ASSESSING THE LOCAL SPATIAL VARIATION IN THE RELATIONSHIPS BETWEEN RAINFALL, VEGETATION AND ELEVATION

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ASSESSING THE LOCAL SPATIAL VARIATION IN THE RELATIONSHIPS BETWEEN RAINFALL, VEGETATION AND ELEVATION

by

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PENILAIAN VARIASI RUANGAN LOKAL DALAM HUBUNGAN ANTARA HUJAN, TUMBUHAN DAN KETINGGIAN

ABSTRAK

Hujan berbeza-beza mengikut ruangan berskala besar ke skala lokal. Unsur-unsur ruangan seperti tumbuh-tumbuhan dan topografi adalah faktor penyumbang kepada variasi taburan hujan lokal. Walau bagaimanapun, apabila menggunakan model global, proses ruangan tidak setempat dalam taburan hujan yang disebabkan oleh faktor tumbuh-tumbuhan dan topografi tidak dapat dikenalpasti. Kajian ini bertujuan untuk menilai variasi ruangan lokal taburan hujan dalam hubungan-hubungan antara taburan hujan, tumbuh-tumbuhan dan ketinggian dengan menggunakan kaedah pendekatan lokal. Pembolehubah utama dalam kajian hubungan ini adalah terdiri daripada kedalaman hujan, *Normalized Difference Vegetation Index* (NDVI) dari satelit imej Landsat 7 ETM + dan data ketinggian dari 174 and 103 lokasi stesen hujan di Wilayah Utara dan Pantai Timur Semenanjung Malaysia. Berdasarkan set data NDVI yang sedia ada pada tahun 2000, 2009 dan 2011, variasi ruangan taburan hujan ditentukan. Corak kluster kecil dalam taburan hujan, tumbuh-tumbuhan dan ketinggian berdasarkan Indeks Moran I dari 0.1 hingga 0.5 menunjukkan bahawa nilai kluster ruangan yang rendah oleh parameter di kawasan kajian. Oleh itu, proses ruangan dalam taburan hujan, tumbuh-tumbuhan dan ketinggian menunjukkan potensi kepada corak variasi bersifat lokal. Corak ruangan bagi pembolehubah ini membawa kepada penerokaan hubungan yang tidak setempat. Untuk mengetahui variasi lokal taburan hujan, teknik *Ordinary Least Square* (OLS) dan *Geographically Weighted Regression* (GWR) digunakan bagi menentukan tiga jenis model iaitu: (1) hubungan lokal antara taburan hujan dan tumbuh-tumbuhan, (2)

hubungan lokal antara taburan hujan dan ketinggian dan (3) hubungan lokal antara taburan hujan, tumbuh-tumbuhan dan ketinggian. Penemuan statistik bagi semua hubungan parameter-parameter ini menunjukkan terdapat variasi lokal yang signifikan apabila nilai Akaike's Information Criterion (AICc) yang diperolehi daripada GWR adalah lebih rendah. Nilai r^2 bagi GWR (0.146 hingga 0.770) adalah lebih baik berbanding nilai r^2 OLS (0 hingga 0.176). Model GWR terbaik dengan nilai perbezaan AICc tertinggi (Δ AICc) bagi tahun 2000, 2011 dan 2009 masing-masing ditemui di Model 1 (164.571), Model 3 (163.946) dan Model 2 (147.605). Perubahan gunatanah dan tumbuh-tumbuhan adalah antara kemungkinan yang menyebabkan hubungan antara taburan hujan dan faktor ketinggian adalah lebih signifikan pada tahun 2011. Lokasi yang signifikan dari variasi taburan hujan berdasarkan faktor tumbuh-tumbuhan dan ketinggian juga boleh ditunjukkan berdasarkan penemuan ini. Dengan keupayaan terperinci yang disediakan dalam data penderiaan jauh, variasi ruangan lokal dalam hubungan pembolehubah adalah tidak mustahil untuk dihasilkan. Oleh itu, hubungan ruangan lokal yang wujud di antara hujan, tumbuh-tumbuhan dan ketinggian di peringkat lokal adalah sangat penting menyumbang kepada variasi ruangan lokal dalam taburan hujan.

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ABSTRACT

Rainfall varies spatially ranging from large to local scales. Spatial elements such as vegetation and topography are the contributing factors to local variations of rainfall. However, local spatial variation process in rainfall due to vegetation and topography is unidentified when using a global model. This study aims to assess the local spatial variation of rainfall in the relationships between rainfall, vegetation and elevation using a local modelling approach. The main data used consist of rainfall depths, vegetation index of Normalized Difference Vegetation Index (NDVI) from Landsat 7 ETM+ satellite images and the elevation data from 174 and 103 locations of rainfall stations within the Northern and East Coast Region of Peninsular Malaysia respectively. Based on the availability of NDVI datasets from the years 2000, 2009 and 2011, the local spatial variations of rainfall were determined. The small clustering patterns in rainfall, vegetation and elevation that were computed in Moran's Index with the value of 0.1 to 0.5 showed low values of the variables being clustered in the study areas. Thus, the spatial process in rainfall, vegetation and elevation demonstrated a potential for local variations. The spatial pattern of these variables led to the exploration of non-stationary relationships. In order to explore the local spatial variation of rainfall, the regression techniques of Ordinary Least Square (OLS) and Geographically Weighted Regression (GWR) were applied to determine three types of models i.e. : (1) the relationship between rainfall and vegetation; (2) the relationship between rainfall and elevation; and (3) the relationship between

