ASSESSMENT OF THE C SATELLITE-BASED AND RAIN-GAUGE RAINFALL

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Thesis submitted in fulfillment of the requirements for the award of the degree of
B.Eng (Hons) Civil Engineering

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UNIVERSITI MALAYSIA PAHANG

JAN 2015

ABSTRACT

Accurate rainfall data at high spatial and temporal resolution is necessary for many hydrological and water management application, and especially in data scarce river watershed. Satellite-based rainfall estimation can be used as an alternative source of rainfall information, but need area-specific calibration and validation. The main study focused was to assess the correlation between TMPA satellite-based rainfall and rain-gauge rainfall for Peninsular Malaysia, for a period of five years (July 2009 – June 2014). The specific objectives include; (i) to establish the satellite-based rainfall of study area, and (ii) to analyse the correlation between satellite-based rainfall and rain-gauge rainfall. In this study, Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis (TMPA) version 7 satellite-based rainfall data obtained from public domain, and monthly rainfall from Jabatan Pengairan dan Saliran, Malaysia (JPS) rain-gauge stations were used. Meanwhile, Geographical Information System (GIS) technique was used to established monthly rainfall maps for study area. Both type of monthly rainfall are retrieved at correspond location. The correlation between satellite-based rainfall and rain-gauge rainfall is statistically analysed. The monthly rainfall values estimated from satellite-based and the measured values shows a very good agreement (correlation coefficients of 63%). The regression line fitted through the origin has a slope of 0.83. For calibrated purposed, regression analysis was carried out. Result indicated good correlation between monthly rainfall TMPA with the corresponding rain-gauge records ($r^2 = 0.55$: $p<0.001$, $n=1116$). The validity of these techniques was tested using Nash–Sutcliffe efficiency (0.80). Meanwhile, the correlation of the monthly satellite-based calibrated rainfall and the measured rainfall increase (r=94%: slope=0.94).

ABSTRAK

Data hujan yang tepat pada resolusi ruang dan masa yang tinggi diperlukan untuk penggunaan hidrologi dan pengurusan air, terutamanya dalam data sungai yang kurang. Anggaran hujan berasaskan satelit boleh digunakan sebagai sumber alternatif bagi mendapatkan maklumat hujan, tetapi kawasan khusus diperlukan untuk kalibrasi dan pengesahan. Fokus utama bagi kajian ini adalah untuk menilai hubung kait antara data hujan *Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis* (TMPA) berasaskan satelit dan tolok hujan bagi Semenanjung Malaysia, bagi tempoh lima tahun (Julai 2009 – Jun 2014). Objektif-objektif tertentu termasuk; (i) menerbitkan data hujan berdasarkan satelit untuk kawasan kajian, dan (ii) menganalisis hubungkait antara data hujan berasaskan satelit dan tolok hujan. Dalam kajian ini, data TMPA diperolehi daripada domain awam, dan tolok hujan bulanan daripada stesen Jabatan Pengairan dan Saliran, Malaysia (JPS) telah digunakan. Sementara itu, teknik sistem maklumat geografi (GIS) telah digunakan untuk menerbitkan peta hujan bulanan bagi kawasan kajian. Kedua-dua jenis hujan bulanan akan diambil dari lokasi yang sesuai. Hubung kait antara hujan berasaskan satelit dan tolok hujan dianalisis secara statistik. Nilai hujan bulanan dianggarkan berasaskan satelit dan nilai-nilai yang diukur menunjukkan hubungan yang sangat baik (pekali korelasi 63%). Garis regresi yang melalui titik 0 mempunyai kecerunan sebanyak 0.83. bagi tujuan kalibrasi, analisis regresi dijalankan. Keputusan menunjukkan hubungkait yang baik antara hujan bulanan TMPA dengan rekod-rekod tolok hujan ($r^2 = 0.55$: $p < 0.001$, $n = 1116$). Kesahihan teknik ini diuji menggunakan formula *Nash – Sutcliffe efficiency (*0.80). Sementara itu, korelasi antara kalibrasi data TMPA dan tolok hujan meningkat ($r = 94\%$: kecerunan = 0.94).

