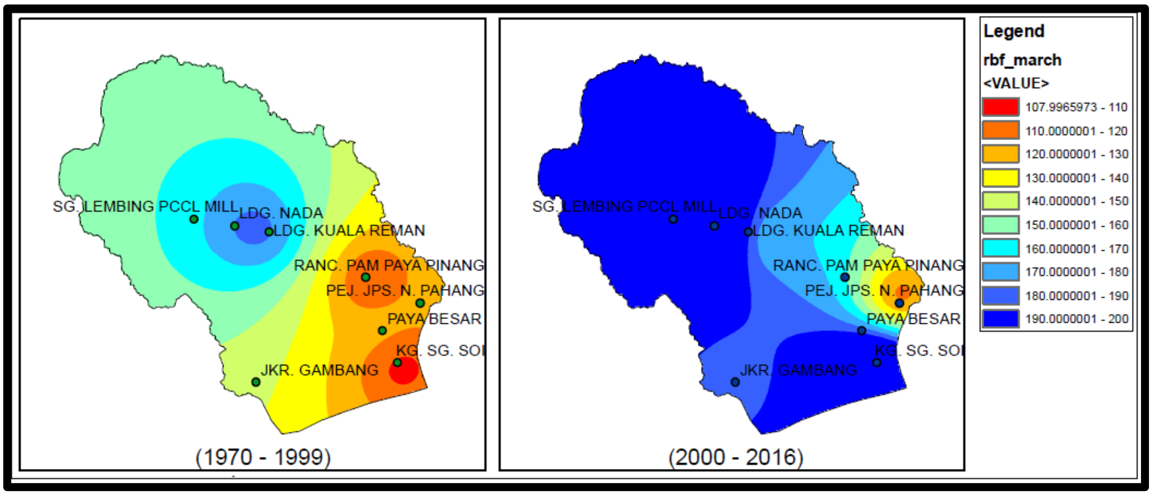


Figure 4.12 Average monthly rainfall for March

From years 1970 to 1999, the maximum average value was obtained at station Ldg. Kuala Reman with average value recorded is 180.43 mm while the minimum average value was obtained at station Kg. Sg. Soi with average value 108.93 mm. On the contrary, average value at station Ldg. Nada, 243.23 mm, which was the highest average value whereas the lowest average value obtained by station Pej. JPS. N. Pahang, 122.06 mm from years 2000 until 2016. March is the month of the final phase of Northeast Monsoon. Compared to the year before 2000, most of the areas received higher precipitation from years 2000 to 2016.

Figure 4.13 shows the average monthly rainfall for April from years 1970 to 1999 and from years 2000 to 2016 respectively.

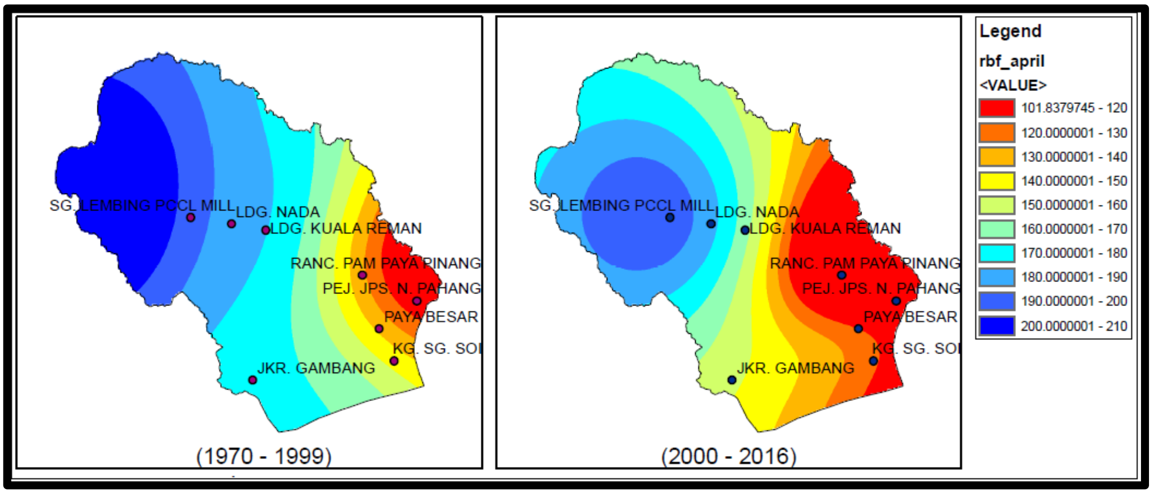


Figure 4.13 Average monthly rainfall for April

From years 1970 to 1999, the maximum average value was obtained at station Sg. Lembing PCCL Mill with average value recorded is 195.24 mm while the minimum average value was obtained at station Pej. JPS. N. Pahang with average value 112.74 mm. In contrast, average value at station Sg. Lembing PCCL Mill, 196.39 mm, which was the highest average value whereas the lowest average value obtained by station Ranc. Pam Paya Pinang, 86.50 mm from years 2000 until 2016. In April, a short transition season will form between the Northeast and Southwest monsoons with light and variable winds and high humidity. Although, most of the areas received lower amount of precipitation after year 2000, the difference of rainfall depth between two time periods is lower than other months. This is one of the months which the total rainfall depth was decreased after year 2000.

Figure 4.14 shows the average monthly rainfall for May from years 1970 to 1999 and from years 2000 to 2016 respectively.

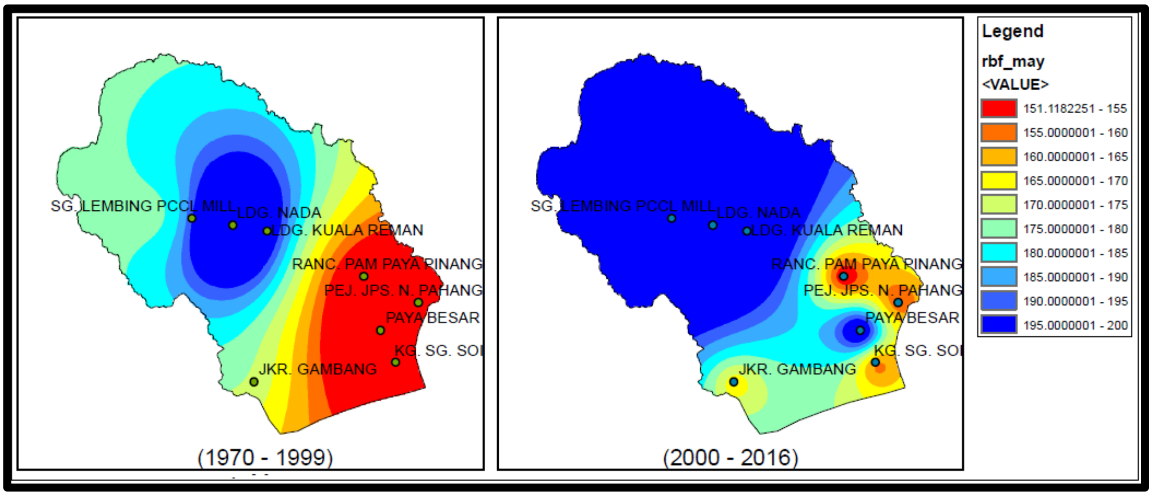


Figure 4.14 Average monthly rainfall for May

In May, Ldg. Nada obtained the highest average values for both years 1970 until 1999 and years 2000 until 2016 with average values recorded 230.15 mm and 257.13 mm respectively. In opposite, the minimum average value from years 1970 to 1999 was obtained at station Paya Besar with average value 132.88 mm while the lowest average value from years 2000 until 2016 was obtained by station Ranc. Pam Paya Pinang, 151.43 mm. Southwest Monsoon Season is starting in the month of May which the dry winds blow from Australian will produce a mostly dry season. The precipitation received from years 2000 to 2016 is slightly higher than the year from 1970 to 1999.

Figure 4.15 shows the average monthly rainfall for June from years 1970 to 1999 and from years 2000 to 2016 respectively.