rainfall, vegetation and elevation. The statistical findings for all relationships had shown significant local variations when Akaike's Information Criterion (AICc) obtained from GWR were lower. The GWR R-squared (0.146 to 0.770) improved the OLS r-squared (0 to 0.176). The best GWR model with the highest AICc difference values (Δ AICc) for years 2000, 2011 and 2009 were found in Model 1(164.571), Model 3 (163.946) and Model 2 (147.605), respectively. Land use and vegetation changes are the possible reasons when the relationship between rainfall-elevation for year 2011 was found to be more significant. The significant location of local spatial variations of rainfall due to vegetation and elevation can also be demonstrated based on the findings. With the detailed capabilities provided in remotely sensed data, the local variations of the relationships are possible to be carried out. Therefore, the spatial relationship that exists between rainfall, vegetation and elevation at the local level are significantly contributing to the local variations in rainfall.

CHAPTER 1

INTRODUCTION

1.1 Background

In the hydrological cycle, precipitation such as rainfall plays a prominent role in water pathways as it circulates throughout the global system. Changes in the precipitation may affect human life. The consequences of extreme rainfall and insufficient rainfall for long periods of time may contribute to the occurrence of flood and drought respectively. Thus, understanding the spatial and temporal distribution of rainfall is important for water management, agriculture, electrical power and flood control, drought and flood monitoring (Adler et al., 2003). Based on the annual and seasonal variation of atmospheric cycle, rainfall patterns can be influenced by atmospheric processes at inter annual to multi-decadal time scales, such as the El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). According to Shaharuddin (2004), rainfall patterns in Malaysia are closely related to the seasonal wind flow patterns and local topographic features. The climate of Peninsular Malaysia is influenced by four seasons or monsoons namely the Northeast Monsoon (November to January), Southwest Monsoon (May to August) and two inter monsoon seasons at different regions.

Recently, rainfall event occurs unexpectedly. An increase in the global temperature is very likely influenced by the changes in atmospheric circulation and therefore increases the evaporation and water vapour. As reported in the Fourth Assessment Report by Intergovernmental Panel on Climate Change (IPCC, 2007), water vapour over oceans has increased about 4 percent since 1970. Malaysia is also experiencing floods and flash floods that are caused by the unexpected high intensity of rainfall events. A scientific report published by the Malaysian Meteorology Department, (Malaysian Meteorology Department, 2009) reveals that extreme rainfall events that had occurred in recent years were possibly due to global climate change. Loo et al. (2015) Nevertheless, the Malaysian rainfall trends are not clearly defined since the parameter has large spatial and temporal variations.

Due to the changes in climate, the amount, intensity, frequency and type of precipitation have also been influenced. As stated by Ackerman and Knox (2007) climate refers to the variations of the physical environment within a certain time scale, topography and its location such as temperature and rainfall. Climate change scenario has always been predicted using a model at global and regional scales. Examples of such models are Global Climates Model (GCM) and Regional Climates Model (RCM) that have been used by meteorological departments in many countries. Unfortunately, there are uncertainties in RCMs and GCMs that make it very difficult to quantify (Malaysian Meteorological Department, 2009). It supports the evidence from Trenberth (2011) that climate models are challenged in their ability to correctly simulate patterns, seasonal variations, and characteristics of precipitation, and the results can be questionable. Furthermore, the climatic environment at micro and local scale levels or microclimates such as rainfall local variation is also impossible to be assessed by a global approach. In order to improve precipitation modelling such as climate diagnostics and weather forecast models, other influencing factors should be explored.

1.2 Problem Statements

Rainfall is a form of precipitation that is crucial for the hydrological cycle. The key factors of rainfall formation are from the geographical effects such as proximity to the ocean, direction of prevailing winds, latitude, elevations, distance inland, orographic effects of hilly areas and local topography. Rainfall variations can be determined by spatial and temporal effects. Temperature (Sanchez-Moreno et al., 2014) are the primary factors affecting spatial and temporal effects of rainfall variation. According to Angeline et al (2017), the nature of the underlying surface and its thermal characteristics affect the small-scale localized climates. However, the effect of physical surface attribute such as vegetation and elevation is also the medium to the occurrence of rainfall local variation.