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Rainfall is a meteorological parameter influenced by climate, topography coverage and land use and land cover. Rainfall pattern is one of the most important inputs and key issues for hydrological sciences and practices (Sangati and Borga, 2009). This information is widely required for flood forecasting, hydrological modelling and designing drainage (Lagouvardos et al., 2013). Rainfall pattern is variable in time and space.

Over the years, remote sensing technology with various algorithms have been used to quantify the temporal and spatial variability of rainfall (Dinku et al.,2007; Islam and Uyeda, 2007; Jamandre and Narisma, 2013). Advances in computer technology and network have enable data, which were mostly obtained from data mining techniques, which can be access freely. However, there are many challenges in the use of this data. Of which are;

- Location of the area of study. The satellite-based rainfall data available in the public domain has been calibrated with field data outside the study area under the Authentication Field (Ground Validation) program with latitudes of 8.72 °N and above and 12.248 ° S and below (http://mirador.gsfc.nasa.gov/). Whereas, the area of study is located between latitude of 1 ° to 7 ° N. Calibration and validation process need to be done in advance to the specific area, so that it can reduce the difference on the estimate value produced (Aghakouchak et al., 2009).

• Monsoon Influences. Rainfall which act as meteorological parameter is spatial and temporal variability and is influenced by the monsoon in specific regions. Islam and Uyeda (2007), found that rainfall from satellite-based image data is estimated more in dry season, and less in the humid season in Bangladesh. Similar in Saudi Arabia, but happens on different month (Almazroui, 2011).

• Pixel size of satellite-based image. Rainfall data from satellite-based (such as, the Tropical Rainfall Measuring Mission (TRMM)) has a pixel size of 0.25° ($625km^2$) and 0.5° ($2500km^2$). This situation limits the use of such data for a wide area and suitable for inputs based on lump model.

1.2 PROBLEM STATEMENT

Accurate rainfall data at high spatial and temporal resolution is necessary for many hydrological and water management applications, and especially in data scarce river watershed. Satellite-based rainfall estimation can be used as an alternative source of rainfall information, but need area-specific calibration and validation. This paper attempts to answer, can TRMM Multi-satellite Precipitation Analysis (TMPA) be used as an alternative source of rainfall data when compared to rain-gauge data.

1.3 OBJECTIVES OF STUDY

The study main focus is to assess the correlation between TMPA satellite-based rainfall and rain-gauge rainfall for Peninsular Malaysia, for the period of five years (July 2009 - June 2014). The specific of this study are as follows:

i. To establish the satellite-based rainfall of the study area;
ii. To analyze the correlation between satellite-based rainfall and rain-gauge rainfall.

1.4 SCOPE OF STUDY

This study was limited to rainfall data for five years starting from July 2009 until June 2014 for both satellite-based and also rain-gauge data. Rain-gauge rainfall data were collected from the Department of Irrigation and Drainage or *Jabatan Pengairan dan Saliran* (JPS) stations across Peninsular Malaysia. Meanwhile, Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis (TMPA) satellite-based data downloaded from public domain.

1.5 AREA OF STUDY

Peninsular Malaysia is located between 1° and 7° north and 99.5° to 104.5° east, and comprises an area of 131 587 km^2. It is composed of highland, floodplain and coastal zones. The Titiwangsa mountain range act as the backbone of the Peninsula, from southern Thailand running approximately south-southeast over a distance of 480 km and separating the eastern part from the western part (Suhaila, Jemain, 2007). Surrounding the central high regions are the coastal lowlands. Peninsular Malaysia is known as a maritime nation. This is because the Peninsular Malaysia has a long coastline along the east side is the South China Sea, while to the westward of the Straits of Malacca.