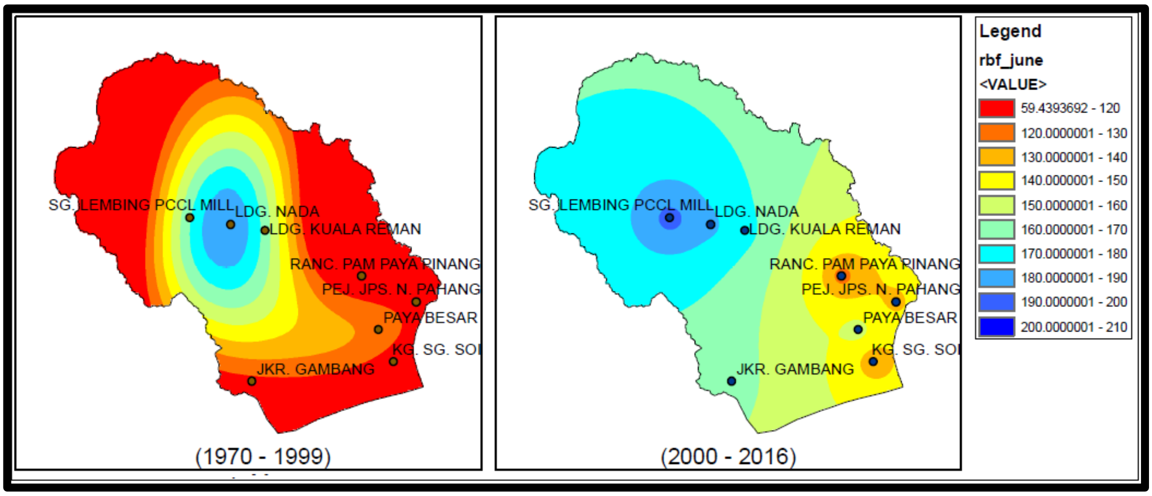


Figure 4.15 Average monthly rainfall for June

In June, Ranc. Pam Paya Pinang obtained the lowest average values for both years 1970 until 1999 and years 2000 until 2016 with average values recorded 104.04 mm and 126.60 mm respectively. However, the maximum average value from years 1970 to 1999 was obtained at station Ldg. Nada with average value 187.17 mm while the highest average value from years 2000 until 2016 was obtained by station Sg. Lembing PCCL Mill, 194.61 mm. In the month of June, Kuantan area is experiencing the Southwest Monsoon Season which is the drier season compared to the other seasons. In spite of that, the areal extent of higher precipitation had been increased after year 2000.

Figure 4.16 shows the average monthly rainfall for July from years 1970 to 1999 and from years 2000 to 2016 respectively.

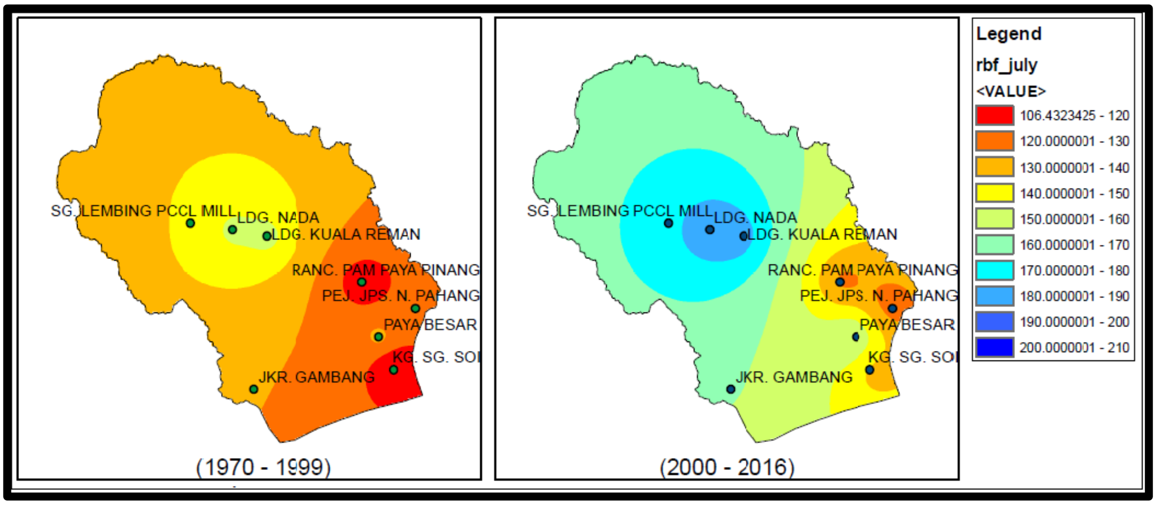


Figure 4.16 Average monthly rainfall for July

From years 1970 to 1999, the maximum average value was obtained at station Ldg. Kuala Reman with average value recorded is 155.46 mm while the minimum average value was obtained at station Kg. Sg. Soi with average value 106.48 mm. In contrast, average value at station Ldg. Nada, 187.81 mm, which was the highest average value whereas the lowest average value obtained by station Pej. JPS. N. Pahang, 126.69 mm from years 2000 until 2016. Kuantan area is in the phase of the Southwest Monsoon and so the weather conditions was drier than June. As can be seen from the map, the amount of precipitation received from years 2000 to 2016 marginally higher than from years 1970 to 1999.

Figure 4.17 shows the average monthly rainfall for August from years 1970 to 1999 and from years 2000 to 2016 respectively.

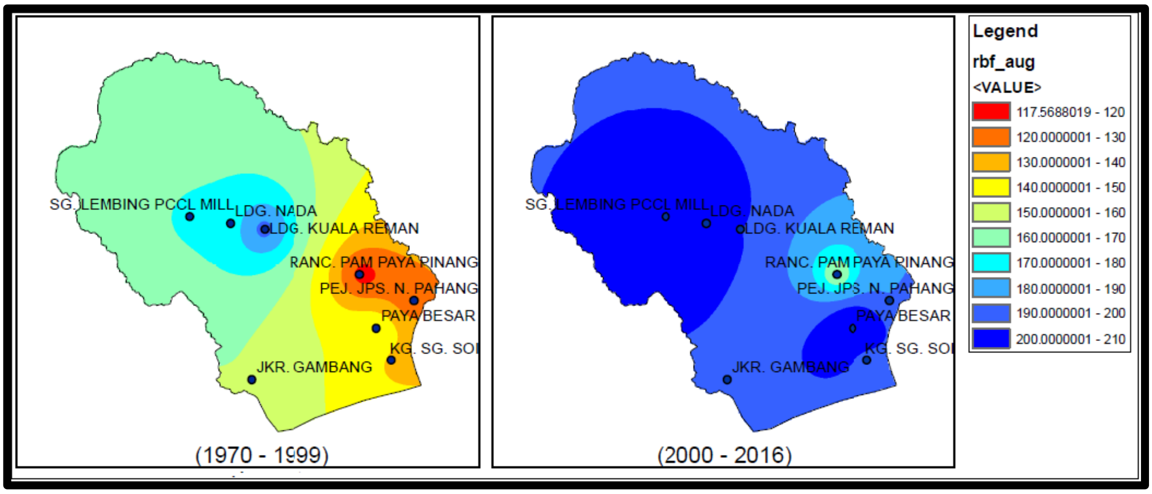


Figure 4.17 Average monthly rainfall for August

In August, Ranc. Pam Paya Pinang obtained the lowest average values for both years 1970 until 1999 and years 2000 until 2016 with average values recorded 118.07 mm and 158.04 mm respectively. However, the maximum average value from years 1970 to 1999 was obtained at station Ldg. Kuala Reman with average value 191.83 mm while the highest average value from years 2000 until 2016 was obtained by station Paya Besar, 229.66 mm. Kuantan is encroaching towards the end of Southeast Monsoon Season and so the precipitation is gradually increasing from this month. As can be seen from the map, the period from years 2000 to 2016 received high precipitation and distributed evenly over the whole study area.

Figure 4.18 shows the average monthly rainfall for September from years 1970 to 1999 and from years 2000 to 2016 respectively.

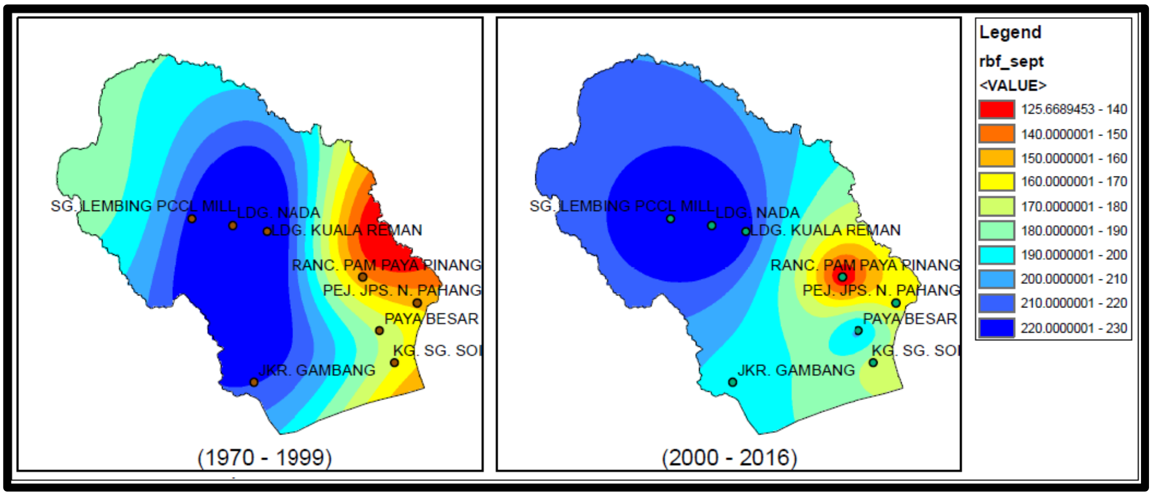


Figure 4.18 Average monthly rainfall for September

In September, Ldg. Nada obtained the maximum average values for both years 1970 until 1999 and years 2000 until 2016 with average values recorded 244.61 mm and 250.09 mm respectively. In opposite, the minimum average values for both years 1970 until 1999 and years 2000 until 2016 was obtained at station Ranc. Pam Paya Pinang with average values 152.09mm and 133.67 mm respectively. Kuantan area is in the final phase of Southwest Season, which is relatively drier conditions, meanwhile several heavy rainfall occurred at several area. As can be seen from the map, the areal extent of high precipitation for years 2000 until 2016 was moved from the middle part towards western part of study area although the rainfall depths between two periods were not much different.