The pattern variation of rainfall can assess climatic variation as revealed by Soltani et al.(2016). In many related studies, the factors affecting rainfall caused by these factors are revealed at a global scale. Most of the studies such as carried out by Johansson & Chen (2003), Trenberth (2011), Schmidt et al. (2014) and Loo et al. (2015) had found that climate is the main factor and primary variable contributing to the rainfall variation. However, the local geographical factors in microclimate have also become the main contributor to the occurrence of rainfall local variation. Perry & Hollis (2005) emphasize on the role of climate data which is often strongly related to topographic and geographic variables, and it is important to incorporate these factors. Thus, it is also crucial to carry out explorations on local rainfall variation. Unfortunately, the local variation is difficult to explore in the past due to unavailable or limited approach. Since spatial data is now available at a local scale, new approaches can be utilized for local rainfall analysis and modelling rainfall variation at a local level.

The primary variables in rainfall spatial variation can be In microclimates, the variation of rainfall might be affected by the relationships among the secondary variables within the spatial context. As mentioned by Gundogdu & Esen (2010), the secondary variables play a major role for spatial and temporal rainfall distribution. The spatial variation of rainfall at the local level is very much influenced by the characteristics of the earth surface including the physical attributes or topography as well as the vegetation cover (Peters et al., 2011). Thus, a comprehensive study on the secondary variables or the influencing factors of rainfall spatial variation such as vegetation and topography is very important to significantly estimate rainfall spatial variation.

The vegetation cover of an area can affect rainfall due to human activities such as deforestation and urbanization (Bajocco et al., 2012). Recent studies of precipitation in urban areas such as found in Shepherd and Mote (2009) reveal the impact of urbanization on the local precipitation of urban areas for developed countries, which may affected by the vegetation heterogeneity. The vegetation heterogeneity may trigger the phenomenon of microclimates based on the spatial relationship between vegetation and rainfall at the local scale area.

Most of the important sources of vegetation indicators are based on the vegetation indices from satellite remote sensing imagery. The remotely sensed vegetation indices namely Normalized Difference Vegetation Index (NDVI) had been used as an indicator for vegetation productivity in relation to rainfall and study on the impact of vegetation to the rainfall variability such as reported by Wang et al.(2003), Klein & Roehrig (2006) and Erasmi et al. (2009). However, the relationship between rainfall and vegetation is generally predicted and demonstrated at the global environment level. Thus, the hidden phenomena at the location base or local level are still proven unsatisfactory in the non-stationary variables such as the relationship between rainfall and vegetation.

Rainfall always increases with topography like elevation due to the orographic effect (Smith, 1979). Cerlini et. al (2005) revealed that the condensation and evaporation forced by atmospheric motion bring about orographic influences. The orographic influences of the rainfall can be categorized from an individual hilly size to mountain ranges. According to Johansson and Chen (2003), mountain slopes and wind direction also give the orographic influence to the rainfall variation over the area. Strong surface process and mountain climates can be identified based on a local scale of precipitation such as found in Rotach and Zardi (2007). Thus, local variation of rainfall may occur due to the interaction between local topography and other variables at a micro scale level. However, the global approach is commonly used to estimate rainfall due to orographic effects. Most of the methods utilize global precipitation datasets for rainfall global modelling from gauging instruments and remote sensing satellite rainfall products (Sun et al., 2017).

When using a global approach, the local variation is unable to be highlighted and may not represent good variations at any individual locations. This shows that the variation factors at the micro level such as microclimates are impossible to be investigated. To really capture detailed variation at a specific location, a locally-based approach should be applied. Conversely, a local model can utilize some subsets of the data which can provide a better model fit (Lloyd, 2011). Thus, the main variations of the physical properties at a very local area such as rainfall and its relationship to other influencing factors need to be explored by local modelling methods.

In order to derive the information related to microclimates, particular emphasis on the relationship between rainfall and other influencing variables should be carried out at a local level. Thus, the implementation of local approach on the variables is believed to be useful for exploring and investigating the localized factors of rainfall variation. Both studies carried out by Propastin and Kappas (2008) and Usman et al.(2013) have indicate better prediction of rainfall-vegetation relationship. The altitude and rainfall relationship has also been established by Brunsdon et al. (2001) as well as Al-Ahmadi & Al-Ahmadi (2013). However, these studies focus on the influences of rainfall on vegetation and topography. Thus, the microclimatic changes in rainfall variation due to the relationship between rainfall and several variables such as vegetation and topography have not been explored.

Current researches in the relationship between rainfall and vegetation carried out by Zhao et al. (2014) and Georganos (2016) define rainfall as the explanatory variable. Until recently, the related researches on the local spatial variations of rainfall in the relationships between rainfall, vegetation and elevation at the local level are still not explored thoroughly.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this study is to assess the local spatial variation in the relationships between rainfall, vegetation and elevation using local modelling approach.

1.3.2 Objectives

Based on the aim above, the objectives are stated as follows:

i. To evaluate the spatial patterns of rainfall, vegetation and elevation.

ii. To model the global relationships between rainfall, vegetation and elevation.

iii. To assess the spatial variation of rainfall based on the relationship between rainfall, vegetation and elevation.