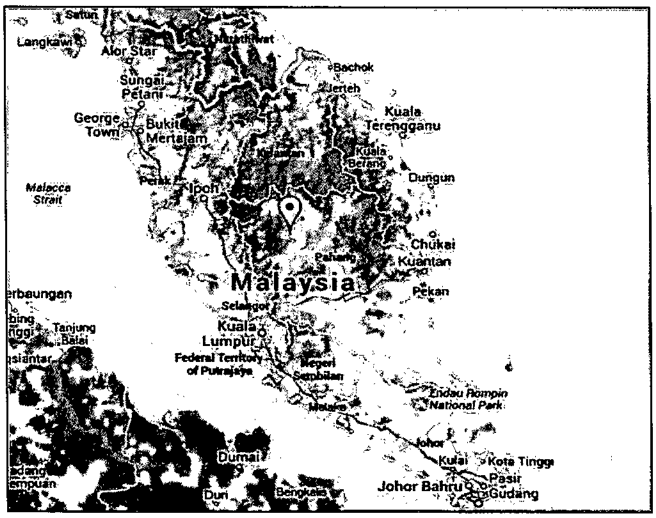

Figure 1-1 : Peninsular Malaysia study area

Source: www.water.gov.my

1.6 SIGNIFICANT OF STUDY

Rainfall is a meteorological parameter and needs to be measured accurately. Many applications of rainfall data could be studied in depth through knowledge of the actual distribution of rainfall. Moreover, the amount of rainfall received over an area is an important factor in assessing the amount of water available to meet various demands for agricultural, industrial and human activities.

1.7 THESIS STRUCTURE

This report consists of five chapters. Chapter one comprises the introduction section. Background of study, problem statement, objectives of study, scope of study and lastly significant of study are included. In chapter two, it comprises related and suitable literature reviews for the research. Chapter three will explained the research methodology used to collect monthly data from rain-gauge and satellite-based data. The data will then be mapped and analyzed to obtain the relationship between both data. The result obtained from the analysis is between rain-gauge and satellite-based is presented and discussed in chapter 4. Finally, chapter five comprises the conclusion of the overall chapter and relates some recommendation for future work in the research field.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Rainfall is one of the crucial input components of the earth hydrological cycle. Accurate rainfall data are important for stable and reliable further hydrologic modelling purposes. Conventionally, measurements have been carried out by using rain-gauges but despite of the high accuracies, it is only limited to a small area (Collischonn, et al., 2008). Apart from the situation, the information is limited and insufficient to provide further understanding of global hydrologic water balance (Adler et al.,). Furthermore, with less distribution over the catchment area in remote areas because of the cost of maintenance, the measurements tend to be inaccurate. Whilst there is ground radar technology available for measuring rainfall, the device is limited to certain extend of kilometers and uncover areas that have been monitored by other stations. With the founding of highly spatio-temporal, radar, and remote sensing, a solution to the limitation of previous technology is found (Chanyatham and Kirtsaeng, 2011).

2.2 DETERMINATION OF RAINFALL BY USING SATELLITE IMAGE DATA.

The study focuses on the needs of developing a technique which can be used to determine the quantity of rainfall with the right information and cheaper cost to retrieve.

Since 1970s, much effort was made to determine the data from satellite image data (Barrett, 1993). The main importance of estimating data by using satellite image data is to provide information regarding to events, the number and data distribution for the field of meteorological, climatological, hydrological and hydrological sciences (Levzzani et al., 2001). The ability of satellite image for estimating data depends on the position of the satellite and the type of sensor used.

Generally, the distribution of information and the number of data from satellite image data can be obtained by either indirectly or directly from the sources (Arkin and Ardanuy, 1989; Barrett, 1993; Levzzani et al., 2002). The observation is done directly by using passive sensors. Rain particle is the main factor of the decreased in upwelling at passive micro frequency wave. Passive sensor traced the microwave energy absorbed and dispersed by the rain particle and changes the information to estimated rate of particles by comparing with the level of radiation from the surface of the Earth. Passive microwave sensor mounted on low satellite orbit caused the derived rainfall information to have scarcity in temporal and spatial resolution; although the information given is reliable (Barrett, 1993). Indirect observation is done by using empirical relationships of temporal and spatial variability between the covered clouds that has a value of lower temperature threshold and rainfall particle. The surface temperature of cloud is obtained by infra-red radiation emitted by the clouds (Levzzani et al.,2002 and Dingman, 2002). An infra-red wave sensor which installed on geostationary satellites at high orbital position, giving a good temporal resolution of rainfall distribution, but the information about rainfall distribution is less effective (Barrett, 1993).