Figure 4.19 shows the average monthly rainfall for October from years 1970 to 1999 and from years 2000 to 2016 respectively.

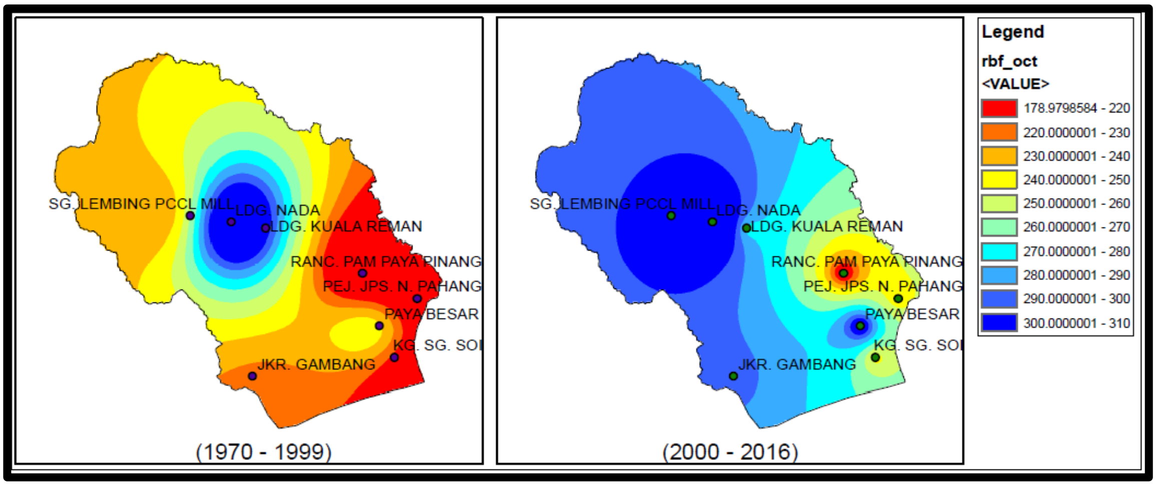


Figure 4.19 Average monthly rainfall for October

In October, Ldg. Nada obtained the maximum average values for both years 1970 until 1999 and years 2000 until 2016 with average values recorded 332.45 mm and 361.44 mm respectively. On the other hand, the minimum average values for both years 1970 until 1999 and years 2000 until 2016 was obtained at station Ranc. Pam Paya Pinang with average values 187.98 mm and 206.91 mm respectively. October is the month that will form a short transition season between the Northeast and Southwest monsoons with light and variable winds and high humidity. After year 2000, the areal extent of high precipitation had been increased.

Figure 4.20 shows the average monthly rainfall for November from years 1970 to 1999 and from years 2000 to 2016 respectively.

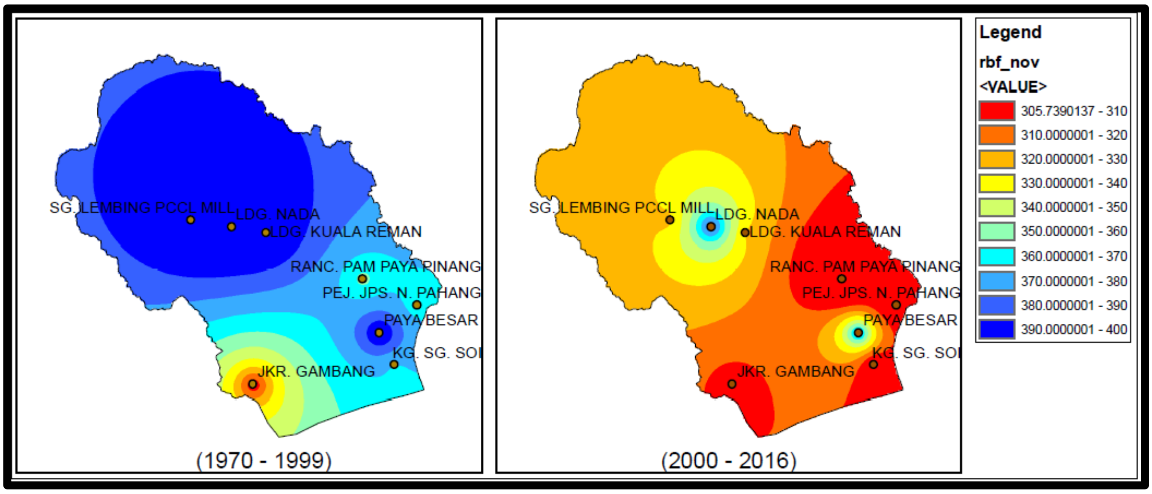


Figure 4.20 Average monthly rainfall for November

From years 1970 to 1999, the maximum average value was obtained at station Sg. Lembing PCCL Mill with average value recorded is 422.37 mm while the minimum average value was obtained at station JKR. Gambang with average value 305.77 mm. In contrast, average value at station Ldg. Nada, 384.15 mm, which was the highest average value whereas the lowest average value obtained by station Ranc. Pam Paya Pinang, 261.69 mm from years 2000 until 2016. Kuantan area is starting Northeast Monsoon Season in this month which bring heavy rainfall. Obviously, the maps show that most of study area received higher precipitation from years 1970 to 1999 and this was one of the months which the total rainfall depth was decreased after year 2000.

Figure 4.21 shows the average monthly rainfall for December from years 1970 to 1999 and from years 2000 to 2016 respectively.

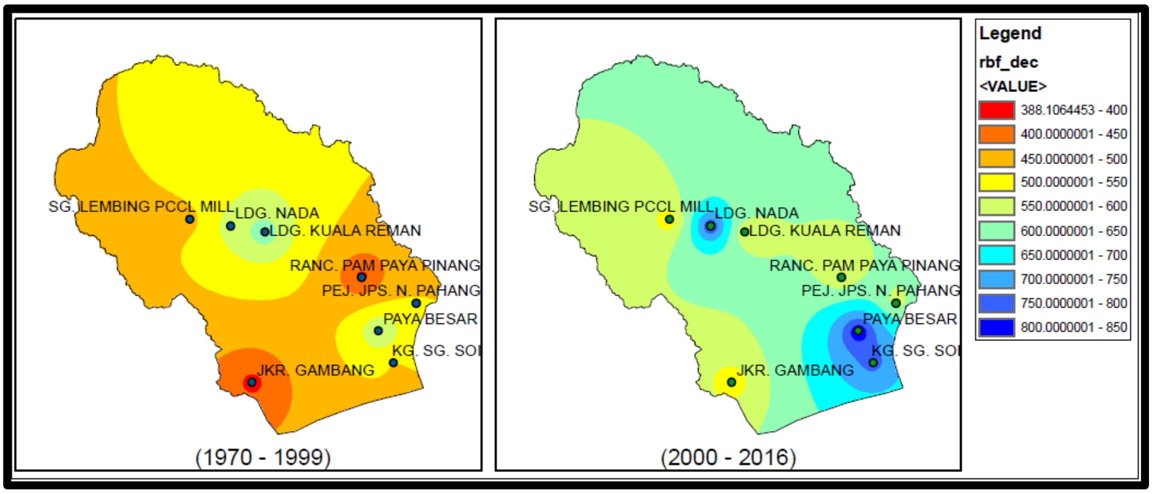


Figure 4.21 Average monthly rainfall for December

In December, JKR. Gambang obtained the lowest average values for both years 1970 until 1999 and years 2000 until 2016 with average values recorded 388.19 mm and 513.20 mm respectively. However, the maximum average value from years 1970 to 1999 was obtained at station Ldg. Kuala Reman with average value 624.19 mm while the highest average value from years 2000 until 2016 was obtained by station Paya Besar, 829.79 mm. Kuantan area is facing Northeast Monsoon Season which bring heavy rainfall. Hence, December is the month that receives the highest precipitation throughout a year. As can be seen from the map, there was a huge difference between two periods in term of rainfall depth and the precipitation amount increased after year 2000.