1.4 Scope of Research

The limitation of this research includes the following:

1) Research study area

The study area consists of six states in peninsular Malaysia. The states are (i) Perlis; (ii) Kedah except for Langkawi Island; (iii) Penang; and (iv) Perak, (v) Kelantan; and (vi) Terengganu. The selection of different sub regions is due to the separated regions by the Titiwangsa Mountains which affect different climates from wind flow and local topographic. Thus, the comparisons of rainfall spatial variation patterns between the regions can be identified. Figure 1.1 shows the location of the 277 rainfall stations of the study areas.

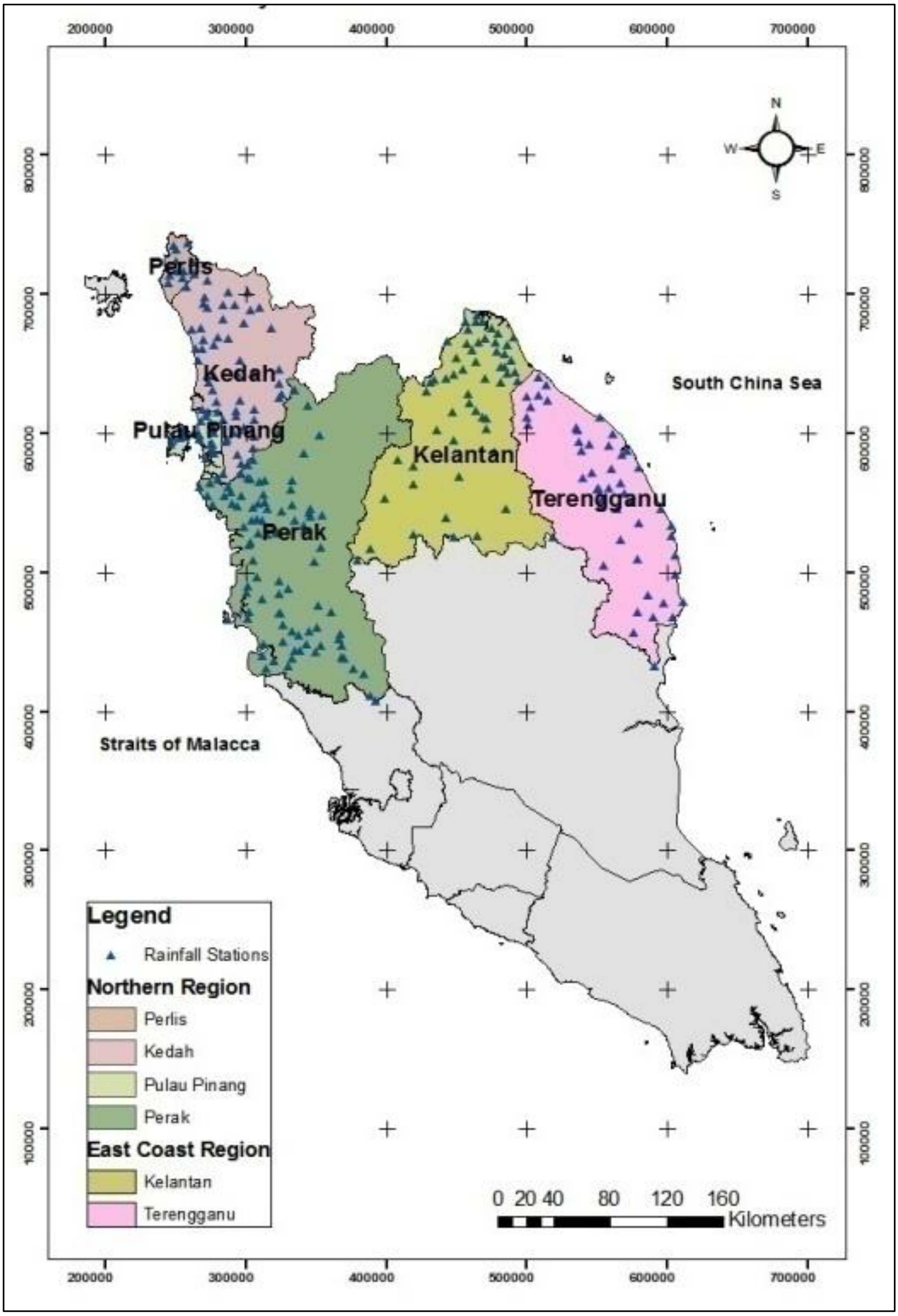

Figure 1.1: Location of Study Areas and Rainfall Stations

2) The availability of rainfall data

In this research, annual rainfall depths between 1996 to 2011 of 277 rainfall stations within the Northern and East Coast Regions of Peninsular Malaysia (refer to Figure 1.1) were used to explore the rainfall spatial variation. The selection of the 16 years of data duration is due to the most rainfall data availability of the stations based on the consistencies of the rainfall station numbers within the period.