2.3 PREVIOUS STUDIES.

The correction of satellite products is usually carried out by comparing the satellite data with in situ rainfall measurements. Much effort has been made in this regard (e.g. Ji and Stocker 2003, Chokngamwong et al. 2005, Dinku et al. 2007). These studies were conducted at global and regional scales (Thailand and Africa, respectively). The TRMM product has shown varying accuracies in different regions and for different adopted methods. Ji and Stocker (2003) and Chokngamwong et al. (2005) observed a correlation of 0.56 and 0.86 between the satellite and rain gauge measurements, respectively. Dinku et al. (2007) observed Nash–Sutcliffe efficiency of 0.81 and 25% root mean square error between the satellite and rain gauge data averaged over 2.5°grid boxes. Villarini and Krajewski (2007) tested accuracy for a single 25 km × 25 km pixel containing 23 rain gauges in Oklahoma and found a correlation of 0.55 between the satellite and rain gauges values.

Hamza Varikoden et al, (2010) used TMPA 3B42v.6 to study the rainfall characteristics in Peninsular Malaysia. It is found significant correlation between TRMM rain rate and rainfall data from Malaysia Meteorology Department (MMD) in example 0.63 to 0.96, over selected area. It is also found diurnal variation of frequency of rain occurrence is different for different locations. Tam et al (2011), used data TMPA 3B43v.6 algorithm study Peninsular Malaysia's rainfall and to analyze the annual rainfall distribution. The data were validated by 24 principle station's rainfall data. The annual rainfall result showed that TMPA data is overestimated and low accuracy, though TMPA data and rain gauge were positive correlation. Ali, M.I.(2014) TMPA 3B42v.6 to study the monthly rainfall distribution in Peninsular Malaysia. It is found that, TMPA-calibrated rainfall able to show the variability effect of climate change. Semire et al, (2012) validate TMPA 3B42 and 3B43v.6 with ground measurement over Malaysia for 10 years period data. It is found that an error bias of ±15% exists between the satellite-based and the ground mean yearly rainfall.

2.4 SATELLITE IMAGE DATA SOURCE TO STUDY

The Tropical Rainfall Measuring Mission (TRMM), cosponsored by the National Aeronautics and Space Administration (NASA) of the United States of America and the Japanese Aerospace Exploration Agency (JAXA) was launched on 27 November 1997 (Kummerow et al., 2000). TRMM main objective is to act as a long-term research program designed to study Earth's land, oceans, air, ice, and life as a whole system. TRMM is NASA's first mission dedicated to observing and understanding tropical rainfall and how it affects the climate (Simpson et al., 1988; Wolff et al., 2005).

TRMM orbit the Earth at an inclination of 35° at lower altitude (350km) on non-synchronous sun orbit with the period of 91.5 minutes for every cycle (15 cycles per day). This orbit provides high space resolution and records of the variability of tropical rainfall daily. TRMM satellite satisfies the knowledge needed to determine the characteristic of rainfall and its versatility through five sensors namely Precipitation Radar (PR), TRMM Microwave Imager (TMI), Visible and Infra-red Radiometers (VIRS), Cloud and Earth Radiant Energy Sensors (CERES), and Lightning Imaging Sensors (LIS). PR, TMI and VIRS sensors are the main sensor that have been used to measure and assess tropical rainfall; although VIRS cannot measure the rainfall directly.

The position of TRMM at lower altitude able it to distinguish the radiation from minor cloud covered, enable the estimation to be more accurate. TRMM allows the determination of rainfall information to be done directly and in a shorter period of time. TRMM has been providing effective rainfall data (TMPA) for more than 10 years (1998 until now). In order to improve the quality of the data, TRMM satellite data products have been processed periodically with enhanced algorithm. TRMM 3B42 data for version 6 (3B42v6) is available 10-15 days after the end of each month (Huffman and Coauthers, 2007). Recent TRMM satellite data are processed using version 7 (V7) algorithms. Recent TRMM satellite data were processed by using version 7 (V7) algorithms. Satellite image data have random difference caused by various factors such as the frequency of sample collected, field of ununiformed vision sensor, and an algorithm for different rainfall (Huffman and Coauthers, 2007). Therefore it is important that the rainfall data derived from satellite image data is validated with rain gauge data to assess the validity of the data.

