CHARACTERIZATION OF MODERN WATER ISOTOPES OF NORTHEAST MONSOON PRECIPITATION IN KELANTAN

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2019

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by

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Thesis submitted is fulfilment of the requirements for the degree of Master of Science

March 2019

ACKNOWLEDGEMENT

First of all, I would like to thanks to Allah the most gracious and most merciful, for giving me strength and wisdom in completing this thesis successfully. Thanks also to Universiti Sains Malaysia and the School of Industrial Technology for accepting me to do my postgraduate study in this institution.

I would like to express my special gratitude to my supervisors, Dr. Muhammad Izzuddin Syakir Bin Ishak and Assoc. Prof. Dr. Yusri Bin Yusop for their guidance and encouragement throughout completing this thesis. They had sacrificed their time and ideas to assist and guide me to complete this journey.

My appreciation also goes to my previous Industrial training supervisor, Mr. Roslanzairi Bin Mostapa from Malaysian Nuclear Agency for helping me to analyze the isotope data, giving his valuable feedback and sharing knowledge to improve my thesis content. Not to forget, thanks to the International Atomic Energy Agency and Malaysian Nuclear Agency for supplying valuable data as a part of my thesis.

I also deeply indebted to my parents for their ending prayer, support, motivation, and blessing. Last but not least, thanks to all my friends for helping and encourage me in completing this thesis.

TABLE OF CONTENT

CHAPTER 3- METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

IAEA	International Atomic Energy Agency
NEM	Northeast Monsoon
ITCZ	Intertropical Convergent Zone
LMWL	Local Meteoric Water Line
SWM	Southwest Monsoon
ENSO	El Nino Southern Oscillation
UNISDR	United Nations Office for Disaster Risk Reduction
GCMs	Global Climate Models
SDG	Sustainable Development Goal
V-SMOW	Vienna Standard Mean Ocean Water
GMWL	Global Meteoric Water Line
MWL	Meteoric Water Line
SWAT	Soil and Water Assessment Tool
D-excess	Deuterium Excess
IRMS	Isotopic Ratio Mass Spectrometer
MTW	Malaysian Tap Water
WMO	World Meteorological Organization
GNIP	Global Network for Isotopes in Precipitation
ETAG	Environmental Tracer Group
WES	Water Equilibration System
CF–IRMS	Continuous Flow Isotope Ratio Mass Spectrometer
SMOW	Standard Mean Ocean Water
IDW	Inverse Distance Weighting
GIS	Geographic Information System

LIST OF SYMBOLS

^{18}O	Oxygen-18
^{2}H	Deuterium
^{1}H	Protium
^{3}H	Tritium
^{16}O	Oxygen-16
^{17}O	Oxygen-17
$H_2{}^{18}O$,	Water
$^{1}H_2H^{16}O$	Water
$\delta^{18}O$	Delta oxygen-18
$\delta^{2}H$	Delta deuterium
ml	Milliliter
^{o}C	Degree celsius
CO_2	Carbon dioxide
$\pm$	Plus-minus
mm	Millimeter
Max	Maximum
Min	Minimum
‰	Per mil
<	Less than
>	More than

PENCIRIAN ISOTOP STABIL MODEN DALAM HUJAN MONSUN TIMUR LAUT DI KELANTAN

ABSTRAK

Ciri-ciri oksigen-18 dan deuterium dalam hujan telah dikaji bagi memahami mekanisma kitaran air semasa musim monsun timur laut dari tahun 2013 hingga 2016. Komposisi isotop dalam hujan di Kelantan telah menunjukkan ciri-ciri monsun dengan memberikan variasi nilai bagi $\delta^{18}O$ dan $\delta^{2}H$ pada hujan di Semenanjung Malaysia yang mencerminkan keadaan iklim serantau; dipengaruhi oleh ITCZ. Walaupun sistem iklim ini bersifat konsisten, kejadian hujan lebat turut mempunyai potensi bagi berlakunya bencana banjir seperti yang berlaku di Kelantan pada tahun 2014. Tanda-tanda hujan yang berterusan telah diperhatikan berdasarkan bacaan isotop pada tahun tersebut. Seterusnya, pada tahun 2015 nilai bacaan isotop pada hujan telah memperlihatkan ciri-ciri fenomena El Nino. Bacaan *D-Excess* yang tertinggi yakni 14.48‰ telah direkodkan pada bulan Disember 2015 yang mencerminkan keadaan yang kering pada masa tersebut. Sementara itu, bagi tahun 2013 dan 2016, hasil dapatan menunjukkan ciri-ciri isotop yang hanya mengikuti konsep *Rayleigh distillation* seperti sediakala. Peristiwa hujan yang dinamik telah diperhatikan pada LMWL dalam sistem tropika dengan menunjukkan variasi oksigen-18 dan deuterium yang berkait rapat dengan perubahan iklim serantau.