4.5 COMPARISON OF ANNUALLY RAINFALL PATTERN

Figure 4.22 shows the average annually rainfall from years 1970 to 1999 and from years 2000 to 2016 respectively.

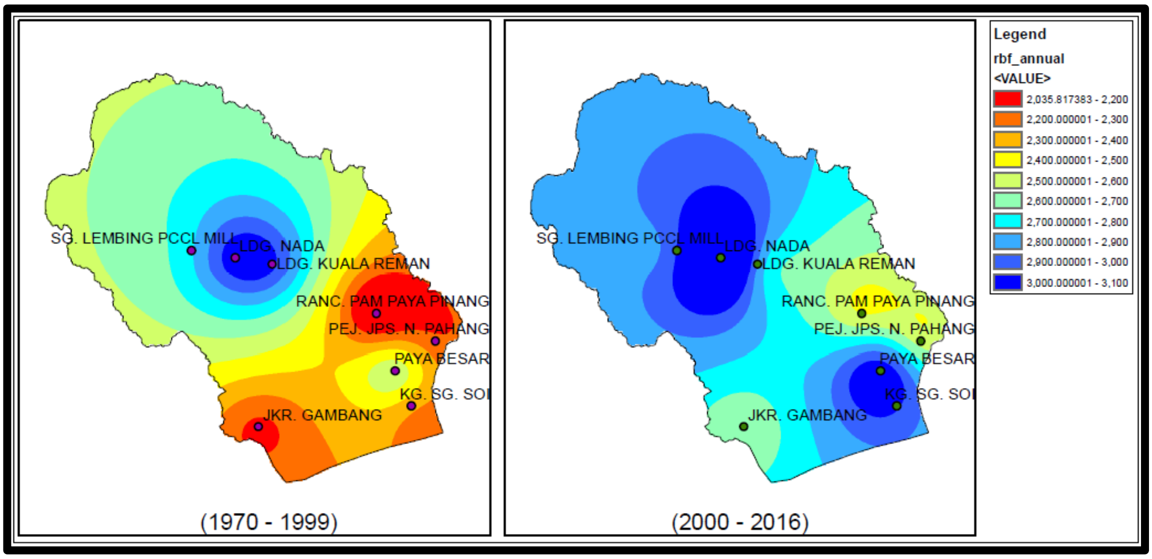


Figure 4.22 Average annually rainfall

As can be seen from the maps, station Ldg. Nada obtained the maximum average values for both years 1970 until 1999 and years 2000 until 2016 with average values recorded 3071.40 mm and 3471.22 mm respectively. On the contrary, the minimum average value for both years 1970 until 1999 and years 2000 until 2016 was obtained at station Ranc. Pam Paya Pinang with average values 2046.73 mm and 2496.98 mm respectively. As a result, it was found that variable regional changes in precipitation between these two periods. In addition, the variation of rainfall depth were also found to be large at each station during the last 47 years, particularly at the mountainous and eastern region of Kuantan. The rainfall pattern on the map of years 2000 until 2016 shows that the areal extent of high precipitation had been increased. The amount of precipitation collected by these stations are mostly depends on the topography and geographic location. Normally, the areas which high altitudes and near to the open sea will receive more precipitation compared to the low area and inland area.

4.6 SUMMARY

The RBFs method is selected as the most optimum spatial interpolation method for rainfall distribution in Kuantan River Basin due to the best results obtained from the analysis by cross-validation method. This result agrees with the findings by Apaydin et al. (2004) and Piazza et al. (2015), stated that RBFs (completely regularized spline) was especially successful for rainfall interpolation. Hence, it is used to develop the isohyet maps of monthly and annually average rainfall.

From the analysis that have been done, for years 1970 until 1999, December is the month that obtained the highest monthly average rainfall in the area where close to mountainous region at station Ldg. Kuala Reman with 624.19 mm while the lowest monthly average rainfall was obtained in inland area at station JKR. Gambang in February with 81.00 mm. Concurrently, for years 2000 until 2016, the highest average monthly rainfall was recorded in the area close to the open sea at station Paya Besar in December with 829.79 mm whereas the lowest monthly average rainfall was obtained in low area at station Ranc. Pam Paya Pinang in April with 86.50 mm. For the highest annually average rainfall was recorded at station Ldg. Nada for both years 1970 until 1999 and years 2000 until 2016 with 3071.40 mm and 3471.22 mm respectively. However, the minimum annually average value for both years 1970 until 1999 and years 2000 until 2016 was obtained at station Ranc. Pam Paya Pinang with 2046.73 mm and 2496.98 mm respectively.

In conclusion, the changes of rainfall pattern in Kuantan River Basin mainly depends on the Northeast Monsoon (November – March), Southwest Monsoon (May – September) and two transition periods (April and October). Overall, the Northeast Monsoon contributes more precipitation over all regions compared to the Southwest Monsoon. Additionally, the rainfall intensity and the areal extent of higher precipitation has also increased significantly over years. The variable regional changes in precipitation but everywhere more intense rainfall events, especially during the Northeast Monsoon where extreme precipitation events occur resulting in major floods.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter comprise of two sections which are conclusion and recommendation. The conclusion and recommendation are subjected to objective and scope of study from chapter 1. The objectives are to develop isohyet maps for Kuantan River Basin using Ordinary Kriging (OK) and Radial Basis Functions (RBFs) methods, to evaluate and identify the most optimum spatial interpolation method for rainfall distribution in Kuantan River Basin and to analyse monthly and annually rainfall pattern maps that developed from the optimum spatial interpolation method for the impact of climate change over Kuantan River Basin.

In this study, rainfall data of 8 rainfall stations distributed over Kuantan River Basin have been analysed and the isohyet maps are drawn for monthly and annually average rainfall for duration of 47 years starting from years 1970 to 2016 by using Ordinary Kriging (OK) and Radial Basis Functions (RBFs) methods. Subsequently, the accuracy and performance of the spatial interpolation methods are compared and evaluated by cross-validation method. From the analysis of the study, the maximum and minimum average rainfall was obtained with the optimum spatial interpolation method (RBFs). Furthermore, the rainfall pattern of monthly and annually in Kuantan River Basin was analysed and compared between years 1970 until 1999 and years 2000 until 2016.

5.2 CONCLUSION

As conclusion of this study, ArcGIS is used to analyse the spatial variation of rainfall patterns. The most optimum spatial interpolation method for this study is Radial Basis Functions method which obtained the better results from the analysis of MAE and RMSE by cross-validation method. According to the study by Apaydin et al. (2004) and Piazza et al. (2015), both of them agree with that the best performance, in terms of accuracy was obtained by RBFs (completely regularized spline) and it was especially successful for rainfall interpolation. Eventually, the RBFs method was used to develop the isohyet maps of monthly and annually average rainfall for this study.

Based on the results, it can be deduced that the monsoon seasons are influenced greatly on the rainfall patterns of Kuantan River Basin. Kuantan region will receives more precipitation during the Northeast Monsoon throughout a year than the Southwest Monsoon. Consequently, river discharge will increase during Northeast Monsoon Season and so resulted on flood event. Usually, December is the month that occur the worst floods in Kuantan due to the high precipitation. Besides, the rainfall pattern is not only influenced by monsoon season, but also the topography and geographic location. The areas which high altitudes and near to the open sea usually are projected to receive more precipitation compared to the lowlands and inlands (Tekolla, 2010).

For the impact of climate change, the amount of precipitation was significant increased and the rainfall distributed more evenly over the Kuantan region over years. The difference of rainfall depth between year 1970 until 1999 and year 2000 until 2016 recorded highest is in the Northeast Monsoon season where extreme precipitation events occur resulting in major floods. There is a number of studies forecasted that climate change will influenced the changing of rainfall patterns that the precipitation and extreme weather events will increase (Zhang *et al.*, 2008; Barr *et al.*, 2007). Floods and water quality problems are likely to be amplified by climate change in most regions. Besides that, the changing of precipitation patterns is expected will more difficult to project in the future (Karl *et al.*, 2009). The occurrence of climate change in Kuantan are mostly due to the deforestation which is the second leading cause of global warming and produces about 24% of global greenhouse gas emissions.