3) The selection and the availability of satellite images

Satellite images were used to generate Normalized Difference Vegetation Index (NDVI) for the vegetation input parameter in the regression model. In this research, Landsat 5 and Landsat 7 ETM+ were used to derive NDVI since the spatial resolution of the image is better than other low spatial resolution images such as MODIS and NOAA. However, the availability of Landsat images limit the data collected. To get the full NDVI scenes coverage of the study area, the image mosaicking of the scenes was performed. Only three complete scenes were available for NDVI data in this research which are the datasets of years 2000, 2009 and 2011.

4) The selection and availability of topographical data

The topographical dataset i.e. elevation is also one of the important parameters used to assess the local spatial variation of rainfall. Basically, the parameters of topography may consist of elevation, slope and aspect. However in this study, only elevation is used since this parameter is good enough to represent topographical factors that related to the local variation of rainfall. The studies related to the significant selection of elevation as the topographical parameter in rainfall variation is discussed in Chapter 2.

The elevation data of the rainfall station provided by the Department of Irrigation and Drainage (DID) was incomplete. Thus, other data sources from Digital Elevation Model (DEM) of contours and GPS measurements were used. GPS measurements for the rainfall stations were needed to complete the elevation data within the study areas since the contours datasets were 20m intervals and for elevation below than 20m was not available.

1.5 Significance of the Study

The spatial variation of rainfall should be related to the spatial factors that affect the rainfall variation. At a local level, the exploration on the spatial variation of rainfall improves the estimation of rainfall local variation with meaningful interpretation and information. Furthermore, the related factors influencing spatial variation of rainfall can be proven.

Understanding the spatial variation of rainfall is beneficial for the local authority, urban planner and other related agencies to control the effects of rainfall local variation in planning continuous development, agricultural and urban areas due to the degradation of the vegetated areas. Instead of associating other factors such as urban heat island, the exploration of the relationships between rainfall, vegetation and elevation is useful to be linked to the phenomenon of current microclimates. The unusual rainfall event may also be associated with a spatial impact such as the effects of unexpected flash floods. Thus, human activities such as deforestation which may reflect the vegetation degradation of the area may also give impact to the spatial variation of rainfall.

From a technical perspective, vegetation measurement can also play a major role to explore spatial variation of rainfall. Without the capability of remotely sensed images in providing scientific computation of vegetation data, the spatial variation of rainfall due to vegetation degradation is impossible to be carried out at numerous points of data. The approach of local regression analysis on the rainfall and its relationship to vegetation and elevation provide effective and significant findings to address the issues related to the spatial variation of rainfall at a local area. Thus, the effect of microclimates to the spatial variation of rainfall can also be explored and analyzed for future planning.

1.6 Organization of Chapters

Chapter 1 highlights the background, issues, problem statements, objectives, overall methodology and the limitation of the research.

Chapter 2 reviews the theoretical background related to rainfall spatial variation. The microclimatic factors that influence spatial variation of rainfall and the explanation on available techniques for spatial variation of rainfall are also given.

Chapter 3 explains the conceptual research framework of the research and the detailed steps in data processing, data analysis and local modelling in the spatial variation of rainfall.

Chapter 4 discusses the spatial patterns of rainfall, vegetation and elevation including the rainfall background analysis of the area.

Chapter 5 focuses on the results and analysis of the spatial variation of rainfall.

Chapter 6 summarize the conclusion of the research findings and recommendations for future work.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Understanding the rainfall is the key to technological innovation in the field of hydrology. Spatial and temporal patterns of rainfall are always being predicted in various approaches. Since rainfall deals with numerous data, applying statistical technique is necessary. This chapter reviews, discusses the theory and other findings that provide the background to this study. Factors influencing rainfall spatial variation as well as the related techniques of rainfall measurement and estimation methods are reviewed comprehensively. The main approach used to model rainfall spatial variation that influences factors in this study is GIS spatial statistics which is discussed in this chapter.

2.2 Hydrological Cycle Water Balance

Water balance is crucial for universal welfare and harmony. Various processes involve in the hydrological cycle to achieve water balance. The processes are based on the pathway where water travels either through air, over the ground surface or through the earth's strata. Most of the hydrologists and meteorologists such as Arnell (2002), Ackerman and Knox (2007) and Ward and Trimble (2004) clarify that water transportation processes such as evaporation, condensation, precipitation, transpiration, infiltration, runoff and groundwater flow are essential in the hydrological cycle. Among these processes, precipitation is the most important component that brings water to the surface of the earth.

According to Davie (2008), evaporation, precipitation and runoff are the fundamental processes of concern in hydrology. Beginning from the sun heat that leads to water evaporation from the surface of the oceans, water will change from liquid to gas or vapour and lifted to the atmosphere. According to Bengtsson (2014), clouds are formed from condensation of water vapour when the uplifted moist air is being cooled and moisturized. Precipitation then occurs when the water vapour condenses into liquid (or solid) again, falls to the earth surface and moves by overland flow through several paths. However, the rates of evaporation and precipitation are imbalanced. At this stage, runoff and groundwater flow to the oceans are very important parts to balance the water cycle (refer to Figure 2.1).