CHARACTERIZATION OF MODERN WATER ISOTOPES OF NORTHEAST MONSOON PRECIPITATION IN KELANTAN

ABSTRACT

The characteristics of oxygen-18 and deuterium in precipitation were investigated to understand the input mechanism of the water cycle during NEM season from the year 2013 to 2016. The isotopic composition of Kelantan precipitation reflects the monsoon signature across time. It demonstrates a little variation of isotopic values for $\delta^{18}O$ and $\delta^{2}H$ in Peninsular Malaysia precipitation which reflects the regional climatic setting that driven by ITCZ. Despite consistent climate system, the precipitation may have potential natural hazard to Kelantan watershed in 2014. Continuous moisture supply is observed showing the enrichment in the isotopic composition during that particular year. Furthermore, it has been observed that the isotopic variation of 2015 precipitation was characterized by the El Nino phenomenon. Highest D-excess reading (14.48‰) was recorded in December 2015 suggesting dry condition effect from this event. While for 2013 and 2016, the results demonstrate common isotopic characteristic which follows the Rayleigh distillation concept. Dynamic water input observed to fall within the LMWL of a tropical system. The variations of oxygen-18 and deuterium in precipitation indicate the isotopic characteristic with respect to particular changes of the regional climate system at a particular time.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Water stable isotope has been a major emphasis on some agencies worldwide in collaboration with International Atomic Energy Agency (IAEA). This issue has been discussed critically in concern to climate change that continuously affects nature and humanity. Malaysia also has been participating in such program to ensure their water resources remain sustainable in the future. This study focuses on characterization of stable isotope of precipitation during Northeast Monsoon (NEM) to understand the dynamic of water input regime in catchment area of tropical region especially in Kelantan watershed. Such understanding will provide useful information on moisture condition and the enrich perspective of water input regime of east coast Peninsular Malaysia.

Kelantan watershed was selected due to its vulnerability to flood disaster, particularly during NEM season. The 2014 flood disaster has been recorded to be the worst flood in Malaysia. This event was worsen when Gua Musang, Kelantan received high amount of precipitation due to three days nonstop heavy rainfall recorded from 21st untill 23rd December 2014 (Baharuddin et al., 2015). The continuous heavy rainfall eventually caused the water level at three main river (Sungai Galas, Sungai Lebir and Sungai Kelantan) to overflow and exceeded the danger level as reported by Portal Rasmi eBanjir Negeri Kelantan (2015). Table 1.1 shows the details on the river water level for three main rivers in Kelantan. The highest water level recorded for Sungai Galas was 46.47 mm which exceeded the danger level (38.00 mm), Sungai Lebir was at 42.17 mm, exceeding the danger level of 35.00 mm and for Sungai Kelantan at Tangga Krai was at 34.17 mm exceeding the danger level of 25.00 mm.

Table 1.1: River water level recorded by Portal Rasmi eBanjir Negeri Kelantan.

Main River	Level (mm)					Date
	Normal	Alert	Warning	Danger	Recorded	
Sg Galas (Dabong)	28.00	32.00	35.00	38.00	46.47	24th Dec 2014
Sg Lebir (Tualang)	23.00	27.00	31.00	35.00	42.17	24th Dec 2014
Sg Kelantan (Tangga Krai)	17.00	20.00	22.50	25.00	34.17	25th Dec 2014
Sg Kelantan (Jambatan Guillemard)	10.00	12.00	14.00	16.00	22.00	26th Dec 2014
Sg Kelantan (Tambatan Di Raja)	1.00	3.00	4.00	5.00	6.89	26th Dec 2014

Climate was identified as the main factor of the 2014 Kelantan flood disaster (Khan et al., 2014; Syakir et al., 2016; Kulatunga, et al., 2016). Such claim highlighted the importance of understanding the particular rainfall regime that drive the water input of tropical region during particularly NEM. In this regards, stable isotopes technique offers a solution in determining the oxygen-18 (^{18}O) and deuterium (^{2}H) of monsoon precipitation, thus, provides insights of the water input system in Kelantan. Rainwater samples at Kota Bharu, Kelantan has been collected to characterize the ^{18}O and ^{2}H which potentially will provide a snapshot in understanding the monsoon regime that drives the water input. This shall complement natural hazard assessment of NEM precipitation in Kelantan.

Many studies have been conducted regarding climatic concern affecting phenomenon such as flood disaster or drought. This will be further explained in Chapter 2. A majority of the studies done have been using conventional method for data collection which include parameters such as: rainfall amount, rainfall duration, rainfall intensity, rainfall aggressiveness and also temperature changes. Such techniques are useful in providing the trend of rainfall pattern which have been used for forecasting the future climate by using the current data (Cooper et al., 2008; Smith, Villarini & Baeck, 2011; Chabala, Kuntashula & Kaluba, 2013). However, isotope technique can provide more understanding on the external factors that drives the water input pattern and shed some light on the moisture condition (Dansgaard, 1964; Kurita et al., 2003) which can give impact toward water cycle (Pang et al, 2011).

1.2 Problem Statement

Monsoon season is often associated with natural disaster such as flood due to continuous heavy rainfall driven by Intertropical Convergent Zone (ITCZ). This extreme event (flood) becoming worse due to the changes in climate (Kulatunga et al., 2016). Climate change is caused by the changes in temperature often referred to as global warming. In tropics contexts, the increase in temperature will lead to greater evaporation of water vapor in the atmosphere and eventually promote the increase in tropical rainfall (O'Gorman & Schneider, 2009; Trenberth, 2011).

In order to adapt with this climate changes, several actions have been taken by researchers by conducting research in relation to future climate. Conventional method is widely used to forecast future climate by using current rainfall data. However, findings using this method would only provide the rainfall pattern. Therefore, the isotopic technique will complement the limitation of the conventional method. Result from this study by using modern data could tell the story on how the moisture condition behave, which cause the flood disaster. By understanding this modern isotopic behavior, this will eventually increase the confidence for future climate prediction by implementing the paleoclimate data for the future study.