5.3 RECOMMENDATION

From the current study, some of the recommendations have been proposed for collecting good quality of rainfall data and obtaining more accurate result of isohyet maps' development:

i. Establish more meteorological and rain gauge stations for Kuantan region.

ii. Take precautionary measures to make the public aware of the climate change.

iii. Take sufficient actions to control the flood events in Kuantan region.

iv. Collect and compare rainfall data from different rain gauge station such as from Meteorology Department of Malaysia.

v. Study the relationship of other parameters likes temperature, wind speed to rainfall isohyet map.

vi. Study the trend and future behaviour of extreme events other than precipitation, such as floods, droughts, heat waves to understand more about the impacts of climate change.

vii. Study the synoptic circulations, particularly during the northeast monsoon where extreme precipitation events occur resulting in major floods.

viii. The uses of ArcGIS 10.2 software should be used widely in the field of civil engineering likes geotechnical, environmental and etc.

ix. The uses of other spatial interpolation methods in ArcGIS 10.2 software for development of Isohyet maps

x. Use others software to develop isohyetal map.

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APPENDIX A

Table A1 Coodinate for each station for Kuantan River Basin.

Station no.	Station name	Latitude	Longitude
3731018	JKR. Gambang	03 42 20	103 07 00
3732020	Paya Besar	03 46 20	103 16 50
3732021	Kg. Sg. Soi	03 43 50	103 18 00
3832015	Ranc. Pam Paya Pinang	03 50 30	103 15 30
3833002	Pej. JPS. N. Pahang	03 48 30	103 19 45
3930012	Sg. Lembing PCCL Mill	03 55 00	103 02 10
3931013	Ladang Nada	03 54 30	103 05 20
3931014	Ladang Kuala Reman	03 54 00	103 08 00

APPENDIX B

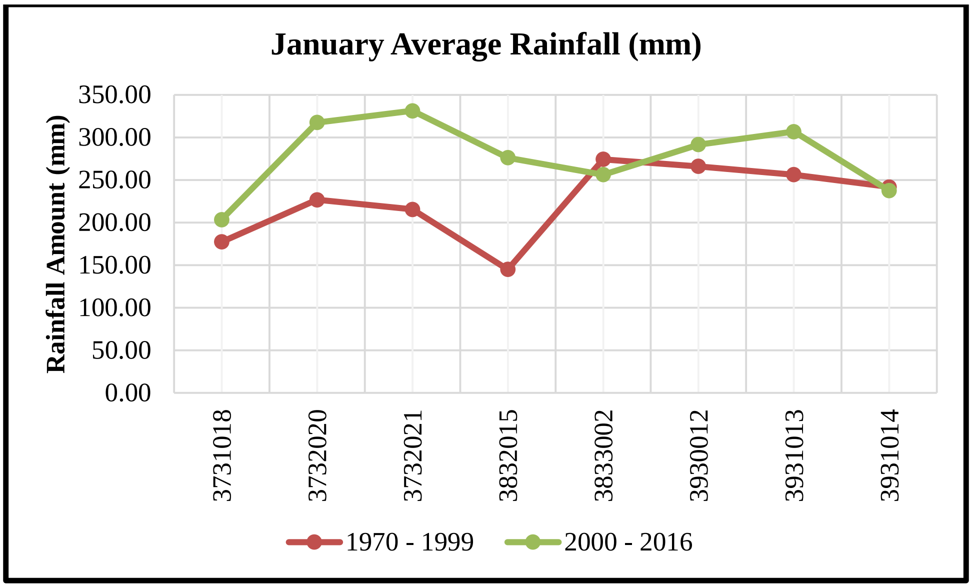
Table B1 Average monthly rainfall (1970 – 1999).

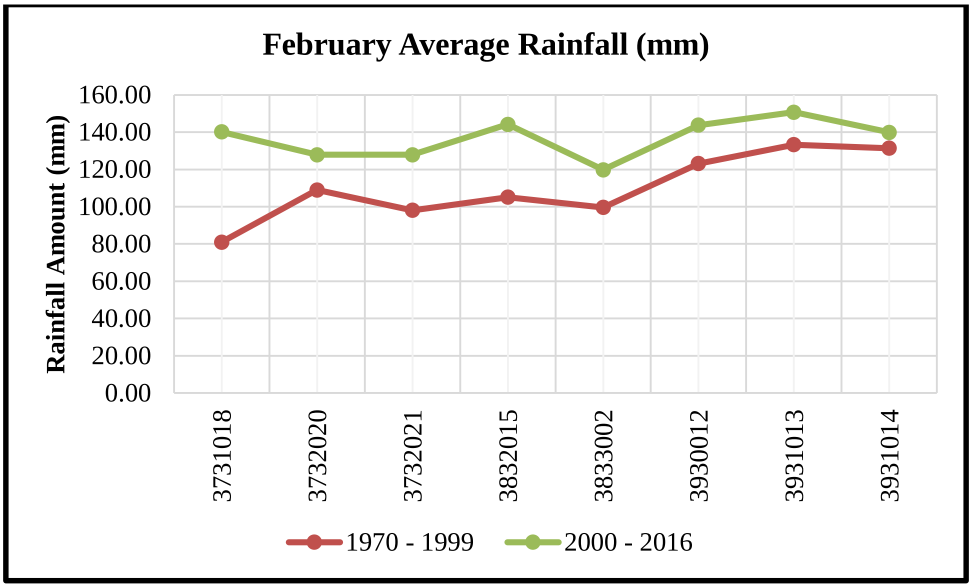
Station no.	**Station name**	**Average Value (mm)**											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
3731018	JKR. Gambang	177.33	81.00	143.05	173.36	173.35	116.70	130.96	158.69	220.38	226.54	305.77	388.19
3732020	Paya Besar	226.78	108.98	122.55	137.69	132.88	125.75	132.30	148.51	177.06	240.62	401.25	594.25
3732021	Kg. Sg. Soi	215.45	98.11	108.93	146.04	133.20	111.35	106.48	138.43	170.09	216.14	370.25	502.42
3832015	Ranc. Pam Paya Pinang	145.11	105.11	111.66	132.07	143.06	104.04	108.51	118.07	152.09	187.98	357.97	394.17
3833002	Pej. JPS. N. Pahang	274.25	99.62	123.10	112.74	140.79	112.31	123.79	123.54	157.29	189.38	364.89	504.87
3930012	Sg. Lembing PCCL Mill	266.09	123.17	166.94	195.24	194.55	168.76	141.56	172.13	224.21	259.71	422.37	488.01
3931013	Ladang Nada	256.24	133.24	180.33	185.53	230.15	187.17	153.73	175.25	244.61	332.45	414.80	574.93
3931014	Ladang Kuala Reman	241.81	131.39	180.43	180.16	206.20	165.10	155.46	191.83	238.36	306.41	413.70	624.19

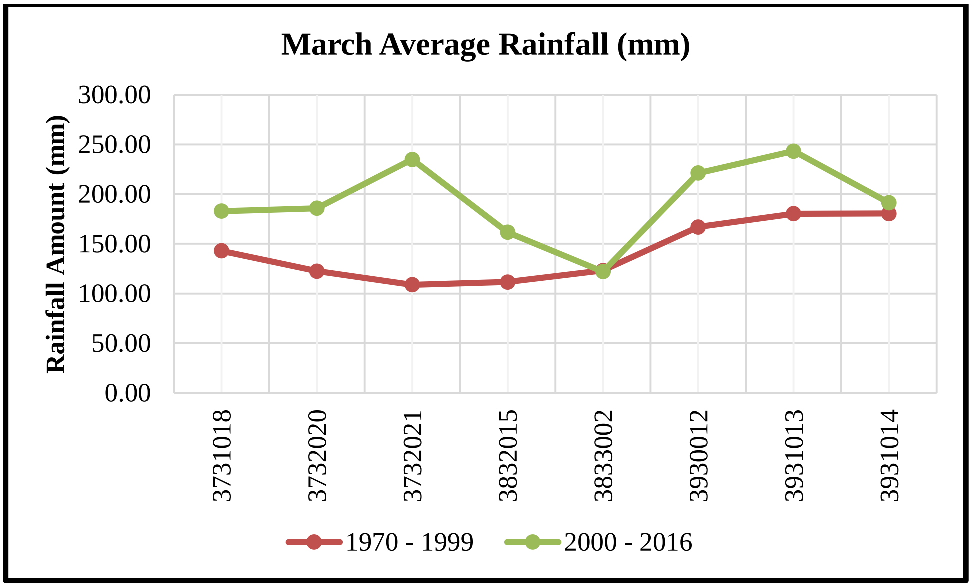
Table B2 Average monthly rainfall (2000 – 2016).