To observe the potential of TRMM satellite image data, many attemps to compare the TRMM satellite-based data with other rainfall measurement methods were made (Adeyewa and Nakamura, 2003; Nicholson et al., 2003a, b; Chokngamwong and Chiu, 2007; Chiu et al., 2006). Adeyewa and Nakamura (2003) have validated TRMM PR rainfall data and 3B43 data analysis with rain-gauge rainfall from Global Precipitation Climatology Center (GPCC) for main climate regions of Africa. Differences were found in terms of area and season. The combined data of TMPA (3B43v6) have a good relationship while the TRMM PR data on the contrary. Nicholson et al. (2003a, b) have been using rain gauge data from 920 stations network in West Africa to evaluate TRMM rainfall data (PR, TMI, 3B43v6) for year 1998. TRMM PR and TMI data showed the tendency of the estimation is more than the rain-gauge rainfall. Meanwhile, the combined MPa (3B43v6) data indicates good agreement with rain-gauge data for monthly rainfall and rainy season. Chokngamwong and Chiu (2007) compares the TRMM rainfall data (TRMM 3B42v5, 3B43v5, 3B42v6 and 3B43v6) with data from 100 rain-gauge stations. They found that 3B42v6 have a good relationship with rain gauge data. Chiu et al. (2006) have compared the TRMM (TRMM Precipitation Radar (PR), 2A25, TRMM Microwave Imager (TMI) 2A12, TRMM Combined Instrument (TCI) 2B31, TRMM 3B42v5, 3B42v6, 3B43v5, and 3B43v6) with the rate of rainfall from rain gauges in the area of New Mexico. High refractive has been discovered for uncombined satellite data algorithms. While the combined MPa (3B43 or 3B42) data have good relationship with rain-gauge data.

However, these studies are limited to a comparison of the monthly rainfall period. For the purpose of hydrology and agriculture, for a shorter period of time such as daily, every five days (pentad), or every ten days (decades) is more appropriate. Comparison of satellite images and the estimated rate of one half of the month was done by Brown (2006) for the India-Sri Lanka and Islam and Alestore (2006) for the area of Bangladesh. Comparison of daily rainfall was done by Chokngamwong and Chiu (2007), Collischonn et al. (2008), Almazroui (2011), and Xiang-Li Hu et al. (2012). TRMM 3B42 version 6 (3B42v6) data has been used by Hamza Varikoden et al. (2010) to study the characteristics of daily rainfall in Malaysia. He found a good correlation between TRMM data and daily rainfall data obtained from the Malaysian Meteorological Department (MMD) with the correlation of 0.63 to 0.96 in selected areas. Ibrahim et al. (2010) has validated TRMM (3B43v6 algorithm) satellite image data with measurement data in the field. It was discovered that the satellite data image produced more annual rainfall data in Peninsular Malaysia compared to field measurements, whilst with low accuracy. In order to reduce the difference in derived rainfall estimation, TRMM satellite data need to be calibrated and validated specifically for the regarding area (Aghakouchak et al., 2009). Almazroui (2011) has done a calibration of daily TRMM rainfall data with each rain gauge data. After the calibration, it is found that TRMM satellite-based rainfall data is almost 100% the same as rain-gauge data.

The use of TRMM data (TMPA) in hydrological field can be seen in Hughes et al. (2006); Saif Ud Din et al. (2007); Collischonn et al. (2008); Su et al.

(2008); Hazarika et al. (2007); Harris et al. (2007); Sahoo et al. (2011), and Xiang-Hu Li et al. (2012). Hughes et al. (2006) found that the rainfall data from satellite images give good results when it is used with the Pitman rainfall-runoff model. Saif Ud Din et al. (2007) used rainfall data from the TRMM satellite images as source of information for quantifying the aquifer charge potential. Collischonn et al. (2008) used TRMM data to produced hydrograph and found out that the result obtained comparable with rain-gauge data. Harris et al. (2007) and Hazarika et al. (2007) found that TRMM data (TMPA) can be used for flood prediction. Su et al. (2008) discovered the potential for hydrologic prediction in an area that does not have data. Sahoo et al. (2011) used rainfall data from GPCP, TRMM (MPA), CMORPH and PERSIANN satellite data to study the water budget in ten (10) basin rivers worldwide namely Mackenzie, Yukon, Mississippi, Danube, Lena, Chang Jiang, Mekong, Niger, and the Murray-Darling Amazon that represent various climate.