1.3 Objectives of the Study

The main aim of this research is to investigate the isotopic behavior of monsoon rainfall during NEM 2013 until NEM 2016. Isotope technique is applied to improve the understanding regarding the moisture condition which can complement the conventional method used. Stable isotope of oxygen and hydrogen of rainwater can give the idea on how the condition of moisture behave and their impact toward the water input regime. These characteristics are effect from the monsoon driven.

Two types of sampling (event-based and monthly-based) are observed to assess the characteristics and the capability of the isotopic technique in understanding the rainfall pattern. Each of stable isotope element in water samples contains its own unique signature. Therefore, the behavior of precipitation formation during NEM can tell the story of the monsoon regime that drive the water input in Peninsular Malaysia.

These are the three main points summarized from the objective discussed above:

1. To characterize the composition of isotopic oxygen-18 and deuterium in NEM precipitation from 2013 until 2016.
2. To define Local Meteoric Water Line (LMWL) of Kelantan and Peninsular Malaysia.
3. To identify the moisture condition of NEM precipitation.

1.4 Hypothesis

Theoretically, the formation of rainfall is dependent with the temperature (Clark & Fritz, 1997). As the temperature of vapor mass drops, condensation process would occur and form the rain. Isotope technique can provide solution to clarify this mechanism through Rayleigh Distillation concept. Therefore, in this study the concept of Rayleigh distillation was applied. Rayleigh distillation concept give the understanding on first event of rainfall that will contribute to the enrichment of isotope composition. Residual vapour and secondary evaporation will cause a depletion in isotopic composition compared to the first event occurred (Clark & Fritz, 1997). This is due to the heavier element of oxygen and hydrogen that fall first to the ground leaving the lighter element. Figure 1.1 shows the illustration of this concept. Such phenomenon allows us to investigate further the ^{18}O and ^{2}H in NEM rainfall, thus provide the understanding on the climatic setting of Kelantan watershed.

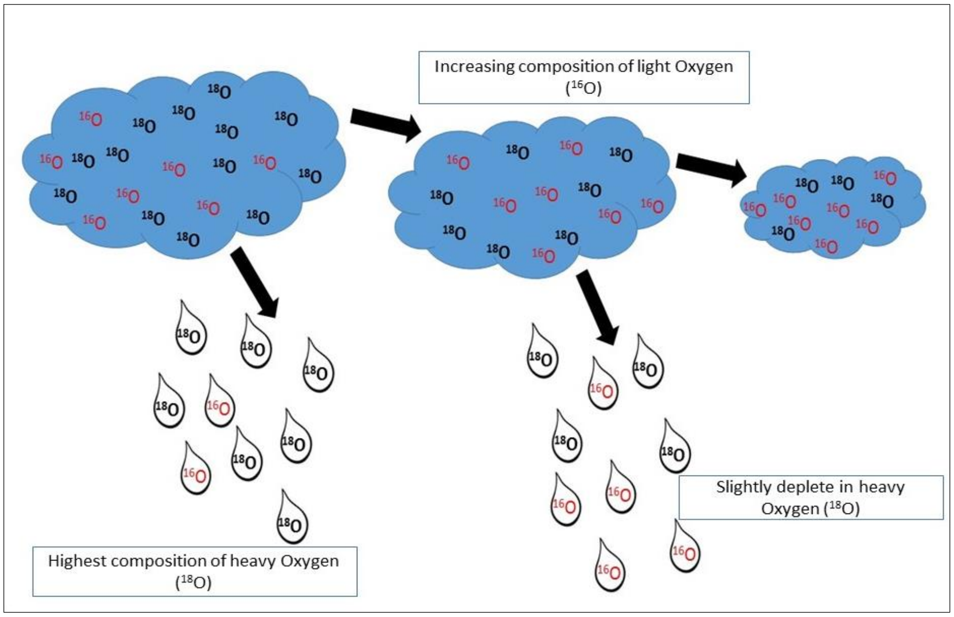

Figure 1.1: Rayleigh Distillation concept in precipitation formation showing enrichment in heavier isotope that fall to the ground on the first event followed by the light isotope.

1.5 Significance of the Study

In this study, the stable isotope of oxygen-18 and deuterium was used as the tracer in water input supply in Malaysia. These molecules have their own fingerprint to track the behavior of precipitation formation and also the moisture source condition which determine the rainfall event at particular time. The characteristic of modern stable isotope of precipitation will give the understanding on how the monsoon rainfall behave which lead to the disaster as seen recently. In addition, by using isotopic technique which include the data from past climate combining with the modern collected data, future climate can be concluded (Bruckner, 2018). In other words, if this study is further explored by identifying the trend that happened in the previous years, full view of climate trend behavior from back then until recent can be identified. This is because, the understanding of the past would help to explain what is happening currently and what will occur in the future year. Therefore, this study can serve the modern isotopic data as the baseline for past climate investigation also called as paleoclimatology. By understanding the modern pattern, it will complement the paleoclimate study to interpret the future climate for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Causes of the Climate Changes

Recently, climate change is one of the critical issues that is discussed worldwide (Sturm et al., 2010). The changes in climate are caused by the effect of global warming. Anthropogenic activities such as deforestation, burning of fossil fuel and etc. had worsened this warming condition. Such activities will lead towards the bulk production of carbon dioxide causing the greenhouse gases to become concentrated in the atmosphere. Greenhouse gases at the atmosphere comprised of carbon dioxide, water vapor, methane, and ozone are used to adjust and keep the earth surface and lower atmosphere at warm condition (Berner & Berner, 1996; Callery, 2017). Infrared radiation from sunlight will be absorbed by these gases and then spread to earth, hindering the heat rising into space too fast to maintain the warmth of the earth. However, the climate will be affected by the presence of too much carbon dioxide in the atmosphere due to the heat trapped at the earth surface (Llewellyn, 2007).