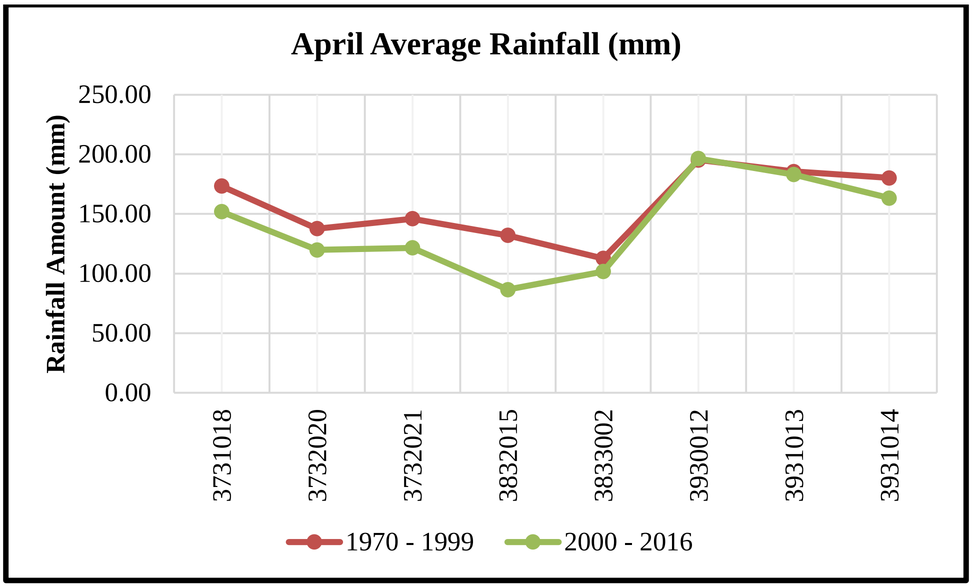
Station no.	**Station name**	**Average Value (mm)**											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
3731018	JKR. Gambang	203.46	140.13	182.88	151.88	167.81	164.83	160.92	198.36	193.57	299.47	301.50	513.20
3732020	Paya Besar	317.39	127.85	185.89	119.83	203.19	153.32	157.50	229.66	200.25	314.07	370.63	829.79
3732021	Kg. Sg. Soi	331.20	127.83	234.85	121.51	160.88	133.93	139.56	193.09	176.47	248.31	295.83	769.65
3832015	Ranc. Pam Paya Pinang	276.08	144.14	161.61	86.50	151.43	126.60	129.63	158.04	133.67	206.91	261.69	557.30
3833002	Pej. JPS. N. Pahang	256.21	119.78	122.06	101.77	156.89	138.56	126.69	191.24	167.25	242.56	287.83	588.03
3930012	Sg. Lembing PCCL Mill	291.56	143.72	221.26	196.39	239.86	194.61	176.55	201.65	239.01	308.87	329.20	525.69
3931013	Ladang Nada	306.80	150.73	243.23	182.96	257.13	182.38	187.81	221.59	250.09	361.44	384.15	781.81
3931014	Ladang Kuala Reman	237.49	139.92	191.37	163.31	231.03	174.63	184.17	200.76	223.83	279.15	330.83	569.94

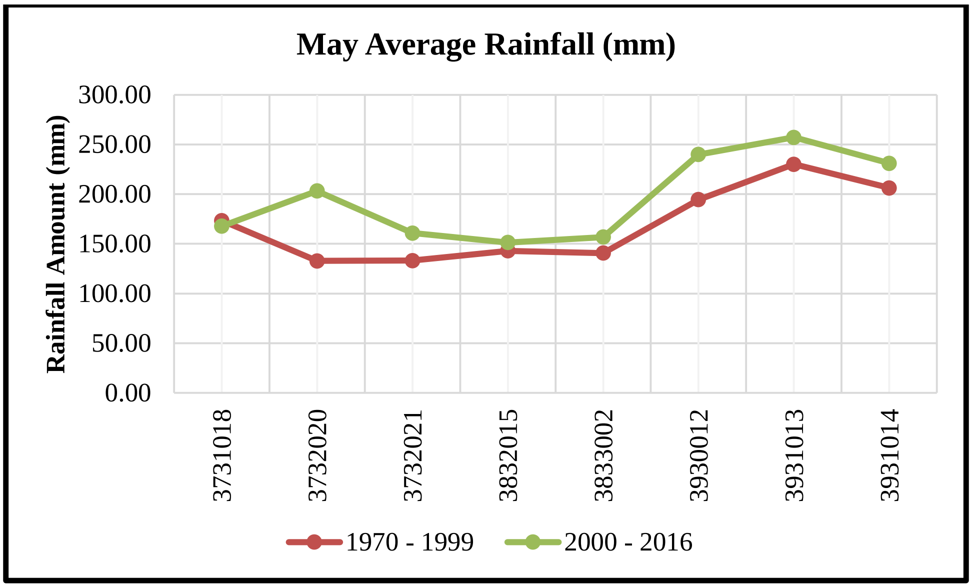
Figure B1 Comparison of average monthly rainfall between years 1970 – 1999 and years 2000 - 2016.