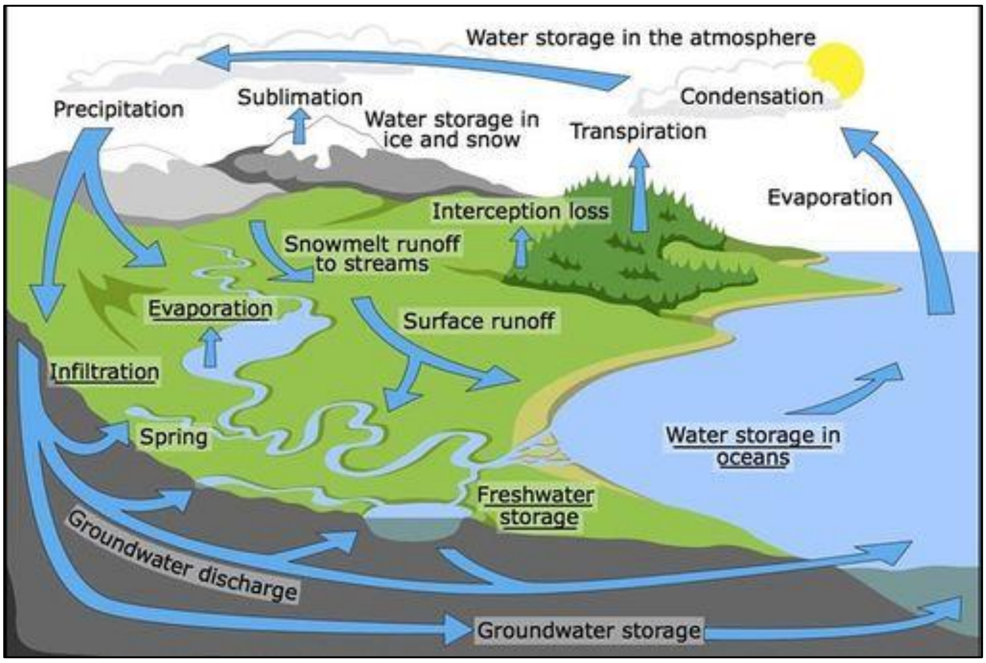

Figure 2.1: Hydrological Cycle
(Source : United States Geological Survey (2013))

2.3 Types of Rainfall

Depending on the atmospheric conditions, rainfall can be in any forms of moisture appearing from the clouds. The atmospheric condition can be influenced by the sun’s heat. Generally, the occurrences of rainfall can be categorized into three types of mechanisms namely convective, orographic and frontal.

In tropical regions, convective rainfall always contributes to the formation of whirling thunderstorms (Rakhecha & Singh, 2009). Convectional rainfall frequently occurs in a short duration and highly localized but heavy. Due to the heat of the sun, the air becomes very hot, light, rises upward and cooled. The air is then condences to form the cumulus cloud, which is then saturated and heavy and thundery rainfall turn out.

Ackerman & Knox, 2007 claims that orographic rainfall is heavy and prolonged which may occur when the air flow is deflected upward by upland areas such as mountains. Details about orographic rainfall are explaned in Section 2.5.2.

The frontal rainfall may occur when the stratus cloud becomes saturated. It is also known as cyclonic rainfall and generally occur beyond the tropics. As mentioned by Arnell (2002), the rises of warm air, later will become lighter, expands, cools and condences to form stratus cloud which lead to the occurance of the frontal rainfall. Tropical cyclones is the example of frontal rainfall, which bring flood risk impact such as found in Zhang et al. (2017).

2.4 Spatial and Temporal Rainfall Variation

Rainfall is highly varied in space and time due to several factors. Basically, the effects of spatial and temporal variability to the rainfall are rainfall amounts frequency and intensity. The rainfall spatial variation is always referred to as the variation of rainfall with respect to the coverage area either point or areal rainfall with the influence of geographical factors, environmental factors and man-made features (Huddart & Stott, 2010). According to Ackerman & Knox (2007) the temporal variability of rainfall depends on time scale or the temporal resolution like hourly, daily, monthly or annual rainfall amounts. The effect of seasonality is considered as an important aspect in the temporal rainfall variability which contributes to the variation of rainfall amount. For example, Varikoden et al.

(2011) explore the rainfall intensities variation for different monsoon seasons in Peninsular Malaysia and categorize the intensities variation based on monsoon seasonal factors.

At the global scale, rainfall spatial and temporal variability in terms of space and time or temporal and spatial variations will fluctuate the climate as studied by Nicholson (2000). The main influencing parameter is more likely geographical factors. Nevertheless, the variations of rainfall are also influenced by the climate change which is related to human activities. Based on the study carried out by Sabziparvar et al. (2014), the geographical factors such as elevation or orographic effects (Cerlini et al., 2005) and latitudinal (Grist & Nicholson, 2001) are the main factors that influence rainfall variation. Meanwhile, human activities such as land degradation anthropogenic activities cause air pollution that affects the atmospheric aerosols as studied in Tao et al. (2012) and Ramachandran & Kedia (2013). Thus, the rainfall variation is also affected. Most of these researchers find that the dynamic of climates such as rainfall variation has been disturbed by the aerosols when the formation of cloud particles and the persistent radiative forces the climate system.