2.5 RELATIONSHIP BETWEEN RAIN-GAUGE DATA AND SATELLITE-BASED DATA AND DESCRIPTIVE STATISTICAL ANALYSIS

Attempts to understand, explain, estimate or predict the incidence and phenomena that occur around us often begins by summarizing information that have been collected. In this study, the distribution of rainfall of study area derived from satellite images. Establishment of a mathematical model empirically needs to be done to get the correlation of satellite-based data with rain-gauge data, then rain will be calibrated. Products of rainfall distribution of the study area were analyzed with descriptive statistics to see spatial and temporal variability.

2.5.1 MATHEMATICAL EMPIRICAL MODEL

Before the establishment of mathematical models, the strength of correlation between dependent variables (JPS rain-gauge rainfall) and independent (TMPA satellite-based data) should be evaluated. Strength of the correlation between the two variables was indicated by the correlation coefficient. Correlation coefficients range from -1 for negative relationship perfect to +1 for a perfect positive relationship. The correlation coefficient defined as;

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{(n-1)S_x S_y}$$

Where: r is the correlation coefficient, x_i and x is the independent variables and average and y_i and y is the dependent variable and averaged. S_x and S_y is the standard deviation of the independent variables and the dependent. The standard deviation is as follows;

$$S_x = \sqrt{\frac{\sum(x_i - \bar{x})^2}{(n-1)}}$$

Where n is the number of data.

When the mathematical model is needed to be derived, the data involved must be obtained. Interaction between data and model applies in many ways:

(a) Data are necessary to obtain the right proposed model known as the empirical model based on full data.
(b) Data required to estimate the parameters that are in a model.
(c) Data necessary to test a model.

When the data have been collected, there are two groups of techniques that can be used to obtain a suitable model. The two (2) techniques are;

(a) Interpolation - to obtain the relationship that has the overall data.
(b) Fitting Model - obtain the best possible correlation function of overall data. Also known as regression model.

In this study, regression analysis was performed between the two variables the following; i) rain-gauge data (the dependent variable), and ii) satellite-based data (independent variables). There are two methods of regression, linear and non-linear. Five general equation has been used as a basis in the process of regression, namely;

i. Linear equations => $y = ax + c$
ii. Logarithmic equation => $y = a.ln\,(x) + c$
iii. Polynomial equations => $y = ax^2 + bx + c$
iv. Power equation => $y = ax^b$
v. Exponential equation => $y = ae^{bx}$

where;

y is the dependent variable,

x is the independent variables, and

a, b, c is an empirical parameter values.

Some phenomena can be modelled well with regression, and some don't. To derive a good model, coefficient of determination is used. Coefficient of determination (r^2) is the ratio between the variance of values published ($\hat{y}$) and measurement (y) for the dependent variable. The total variance for dependent variable explained by the independent variables;

$$r^2 = \frac{S\hat{y}^2}{Sy^2}$$

Where;

$$S\hat{y}^2 = \frac{\Sigma(\hat{y} - y)^2}{(n-1)}$$

$$Sy^2 = \frac{\Sigma(y_i - \hat{y})^2}{(n-1)}$$

But is not the main determinant coefficient to describe goodness of fit of the relationship between the dependent variable and independent variables.

2.6 CONCLUSION

Several criteria were chosen including readiness model, input data requirements, the ability of the model to make predictions and assumptions. However, some agreement must be reached to ensure these criteria can be used for practical use. A balance is required between existing data, the complexity model and desired outputs of the model. The main problems related model is relatively complex to readiness data, the choice of objective function and related problems in identifying the structure of the model chosen and parameter estimates.

Rainfall data from satellite images combination of multi-platform and multi-senses had shown a good correlation with rain-gauge data. The calibration process is specifically required for best results of satellite image data of an area. Rainfall data from TMPA satellite images had been calibrated with rain gauge rainfall data in various countries in Asia; India (2006), Thailand (Chokngamwong and Chiu, 2006), Bangladesh (Islam and Alestore, 2007), and Nepal (Islam et al., 2010). However, previous studies concentrated more in the tropical area, outside of the study area and the dry zone in Saudi Arabia (Al-Mazroui, 2011).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter describes the phases involved in achieving the study objectives. There were FOUR (4) phases, namely; i) Data collecting, ii) Pre-processing of Data, iii) Processing, and iv) Result and analysis (Figure 3.1). The first part will be explaining about how all the data needed being collected. The second part, pre-processing performed on the data obtained before processing data can be applied. As for the third part, explained how to publish the parameter, which consist of the coefficients and relationship between the TMPA satellite-based rainfall with the rain-gauge rainfall and produces the data model analysis. While the results and analyses are described in CHAPTER 4.