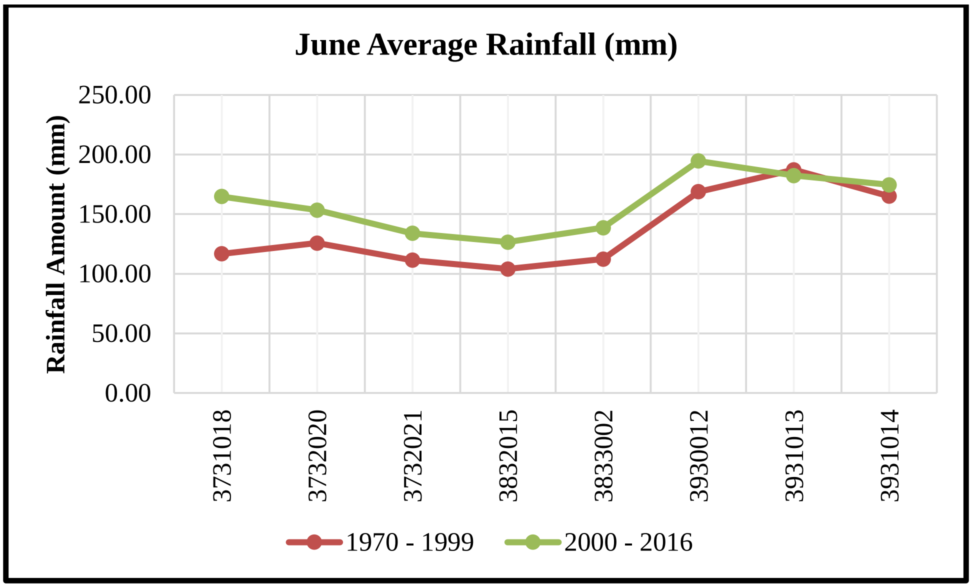


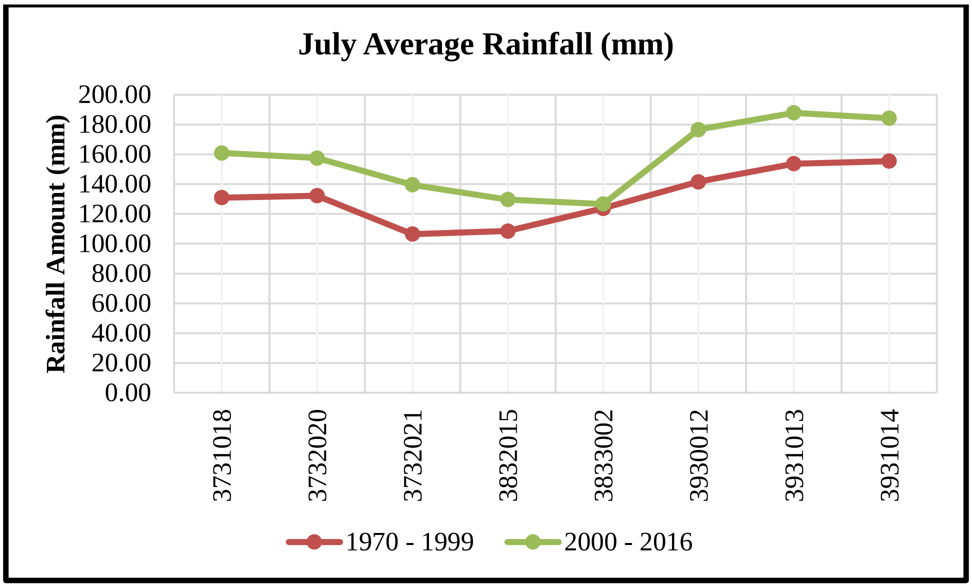


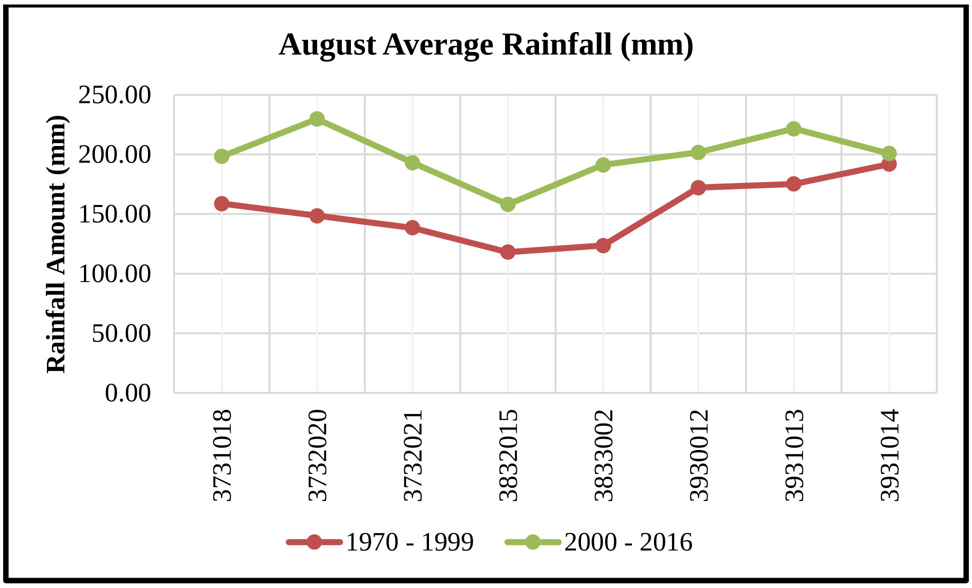


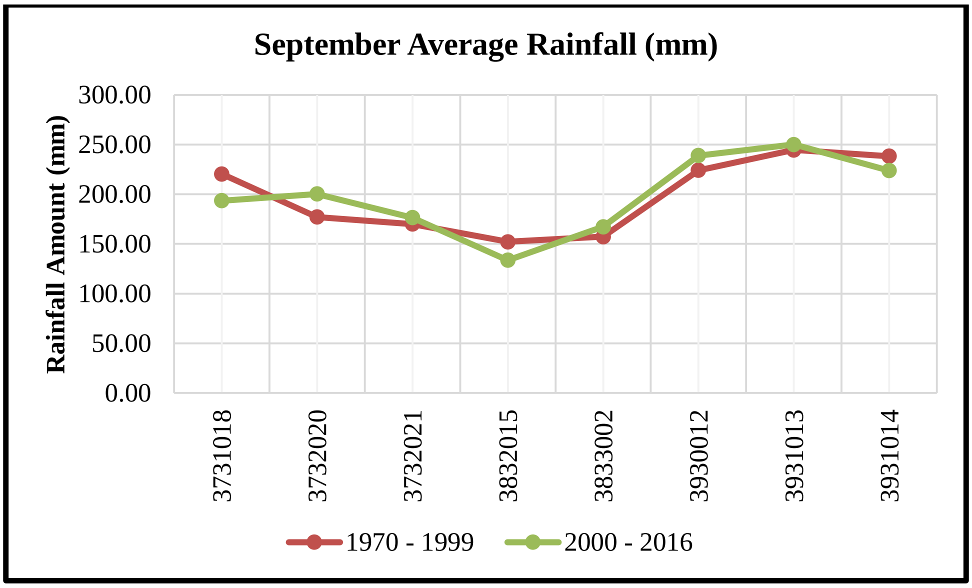

April Average Rainfall (mm)
Rainfall Amount (mm)
250.00
200.00
150.00
100.00
50.00
0.00
3731018
3732020
3732021
3832015
3833002
3930012
3931013
3931014
1970 - 1999
2000 - 2016

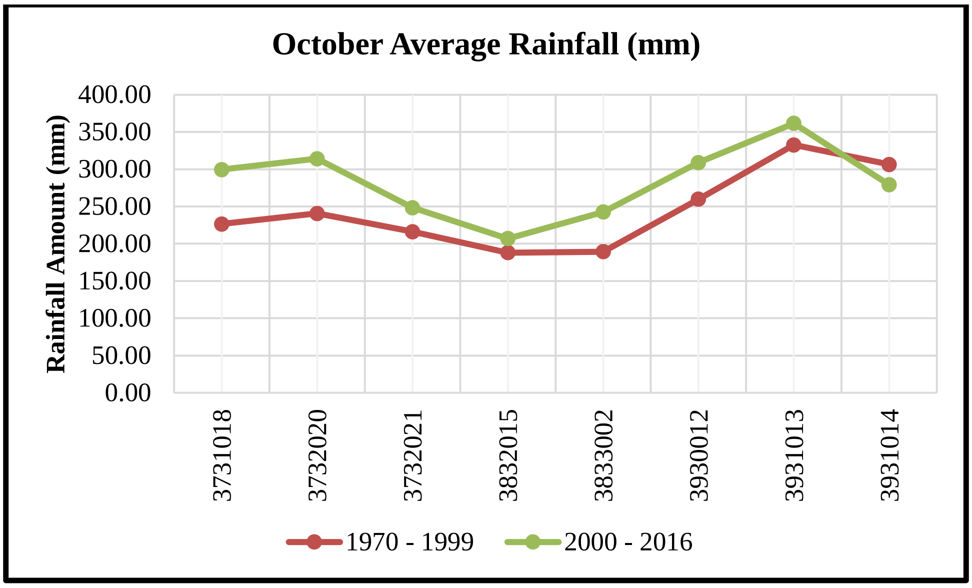

May Average Rainfall (mm)
Rainfall Amount (mm)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
3731018
3732020
3732021
3832015
3833002
3930012
3931013
3931014
1970 - 1999
2000 - 2016

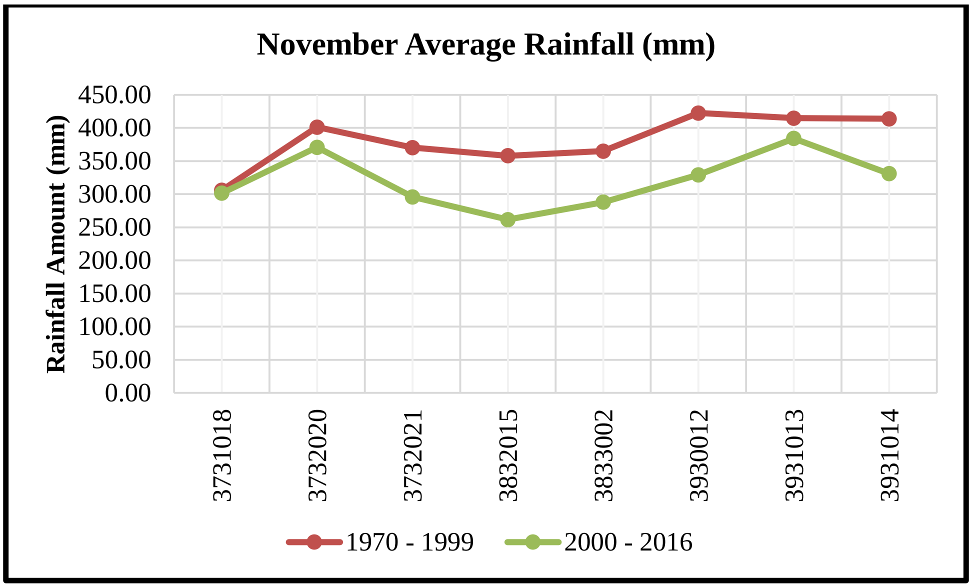

June Average Rainfall (mm)
Rainfall Amount (mm)
250.00
200.00
150.00
100.00
50.00
0.00
3731018
3732020
3732021
3832015
3833002
3930012
3931013
3931014
1970 - 1999
2000 - 2016


July Average Rainfall (mm)
Rainfall Amount (mm)
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
3731018
3732020
3732021
3832015
3833002
3930012
3931013
3931014
1970 - 1999
2000 - 2016


August Average Rainfall (mm)
Rainfall Amount (mm)
250.00
200.00
150.00
100.00
50.00
0.00
3731018
3732020
3732021
3832015
3833002
3930012
3931013
3931014
1970 - 1999
2000 - 2016


September Average Rainfall (mm)
Rainfall Amount (mm)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
3731018
3732020
3732021
3832015
3833002
3930012
3931013
3931014
1970 - 1999
2000 - 2016


October Average Rainfall (mm)
Rainfall Amount (mm)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
3731018
3732020
3732021
3832015
3833002
3930012
3931013
3931014
1970 - 1999
2000 - 2016


November Average Rainfall (mm)
Rainfall Amount (mm)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
3731018
3732020
3732021
3832015
3833002
3930012
3931013
3931014
1970 - 1999
2000 - 2016