At the local scale, spatial variation of rainfall is part of microclimatic variation of an area whereas the larger scale of meteorology conditions and the localized topographic elements are considered as the main contributors of the variation. Hence, the contributing factors of microclimatic features can be considered as the factors affecting rainfall spatial variation at the local level. The factors affecting microclimates can be divided into two categories: natural environment and man-made features (Rosenberg et al., 1983). Details of these factors will be discussed in the next section.

2.5 Microclimates

Climate conditions of an area are the main influencing factors to the formation of rainfall, which is a form of precipitation. Rainfall spatial variation regarding climates can be categorized based on the scale of the studies. As mentioned by Sani (1995), climates can be divided into four types of scales: macroclimate, regional climate, mesoscale climate and microclimate. Therefore, the level of rainfall spatial variation can be determined based on the scale range of the climates. At macroscale to the mesoscale level, the variation of rainfall may be induced by meteorological factors and other climatic elements such as geographical factors.

According to Peters et al. (2010), topographical surface and vegetation cover are the main contributing factors to the local variation of rainfall. Land use type such as forested area, urbanization, industrialization and residential also induce the microclimate conditions of the area. Hence, the factors that affect microclimates can be classified into two main factors that are natural environment and man-made as mentioned in the previous section. The natural environment consists of physical attributes of topographical and earth characteristics such as soil type and vegetation cover as well as the sun angle exposure and latitude. While, the examples of man-made factors are artificial structures of building and road, deforestation and land cover changes. In this chapter, only the earth surface characteristics in the microclimates conditions as related to the rainfall spatial variation or vice versa will be reviewed in detail which are topographical features and vegetation cover.

2.5.1 Vegetation

Vegetation is one of the natural environmental factors that affects climate since it covers part of the earth. All kinds of plants from evergreen forest to grassy meadows and cropland are categorized as vegetation. In the concept of hydrological cycle, vegetations contributes to the process of water cycle and the earth's energy balance as described by Kuchment (2004). As stated in the earlier section of this chapter, i.e. Review of the hydrological cycle, some of the water vapour can also be released by vegetation. By controlling the humidity and temperature surrounding their leaves through the process of transpiration, micro-weather can be produced by vegetations. Through the evatranspiration process, both albedo and the amount of water vapour and carbon dioxide can be affected by vegetation.

The influence of vegetation to global climate change has studied by Poorter & Perez-Soba (2001) which the cause is excessive Carbon Dioxide (CO_2) in the air released by the fuel combustion or deforestation. It will affect the natural process of photosynthesis. When the vegetation cover declines due to deforestation, the level of CO_2 also increases since the evapotranspiration process is intercepted and brings more runoff from land into stream and rivers. Morie (2007) mentions that vegetation degradation due to the changes of forest to other land use, e.g. bare land, agricultural or built area may increase runoff and frequency of flooding. The hypothesis by Nicholson (2000) also supports the role of vegetation that can affect rainfall variation at large scale atmosphere since the mechanism between land surface such as vegetation cover, albedo and soil moisture and the atmosphere will cause fluctuations of rainfall amounts and patterns.

On the other hand, microclimates are also induced by the variation of vegetation. Crocker (1956) mentions that the presence of vegetation apart from type of soil and type of plants is one of the important elements in determining the microclimate. At the local scale, the air flow patterns, local temperature and humidity changes, and the effect to the microclimate as elaborated by Hogan (2012) can also be influenced by vegetation cover. Therefore, the spatial patterns of rainfall are also impacted. Other related factors that support the vegetation cover as the natural factor affecting microclimates are wind speed and direction, and the structure of vegetation cover itself such as forest density and canopy. These facts clearly demonstrate that there are spatial relationships exist between rainfall and vegetation.

Basically, vegetation can be measured in various approaches based on the data requirements of the application. As described by Bonham (2013), vegetation frequency, cover, density and biomass are the necessary attributes in vegetation measurement. The methods used to measure vegetation attributes are sampling and surveying. Nevertheless, the vegetation measurement for a larger area is more practical to be carried out using remote sensing approach. To quantify the vegetation as the parameter based on remote sensing technique, vegetation index or vegetation indices are needed. The terms of vegetation index (VI) has been explained by Gao (2009) as an arithmetic disparity between pixel values or the algorithm which is generated from the combination of remote sensing bands of the same imagery. In essence, the VI of remote sensing images represents the greenness level and biomass of vegetation.

The finding on vegetation classification by Jackson & Huete (1991) reveals that the Normalized Difference Vegetation Index (NDVI) is one of the most commonly used of the vegetation indices. The NDVI values can be affected by many factors such as vegetation photosynthetic activity, total vegetation cover, biomass, vegetation and soil moisture. Thus, NDVI can be used in various researches since the index values can be correlated with many ecosystem attributes. In addition, the differences in illumination within an image due to slope and aspect can be compensated and differentiated in temporal images such as wet and dry seasons based on the ratio of two bands from NDVI helps. As such vegetation indices like NDVI are possible to be used in monitoring and detecting significant changes of the ecology.