Changes in climate can influence the hydrological cycle in many ways. The exchanges of moisture and heat between the atmosphere and the earth's surface will eventually affect the dynamic of the climate system (Chahine, 1992). This will eventually result in an extreme weather change whereby the wet season become wetter causing the abundance of water and the dry season become drier thus affecting the water availability (Ismail & Haghroosta, 2018). Therefore, by identifying changes in the trend of wet spells characteristics will provide useful information in predicting future climatic events since these variables are closely related to extreme weather (Deni et al., 2009).

2.1.1 Impact on Climate Change: Extremes Weather in Malaysia

Malaysia is located in the tropical zone, somewhere in the equator which will receive a large amount of heat from sunlight due to its position. It has the temperature ranges from 21°C to 32°C and has high rainfall variability (Syafrina et al., 2017). The greatest warming in the tropics had produced a belt of low-pressure effect from the warm condition. It will causing the warm air rise and form a region called as Intertropical Convergence Zone (ITCZ). It is also known as cloud bend. ITCZ is the region that circles the Earth, near the equator, where the trade winds of the Northern and Southern Hemispheres come together (National Centre for Atmospheric Research, 2018).

The monsoon seasons in Malaysia are controlled by the Northern and Southern hemisphere. During winter in the northern hemisphere, the combination of high pressure on China and low pressure over Australia pushes the ITCZ further south, bringing the Northeast Monsoon (NEM) (November to March) over Malaysia. The NEM brings the heaviest rainfall of the year. While during the northern hemisphere’s is summer and having low pressure over Asia and high pressure over Australia, the ITCZ migrates to the north. At this time Malaysia is experiencing the Southwest monsoon (SWM) (June to September). The average monthly rainfall for a few stations in Malaysia recorded less than 10 mm during this season (Wai et al, 2005).

As mentioned by Schiermeier (2011), climate warming is already causing extreme weather events that affect the lives of millions. Unfortunately, climate changes not only triggers the extreme weather event but also brought uncertainties in the behavior of certain weather phenomenon (Imran et al., 2014) due to its ability to control the monsoon. As a result, rainfall in many tropical regions of the world has marked fluctuations from year to year, and from decade to decade (Trewin, 2014). However, the pattern of monsoon may also be complicated by El Nino-Southern Oscillation (ENSO) (Stephen & Rose, 2005). El Nino had influenced the rainfall behavior in many parts of the tropics by changes in ocean temperatures in the eastern and central equatorial Pacific and has impacted on climate over many parts of the world (Trewin, 2014; Suhaila, 2015).

Previously, Malaysia had experienced an El Nino event during the year 1997/1998 (Yusof et al, 2012; Santoso, 2017). Again, in early 2005, large regions of Peninsular Malaysia have experienced a prolonged period of dry spells (Yusof et al, 2012). This El Nino phenomenon can also disturb the rainfall pattern over a different part of the world. El Nino events can cause some region to experience dry condition which may lead to drought. This is due to the changes in temperature that can give impacts on climate factor. In 2015, western Pacific including Malaysia again has experienced the El Nino (Santoso, 2017).

2.1.2 Flood Phenomena in Kelantan: A Classical Case of Malaysia's Flood Disaster

Natural disasters caused by nature are unavoidable, but by being aware of the impact and also being prepared with a disaster recovery plan is an action that should be looked into thoroughly (Akasah & Doraisamy., 2015). Flood is one of the natural disasters that happen caused by an overflow of water that submerges towards the land which is usually dry. It could happen due to several causes such as heavy rainfall, river overflow, strong wind in coastal areas and dam breaking. Increasing rainfall intensity has caused increase cases of flash flood and landslide within this few decades (Syafrina et al., 2015).

Recently, Malaysia had experienced some phenomena effect from the extreme weather. The events of extreme rainfall have occurred annually during NEM on the east coast states such as Kelantan, Pahang, and Terengganu, followed by Sabah and Sarawak. These states had face intense floods due to long-term or heavy rainfall (Suhaila & Jemain, 2009). This may be due to the more frequent rainy days received from the NEM (Deni et al., 2009). Even though NEM is the typical season for Malaysia having the wetter condition, but recently the behavior of rainfall become weirder.

The widespread flooding which occurred in the southern areas of Peninsular Malaysia from mid-December 2006 to late January 2007 was caused by the extreme rainfall and prolonged intense wet spells (Tangang et al., 2012). This event had contributed to around RM 2 billion losses to the country (Deni et al., 2009). While during the 2014 flood, we were surprised by the news when Kelantan suffered ‘tsunami-like disaster’ which is the worst ever in the history of a flood than the one in 1967. This weird event had caused Kelantan to collapse. The total loss of flood which occurred in Kelantan had recorded RM 200 million cost which reported to be the worst flood disaster that happened in Malaysia (FMT News, 2014). It is considered to be the worst flood in a decade where more than 200,000 people became a victim due to this disaster (Akasah & Doraisamy., 2015; Su-Lyn, 2015). Other than that, in 2016, RM 30 million cost by the flood effect also been recorded in Malaysia (News Straits Times, 2017).