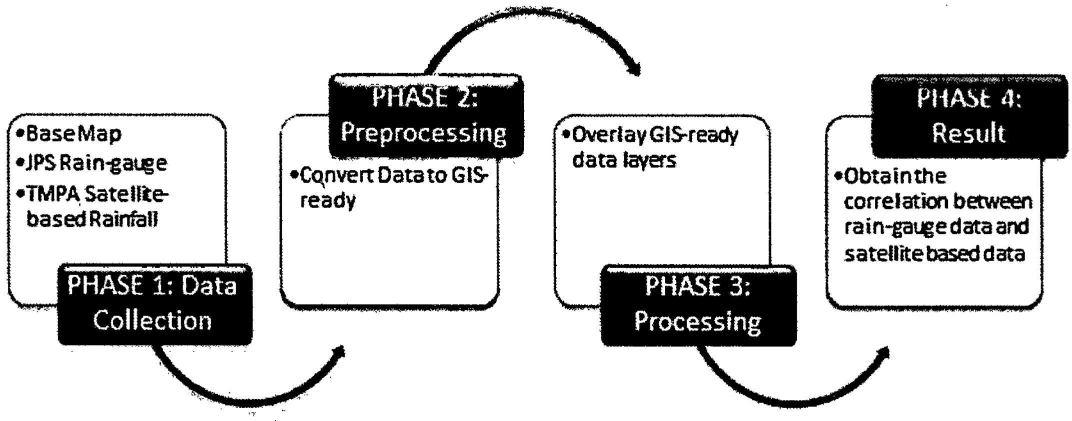

Figure 3-1 : Flow Chart of Methodology

3.2 MAIN PHYSICAL CHARACTERISTICS AND CLIMATE OF STUDY AREA.

Peninsular Malaysia is part of Malaysia country. Another part of Malaysia is known as East Malaysia which composed of Sabah and Sarawak. Peninsular Malaysia and East Malaysia have been separated by the South China Sea. Peninsular Malaysia is located at latitude of 1-7°N and the longitude of 99.5-104.5°E. Area of Peninsular Malaysia is 131,798.35 km^2, and is divided into 11 states and two federal territories, namely Wilayah Persekutuan Kuala Lumpur and Wilayah Persekutuan Putrajaya. The largest state in Peninsular Malaysia is known as Pahang with the area of 35,965 km^2 while the smallest is known as Perlis with an area of 795 km^2 (Figure 3.2.1). Peninsular Malaysia is made of series of mountain range as its backbone. The backbone, also known as Titiwangsa Range (*Banjaran Titiwangsa)* or Main Range (*banjaran besar)* also served as natural borders between states. Its land area is covered with tropical rainforests. Since 1960, the forest area has been widely explored for several expansion farmland and settlements to increase the population's economic activity. It has changed the landscape with river basin cover and land use land cover (LULC).

Peninsular Malaysia climate information can be obtained from the Department of Irrigation and Drainage (JPS) official website (www.water.gov.my). The following study area is located in the equatorial zone. The overall climate is equatorial but for certain part of Malaysia, especially in the northern part of Peninsular Malaysia, it experienced a tropical monsoon climate. Climates subjected to the influenced of the sea and the changes of sea breeze system blowing from the Indian Ocean and South China Sea. The climate is usually divided into south-west monsoon (May-September), northeast monsoon (November-March) and monsoon months between April and October. Both seasonal wind patterns and local topographical characteristic determine the rainfall pattern in the study area.

Figure 3-2 : Study Area.

3.3 DATA COLLECTING

The methodology of the study is shown in Figure 3-3. This section is subjected to how all the data are being collected. Satellite-based rainfall data act as the main source to derive the rainfall data model. The supporting data are the rain-gauge data and reports on previous study. The supporting data are important for calibration and validation purpose.