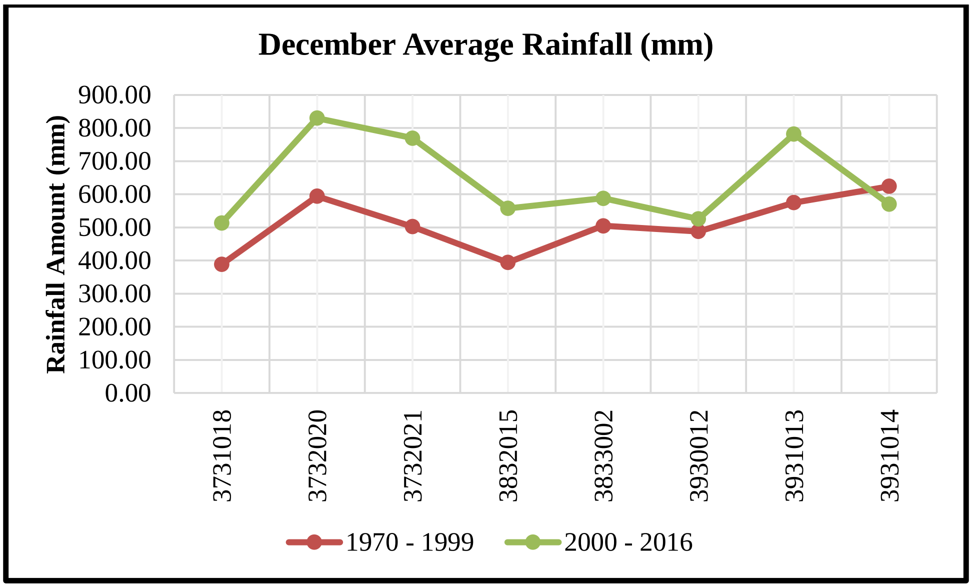

December Average Rainfall (mm)
Rainfall Amount (mm)
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
3731018
3732020
3732021
3832015
3833002
3930012
3931013
3931014
1970 - 1999
2000 - 2016

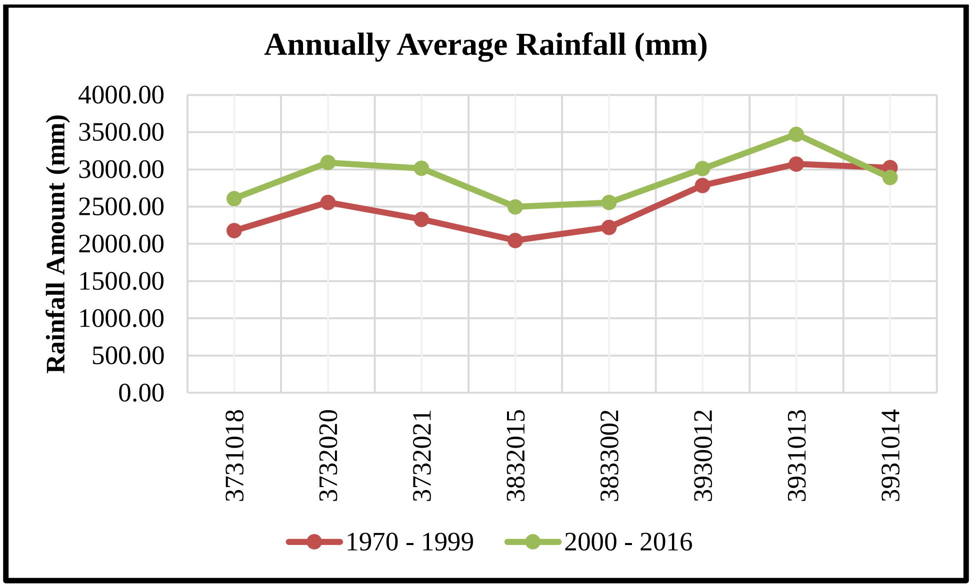
Table B3 Average annually rainfall (1970 – 1999).

Station no.	Station name	Average Value (mm)
3731018	JKR. Gambang	2176.32
3732020	Paya Besar	2557.24
3732021	Kg. Sg. Soi	2328.87
3832015	Ranc. Pam Paya Pinang	2046.73
3833002	Pej. JPS. N. Pahang	2222.19
3930012	Sg. Lembing PCCL Mill	2785.11
3931013	Ladang Nada	3071.40
3931014	Ladang Kuala Reman	3023.19

Table B4 Average annually rainfall (2000 – 2016).

Station no.	Station name	Average Value (mm)
3731018	JKR. Gambang	2609.45
3732020	Paya Besar	3091.70
3732021	Kg. Sg. Soi	3014.91
3832015	Ranc. Pam Paya Pinang	2496.98
3833002	Pej. JPS. N. Pahang	2555.51
3930012	Sg. Lembing PCCL Mill	3009.30
3931013	Ladang Nada	3471.22
3931014	Ladang Kuala Reman	2890.65

Figure B2 Comparison of average annually rainfall between years 1970 – 1999 and years 2000 - 2016.



APPENDIX C

Table C1 Summary statistics for the interpolation of monthly rainfall estimation (1970 – 1999).

Month	Maximum			Average			Minimum			MAE		RMSE	
	Measured Value	OK	RBF	Measured Value	OK	RBF	Measured Value	OK	RBF	OK	RBF	OK	RBF
January	274.25	225.38	242.18	225.38	225.38	227.90	145.11	225.38	202.41	34.56	37.68	42.01	48.46
February	133.24	132.86	129.71	110.08	116.76	115.30	81.00	91.83	99.07	11.56	9.35	17.14	12.93
March	180.43	185.50	175.47	142.12	139.01	143.91	108.93	67.71	113.31	23.20	10.70	28.43	14.04
April	195.24	195.52	189.97	157.85	160.49	159.44	112.74	126.56	123.00	8.11	6.48	10.49	7.54
May	230.15	248.84	222.15	169.27	170.92	172.11	132.88	126.07	136.79	20.75	12.13	25.65	15.19
June	187.17	201.98	192.35	136.40	143.43	144.07	104.04	109.66	110.00	19.26	14.22	23.32	15.94
July	155.46	151.14	143.85	131.60	133.75	132.48	106.48	112.05	116.41	13.87	11.89	16.80	15.17
August	191.83	187.14	179.83	153.31	155.75	154.40	118.07	128.33	132.74	16.33	14.92	20.06	18.55
September	244.61	247.58	243.63	198.01	198.14	199.50	152.09	114.96	148.37	18.58	13.81	23.61	16.76
October	332.45	319.07	315.61	244.90	258.20	258.64	187.97	201.57	202.23	33.97	33.71	38.23	36.90
November	422.37	422.37	405.73	381.37	396.97	386.19	305.77	360.53	364.54	34.31	29.46	43.97	37.98
December	624.19	527.02	542.77	508.88	510.96	522.07	388.19	488.74	476.33	77.16	78.51	93.39	94.15
Annual	3071.40	2982.33	2918.51	2526.38	2647.08	2605.36	2046.73	2196.72	2234.17	272.17	247.85	317.43	282.27

Table C2 Summary statistics for the interpolation of monthly rainfall estimation (2000 – 2016).

Month	Maximum			Average			Minimum			MAE		RMSE	
	Measured Value	**OK**	**RBF**	**Measured Value**	**OK**	**RBF**	**Measured Value**	**OK**	**RBF**	**OK**	**RBF**	**OK**	**RBF**
January	331.20	294.40	296.41	277.52	281.66	282.55	203.46	262.34	261.92	39.86	39.99	46.51	47.07
February	150.73	148.20	144.89	136.76	136.85	136.77	119.78	129.34	130.33	6.45	6.66	7.80	8.38
March	243.23	201.85	239.93	192.89	192.25	199.51	122.06	169.87	155.81	34.24	31.08	42.59	37.14
April	196.39	192.98	186.37	140.52	142.36	142.96	86.50	67.10	102.25	19.17	11.11	22.07	15.10
May	257.13	255.40	228.36	196.03	202.56	200.93	151.43	158.30	161.14	27.77	27.46	33.00	29.95
June	194.61	191.06	177.90	158.61	159.73	158.79	126.60	130.48	138.99	10.22	14.00	12.98	16.64
July	187.81	185.82	178.84	157.85	162.90	159.93	126.69	133.97	136.22	13.81	13.14	16.11	15.64
August	229.66	205.19	209.56	199.30	199.40	201.34	158.04	194.96	186.67	15.99	18.43	22.96	25.11
September	250.09	247.09	228.90	198.02	205.62	201.70	133.67	161.41	167.23	21.22	21.11	29.27	27.96
October	361.44	299.71	317.72	282.60	282.31	285.81	206.91	261.89	246.57	39.44	43.33	47.89	49.86
November	384.15	328.57	347.21	320.21	320.60	325.18	261.69	311.07	290.65	37.71	40.07	44.54	46.58
December	829.79	670.28	692.55	641.93	642.19	660.44	513.20	615.09	557.74	130.40	139.63	137.19	146.83
Annual	3471.22	2944.77	3335.18	2892.47	2892.95	2990.61	2496.98	2821.82	2777.35	292.83	291.74	343.66	340.30