2.1.3 Adaptation to Climate Change

This study will provide new insight in understanding the monsoon regime that drives the water input in Peninsular Malaysia and eventually will complement the natural hazard assessment of NEM precipitation in Kelantan thus will allow us to adapt to the climate change. The ability to understand the hydrologic processes at continental and global scales is becoming increasingly important because of the need to predict the effects of large-scale changes in land use and in climate (Dingman, 1994).

The paleoclimate and archeological research have made it plausible that wet and dry climatic condition have often been the trigger of disasters. Unfortunately, man had helped to aggravate the situation also called as Anthropocene (Sturm et al., 2010). The Anthropocene is the current geological age where the human activity has been the dominant influence on climate and environment which give impact towards the global hydrological cycle (Cuadrado-Quesada et al., 2018). Anthropocene is characterized by rapid change in the human-natural resource related to the extent that humanity could be considered. It has also been characterized by the intense use and misuse of natural resource (Cuadrado-Quesada et al., 2018).

Tracing changes via isotopic variations of oxygen and hydrogen during wet spells (NEM) will provide useful information in predicting future climatic events since these variables are closely related to extreme weather events such as flood disaster (Deni et al., 2009). This is because, rivers are very sensitive to the climate as it will give impacts on water resources management and flood control. (Kong & Pang, 2012). Flood will occur when the water input (rainfall) is more than the water output (river flow rate). The adaptation to the climate change is needed in managing the incoming disaster will happen.

This is to reduce the number of death as well as an increased cost due to the damage (Othman et al., 2015).

United Nations Office for Disaster Risk Reduction (UNISDR) had worked on Sendai Framework for disaster risk reduction. This framework consists of four major aims in reducing the disaster that frequently happens nowadays; 1) to understand the disaster risk, 2) to manage disaster risk, 3) to adapt the disaster risk and 4) to prepare for effective response and to recovery, rehabilitation, and reconstruction. Therefore, relating this study with the effort made by UNISDR in this Sendai Framework, by observing and collecting the modern climatic data as a projection for the future climate pattern can humbly contribute in assisting to achieve the third aim of Sendai Framework which is the adaptation for the disaster risk as this study will provide a better understanding of the water input regime.

2.2 Towards the Reconstruction of Precipitation Behavior

In climatology research, understanding the mechanism that drives the climate variability is crucial which highlights the importance of paleoclimatology research (Sturm et al., 2010). It has also been a concern for the sake of managing the global water resource (Cuadrado-Quesada et al., 2018). Isotopic composition of precipitation can offer major relevance for climatological and hydrological studies (Araguas-Araguas et al., 2000). Stable isotopes in water are considered as a powerful tool for paleoclimatology because the strong apparent links exist between some relevant meteorological parameters, such as surface air temperature, amount of rainfall, and the distribution patterns of stable isotopes in rainfall observed for present-day of climatic conditions (Darling, 2011). Thus, the paleoclimate data collected can provide important ground truth for the model and can lead to improved model simulation of future climate (Robinson & Harry, 2010; Logan et al., 2015).

Modern stable isotopes of oxygen and deuterium can be used to reconstruct the event of rainfall by observing the moisture supply pattern that would give impact toward the water cycle. Towards the effort of reconstructing the climatic pattern requires a combination of the modern data with the paleoclimatic data. The modern stable isotopic study can provide the data for the current pattern of precipitation behavior. This illustrates the isotopic pattern interpolating and highlighting the target area for future rainfall sampling (Bowen & Revenaugh, 2003). While the paleoclimate study can investigate the past climate in term of temperature fluctuation. By reproducing past climate data, it will increase the confidence and the ability to forecast the future climate (Araguas-Araguas et al., 2000). Therefore, by reconstructing the past climate variability and identifying its drivers can improve the understanding of the complex earth system dynamic which is the basis for climate prediction (Sturm et al, 2010).

As mentioned before, in reconstructing the precipitation behavior for the climatic projection, the combination data of past, present, and future are involved. Four stages of study are needed to validate the future climate projection. First is to investigate the past environment condition (temperature and sea level) by using proxy record such as fossil. Second is by observing the modern climate. The third stage is by combining the past climate data and modern climate data and analyzing it by using a computer model. Lastly, past climate can be concluded and future climate can be predicted (Araguas-Araguas et al., 2000; Bruckner, 2018).

In order to relate, this study will act as the baseline data in projecting the climatic pattern for future by collecting and observing the modern isotopic pattern of precipitation behavior. The precipitation trend in short-term and long-term sampling was observed to see the climatic trend and to understand the modern stable isotopic study as it is important to pursue the paleoclimate studies in future.

2.3 Precipitation Formation

Hydrological cycle studies are an important aspect of hydrology to address water-related issues (Zhang et al, 2000). The hydrological cycle involves five main components which are cloud and radiation, atmospheric moisture, precipitation, ocean fluxes and the land surface processes (Chahine, 1992). The hydrological cycle describes the movement of water on, above and below the surface of the Earth. Hydrologic cycle or also known as water cycle is the process of precipitation formation caused by the condensation of the water vapor that evaporates from the surface water to become a cloud. As the cloud gets heavy, the rain droplet would fall to the land surface and continue the process. At various stages in the cycle, water can change states from a solid to a liquid and even to a gas.