The first concept of NDVI was introduced by Kriegler et al. (1969) and Rouse et al. (1973) was the first inventor of NDVI to monitor vegetation system. There are several NDVI datasets that can be obtained from spectral bands with different spatial and temporal resolutions of satellite images. Pettorelli et al. (2005) review four types of satellite images that are capable to capture vegetation measurement for NDVI. Table 2.1 summarizes the NDVI datasets taken from different satellite data. In remote sensing images, the algorithms of NDVI can be derived from the spectral bands of visible red (0.58-0.68 micrometers) and the near-infrared (0.75-1.1 micrometers). The equation of NDVI is shown in Equation 2.1 where the subtracted of near-infrared (NIR) to red band (RED) is divided by the sum of near-infrared and red bands.

$$NDVI = (NIR - RED) / (NIR + RED)$$

(Equation 2.1)

where

NDVI - Normalized Difference Vegetation Index

NIR - Near Infrared

RED - Visible Red

The greenness level of vegetation from NDVI is based on the fact that the healthy vegetation reflects NIR while absorbing red. It can be interpreted based on the index measurement ranging from 1 to -1. The large amount of vegetation properties is indicated by large values of NDVI ranging from +0.2 to +0.9. The high values of NDVI represent dense vegetation and can be found in tropical forests which can approximately be interpreted from 0.6 to 0.5 index values. The moderate values of NDVI can be found in shrubs and grassland or field crops areas with the index values approximately ranging from +0.2 to +0.5. The pixel values between -0.1 and +0.1 represent bare soils area while the negative NDVI values indicate barren rock, clouds and water including snow and ice (Weier and Herring, 2000).

Table 2.1: List of NDVI from different Satellite Images
(Source: (Pettorelli et al., 2005)

Satellites/Sensors	Sensors	Spatial Resolution/Dataset	Temporal Resolution
NOAA (National Oceanic and Atmospheric Administration)	AVHRR (Advanced Very High Resolution Radiometer)	8km/PAL 16km/GVI 8km/GIMMS	1 day, 10-day, monthly seasonal weekly, monthly, seasonal bimonthly index (10-day for Africa)
TERRA (Earth Observation System AM - EOS AM)	MODIS (Moderate-resolution Imaging Spectroradiometer)	250m - 1km/MOD13	16 days
Landsat 4, 5 Landsat 7 Landsat 8	TM (Thematic Mapper) ETM+ (Enhanced Thematic Mapper) OLI (Operational Land Imager)	30m 30m	16 days
VGT (VEGETATION)	SPOT (Satellites Pour l'Observation de la Terre/Earth Observation Satellite)	1km	10 days

2.5.2 Topography

As one of the most common climatic variables, rainfall becomes a very critical phenomenon since it regulates water cycle in the environment. As written by Linacre and Geerts (1997), climate is governed by geographical factors. Such influencing factors are hemisphere, latitude, elevation, distance inland, sea surface temperature upwind, upwind topography and local topography. Nevertheless, the sufficient information of climate will be based on temperature, precipitation, wind direction and topography. Studies regarding the effects of local topographical features to the rainfall spatial variation have been carried out on elevation (Daly et al., 1994; Daly et al., 2002), slope (Basist and Bell, 1994) geographic location and aspect (Oettli and Camberlin, 2005) and proximity to moisture area (Hayward and Clarke, 1996).

As one of the natural environmental factors, topography can induce spatial variation of rainfall. Elevation is the main feature of topography that affects precipitation of an area. The term orographic precipitation or relief as mentioned by Wan Ruslan (1994) is used to describe precipitation at highlands or mountainous areas. The precipitation amounts and intensity of an area vary based on three factors namely elevation and mountain barrier structure, air moisture and stability as well as the thickness layer of lifted moist air. Bookhagen and Burbank (2006) demonstrated that high altitude locations receive maximum rainfall amount during past, intensified monsoon phases with similar distribution of relief based on the study of the relationship between topography, relief and rainfall location. Another finding by Johansson and Chen (2003) also revealed the strong relationship between daily precipitation amounts and the orography when the relationship between precipitation and topography is established at the rain gauge located near the mountainous area. This demonstrates that the topography elements such as elevation can affect the spatial variation of rainfall where most high altitude locations and relief are likely to receive maximum amount of rainfall compared to low land areas.

Other topographical features such as slope, geographic location as well as aspect and proximity to moisture area also contribute to the variation in rainfall amount. As studied by Basists and Bell (1994), the relationship between mean annual precipitation and slope at five different locations are linear compared to other topographical features. This shows that slope is more significant to be utilized as the predictor factor relating the topography to the rainfall spatial variation. However, the geographic location and aspect can also be associated to the rainfall spatial variation since the exposure of the regions to the seasonal factor