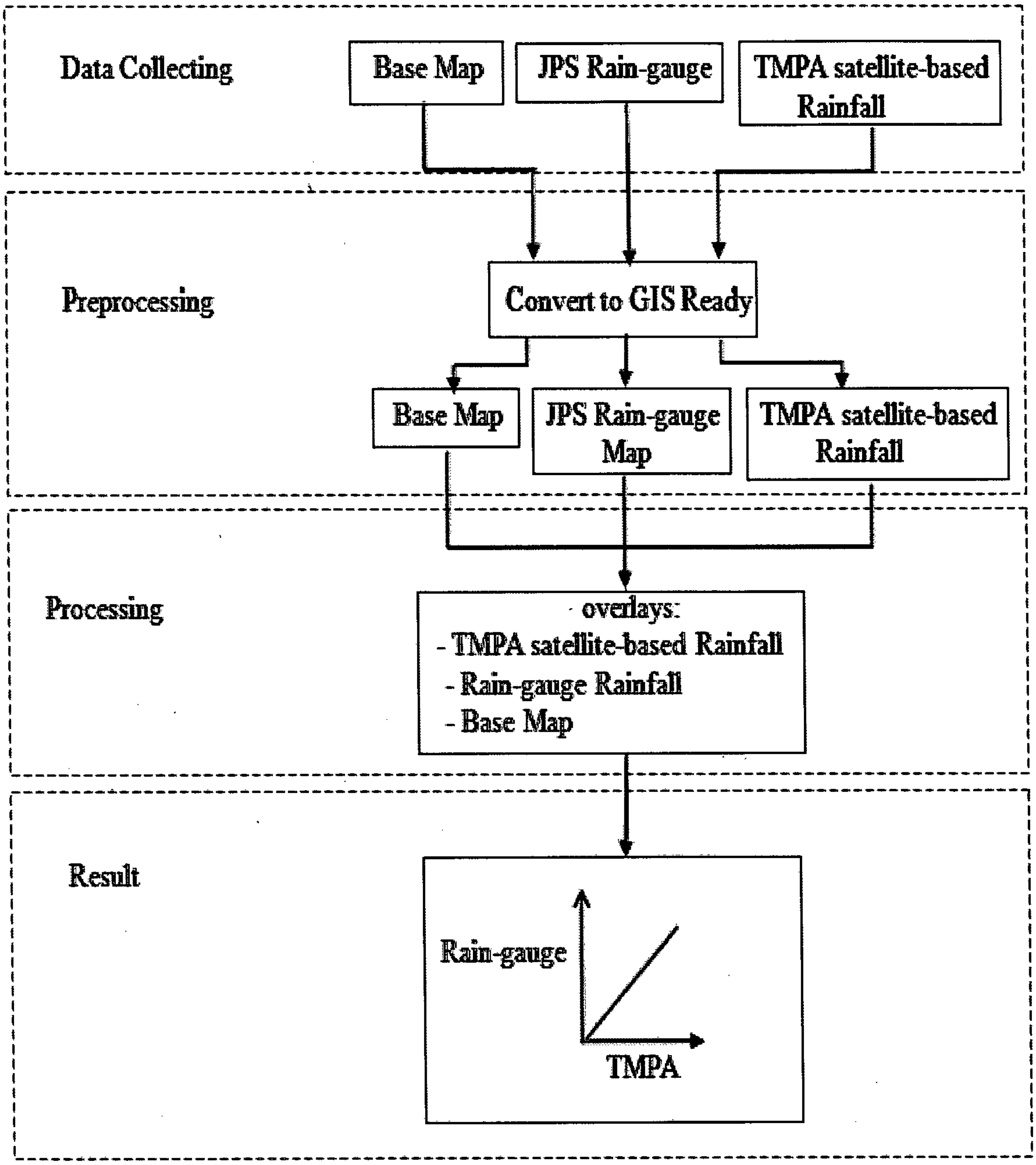

Figure 3-3 : Methodology of Study

3.3.1 TMPA SATELLITE IMAGE DATA.

Satellite-based TRMM rainfall data were obtained from public domain archives (NASA). This archive database has provided a wide range of rainfall data products processed with various types of algorithms in form of the distribution of daily rainfall