In this study, we will focus on one of the processes from a hydrological cycle which is precipitation. Precipitation which is the product of the hydrologic cycle is one of the most difficult processes to be model and predict (Chahine, 1992). Precipitation is the process of the decline of water from the atmosphere to the surface of the earth. This term covers many forms of water such as snow, hail, sleet, and rainfall (Davie, 2008). Giorgi et al (1996), stated that the formation of precipitation depends on the elevation for example, during the cold season, precipitation form at very high elevation supposedly would be decreased due to deficiency of water vapors. The precipitation amount that falls in each area is spatially and temporally different (Davie, 2006).

The process of precipitation formation is dependent on the temperature that allows air to trap the water vapor. If the air is in a cool state, less water vapor to be maintained (Davie, 2008). The formation of precipitation requires a four-step process; 1) cooling of air to approximately the dew-point temperature; 2) condensation on nuclei to form cloud droplets or ice crystals; 3) growth of droplets or crystals into raindrops, snowflakes, or hailstones; and 4) importation of water vapor to sustain the process (Dingman, 1994).

2.3.1 Precipitation Behavior in Tropical

In the global climate system, the tropical region is paramount for the moisture transfer and heat to the higher latitudes to maintenance the climatic equilibrium (Stephens & Rose, 2005). The characteristic of this region is having the small annual range of the temperature (Trewin, 2014). The annual variability of tropical rainfall is strongly related to the annual variability of the sea surface temperature, reflecting the strong coupling between the ocean and the atmosphere (Chahine, 1992). There are three types of rainfall that has been discussed by previous researchers in determining the trends of climatic events (Deni et al., 2009) which are 1) orographic rainfall occurs when an air stream is forced to rise over a mountain range and the air becomes cooler; 2) convective rainfall is associated with hot climate, and mostly occurs in tropical areas; and 3) frontal or cyclonic, which the rainfall occurs when warm air is forced to rise over colder air (Suhaila & Jemain, 2009; Dingman, 1994)

Among these three types of rainfall, the convective rainfall shows more characteristic reflecting the tropical region. The convective precipitation occurred due to the warm rise of lighter air in the cooler, denser, and stable environment (Gat, 2010). In general, this type of precipitation occurs in tropical zones whereby, the surface of the ground is heated unevenly on a hot day, hence, the hotter air will be lifted into the atmosphere and replaced by the cold air in its place. Convective precipitation occurs as a result of adiabatic cooling associated with the bulk of air that rise because they are less dense than the air that surrounds them (Dingman, 1994). Usually, the convection rain occurs within a short time and has high rainfall intensity (Gat, 2010; Civil Engineering Solution, 2013). This type of precipitation produces very intense rain, often accompanied by lightning, thunder, and hail, covering small areas and lasting less than an hour (Dingman, 1994).

2.4 Characterization of Precipitation

Water that enters the land phase through the hydrologic cycles is in the form of precipitation. With the development in industrialization as well as the rapid growth in the population, analyzing precipitation characteristics particularly on tracing the trends of wet spells is one of the important components in managing water resources not only in Malaysia but also other places in the world (Deni et al., 2009). Thus in order to assess, predict and forecast hydrologic responses, hydrologists need to understand how this characteristic of precipitation such as the amount, rate, duration and quality of precipitation is distributed in space and time (Dingman, 1994). Among these parameters, the number of rain-day, the rainfall intensity (amount per unit time) especially for extreme events and the distribution of rain-days over the season can be noted (Salih et al., 2018). Rainfall characteristics are also indicative of the underlying mechanism, such as weather. It is due to the large-scale circulation that has slow-moving weather systems or to local convection (Salih et al., 2018). The examination of these features can provide insights into the fluctuations of forcing and the mechanisms that give rise to natural hazards affected by the changes in climate, such as droughts and floods (Salih et al., 2018).

2.4.1 Case Study on Characterization of Precipitation

2.4.1(a) Case Study on the Conventional Technique

Global Climate Models (GCMs) is one of the methods used conventionally to project and evaluate the water resource changes (Xu, 1999). It acts by monitoring the current climate behavior and project the future climate pattern by observing the annual rainfall relating to the changes in temperature. A study was done by Tan et al., (2017) stated that, to achieve United Nation Sustainable Development Goals (SDGs), evaluation of future water resources under climate change is important to develop better water management system and climate adaptation strategies. GCMs are reasonably reliable in describing the response of the climate system to various forcing, but usually have a too coarse spatial resolution to provide the detailed regional-scale information needed for example for hydrological applications, water-resource management or for agricultural or urban planning (Salih et al., 2018).

Moreover, most researchers used the conventional method to monitor current precipitation and for predicting the future precipitation. For more example, Table 2.1 provides the summary of 10 years study related to the climatic concern by using conventional techniques.

Table 2.1: 10 years study of disaster-related study which concerns on climate changes.

Reference	Aim	Method: Parameter used
Murphy & Timbal, 2008	1) To simplify the conditions and mechanisms that affect the climate.	1) rainfall amount 2) temperature trend
Cooper et al., 2008	1) For the adaptation of climate change and prediction of future climate variability	1) weather forecasting
Espinoza et al., 2009	1) To provide a comprehensive study of rainfall variability 2)To determine the trend annual rainfall	1) Monthly rainfall amount
Risbey et al., 2009	1) To address the rainfall variability	1) rainfall data 2) Sea surface temperature data
Rotstayn et al., 2010	1) To understand the key drivers of decreasing rainfall	1) mean climate 2) rainfall amount
Batisani & Yarnal, 2010	1) To examine the climatic phenomenon 2) To investigate the signs of climate change 3) For climate adaptation.	1) rainfall amount
Mandapaka et al., 2010	1) To investigate the spatial structure of rainfall fields.	1) Radar-rainfall
Engida & Esteves, 2011	1) To study the temporal characteristics of daily rains at two stations in the region of the Upper Blue Nile Basin 2) To calibrate and evaluate a daily rainfall disaggregation model.	1) Rainfall intensity
Villarini et al., 2011	1) Analysis of spatial extremes of rainfall and flooding 2) to characterize the rainfall distribution	1) Total rainfall distribution
Smith, Villarini & Baeck, 2011	1) To analyze spatial and temporal structure of flood	1) climatology of floods 2) heavy rainfall data
Emmanuel et al., 2012	1) To characterize the spatial and temporal variability of different types of rain events	1) amount of rain 2) duration of rainfall 3) rain intensity
Jain, Kumar & Saharia, 2013	1) To determine trends in the monthly, annual, and seasonal total rainfall; maximum, minimum, and mean	1) temperature 2) the amount of rainfall

	temperatures; and diurnal temperature range	
Chabala, Kuntashula & Kaluba, 2013	1) To assess the extent of change in rainfall and temperature 2) To ascertain the occurrence pattern of extreme climatic events.	1) Rainfall amount 2) Temperature
Trono et al., 2014	1) To design and develop an integrated web-based system for tropical rainfall monitoring.	1) rainfall intensity
Wang & McBean, 2014	1) To assess relationships between the period of historical rainfall record and the uncertainties of predictions.	1) rainfall intensity 2) rainfall duration 3) rainfall frequency
Garambois et al., (2014)	1) For predicting flood and characterizes flood magnitude.	1) Rainfall amount
Califano, Mobilia, & Longobardi, 2015	1) To investigate the temporal changes occurring in extreme rainfall	1) Rainfall duration 2) Rainfall consistency
García-Barrón et al., 2015	1) To analyze temporal irregularity of rainfall aggressiveness	1) Rainfall aggressiveness
Haque, Rahman & Samali, 2016	1) To understand the plausible impacts of climate change on the performances of a residential rainwater harvesting system	1) daily rainfall losses 2) daily water demand
Aliasa et al., 2016	1) To identify factors influencing the extreme flood	1) rainfall frequency
Wong et al., 2016	1) To characteristics of rainfall distribution and rainfall variability	1) rainfall amount
Al-Safi & Sarukkalige, 2017	1) To evaluate the impacts of future climate change	1) rainfall mean 2) temperature 3) streamflow 4) long-term monthly
Syafrina et al., 2017	1) To identify the best distribution of rainfall intensity	1) rainfall amount 2) hourly temperature 3) hourly relative humidity 4) Hourly wind speed.
Irwan et al., 2017	1) To determine how the rainfall pattern can effects flooding as this area is vulnerable to flood disaster.	1) rainfall amounts 2) the number of rain days
García-Barrón et al., (2018)	1) To define and calculate rainfall aggressiveness risk.	1) rainfall aggressiveness

From the 10 years study of disaster-related study whereby conventional methods adopted, one can conclude that, due to the limitation of these studies (parameter listed in Table 2.1), only data on the trend of rainfall related with the temperature changes were produced. They also include the current climatic data which gives the result in the physical parameter from the rainfall behavior. In conclusion, this method still lacking in providing the understanding of why the rain production is less or more; which could result in flood disaster.

2.4.1(b) Case Study on Stable Isotope Technique

The isotope hydrology approach is becoming more relevant to current hydrological studies. Since 1953, these researchers (Dansgaard, 1953; Epstein & Mayeda, 1953; Friedman, 1953) have been involved on isotope composition of precipitation to understand the characteristic of circulation pattern and movement of water by using the stable isotope technique. Then, in 1957, International Atomic Energy Agency (IAEA) was established in concern on the nuclear technology. The IAEA enables nation to utilize atomic science and innovation to screen outflows and natural changes to the sea and biological communities, as well as relieving wellsprings of ozone-depleting substance emanations from vitality creation and land utilization, and adjust to new atmosphere substances including sustenance and water deficiencies and environment misfortunes (IAEA, 2017).

Water stable isotope can investigate the climatological and hydrological signal of water. They also can give the understanding on the recharge mechanism and to identify the sources and the origin of surface water. Besides that, it has also been used to measure a wide range of climate archives and to reconstruct the regional climate variation (Sturm et al., 2010); whereby this will provide a way to understand the processes involved in environmental change, the interactions among elements of the ocean-atmosphere-land surface system, and the rates of natural climatic variability (Thompson, 2004). However, the interpretation of the isotopic signal in tropical can be complicated due to the impact of neighboring vegetation, the origin of the moisture and convective process (Sturm et al., 2010).

These are some research papers that have reported about the study on characterization of precipitation in the global state, regional and also in the local state due to their concern on the climate changes by using this nuclear technique. Firstly, Moore (2016) has been discussing the tracer in precipitation budget in the tropic and orographic snow. She conducted this study to observe the amount effect and to determine the growth pathway of measured precipitation in the tropics and orographic snow in the mid-latitudes.

In another study, stable isotope has been used to investigate on how the moisture that evaporates from the land surface contribute to summer precipitation. They found out that stable isotope can be used as a tool to investigate the source of moisture derived from the land surface that contributes to the precipitation during summer (Kurita et al., 2003). Furthermore, stable isotope has also been used to prove amenable to physical and meteorological analysis. They are useful for deriving physically based calibration of climatology relationship between isotope ratios and temperature or precipitation amount for both present and past climate pattern (Gedzelman and Lawrence., 1990). Therefore, the investigation of the variation in the precipitation pattern over the major monsoon belt can be achieved (Imran et al., 2014).

Furthermore, in the conventional technique, the GCMs are unable to satisfactorily resolve key aspects of tropical climatology (Verdon-Kidd et al., 2017). GCMs also have no direct observation of climate variable. Therefore, it needs the proper interpretation to reconstruct the past climate change to validate the model (Sturm et al., 2010). Based on the previous study, other limitations of using GCMs is depending largely on the time-space resolution for the validity of the parameterization schemes. Thus, it is necessary to develop another independent method for verifying those model result (Yamanaka, 2002).

Many researcher studies about paleoclimate due to their concern on future warmer climate as predicted by the Intergovernmental Panel on Climate Change (IPCC). Paleoclimate study is conducted to answer the question about what the earth was like in the past and enable projection, plan, and preparation for the future (Robinson & Harry, 2010). It also gives the insight into the mechanism of climate change and the functioning of the earth system (Thompson, 2004). Essentially, isotope technique is useful in proxy record for paleoclimate study (Noone & Simmond., 2002). In addition, by reproducing the past climate, it will increase the confidence in the GCMs ability to forecast the future climate (Robinson and Harry, 2010).

In conclusion, stable isotope had followed the expected pattern and trend for the tropical river basin, highlighting the potential for modeling the water and carbon hydrologic cycle and interpreting the paleo-isotope proxies using stable isotope (Stephen & Rose, 2005). Moreover, due to the rapid population, and experiencing the problem of water shortage, we can use isotope analysis to assess source of rainfall and flux of water in the watershed for the assessment of water quality and quantity in watersheds. Last but not least, the condition of moisture source in the particular area which would result in disaster also can be resolved by interpreting the D-excess.

2.5 Application of Isotope Hydrology in Characterizing the Precipitation

Hydrology is a science that studies the water bodies, water events, water movements, their chemical and physical properties and their responses toward the environment (Federal Council for Science and Technology, "Scientific Hydrology", Washington, 1962). In isotope, hydrological study acts as a substance in understanding the water cycle more effectively. For the best results, this method should be complemented by several other methods such as surface hydrology, hydraulics, hydrogeology, geophysical and geochemistry (Rao, 2006).

Generally, isotopes are the same elements of atoms that have the same number of protons but differ in neutron numbers. Figure 2.1 shows an example of an isotope notation. Isotopes have the same chemical reaction but differ from mass and its physical properties (Herzog, 2016). A stable isotope is an element that contains nonradiogenic nuclide and does not decay. It also has a long half-life that causes them to become a radioactive isotope. Each element has both stable isotope and also a radioactive isotope (Stable Isotope, n.d).

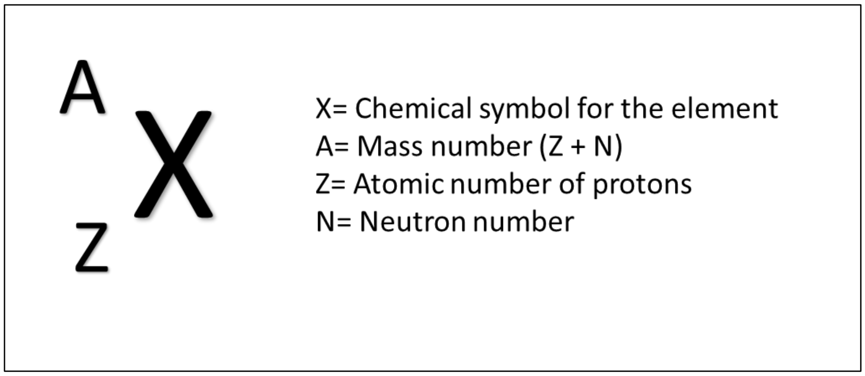

Figure 2.1: Isotope Notation

In isotope hydrology, the element of hydrogen and oxygen have stable and radioactive isotopes (Gat, 2010). Elements of hydrogen and oxygen, both having three different isotopes. For hydrogen, they have protium (^{1}H), deuterium (^{2}H) and tritium (^{3}H). For oxygen, oxygen-16 (^{16}O), oxygen-17 (^{17}O) and oxygen-18 (^{18}O). Tritium is known as radioactive isotope (Gat, 2010). Chemical elements of a stable isotope of oxygen and hydrogen in a water molecule are dominantly used for the hydrologic study and climatology. A good understanding of isotope fractionation is important in taking into account the composition of isotopes in the precipitation as well as the main source of the proses of hydrological systems (Pang et al, 2011).

Isotope water is also influenced by the history of water which influences evaporation from the ocean, precipitation amount and moisture input into the atmospheric from the land surface also called as recycled water (Kurita et al., 2004). The stable isotopes of water, ^{18}O and ^{2}H, are naturally occurring and incorporated within the water molecule ($H_2{}^{18}O$, $^{1}H_2H^{16}O$). They particularly act as the useful tracers of water cycling as they undergo measurable and systematic fractionation as water is transported, evaporates and exchanges among phases in the water cycle.