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COMPARISON OF DIFFERENT METHODS IN ESTIMATING POTENTIAL EVAPOTRANSPIRATION

AYU SHAKIRA BINTI SHAFIE

Report submitted in partial fulfillment of the
requirement for the award of the degree of
B. Eng. (Hons.) Civil Engineering

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion this project is satisfactory in terms of scope and quality for the award of Bachelor of Civil Engineering (Hons).

Signature :

Name of Supervisor : DR. NURUL NADRAH AQILAH BINTI TUKIMAT

Position : LECTURER

Date : 24th JUNE 2016

STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name of Student : AYU SHAKIRA BINTI SHAFIE

ID Number : AA12139

Date : 24th JUNE 2016

Exclusively dedicated to my beloved family, friends, and lecturers for their endless support and encouragement throughout my years as a student at University Malaysia Pahang.

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ABSTRACT

Evapotranspiration (ET) is a term used to describe the sum of evaporation and transpiration form land surface to atmosphere. Considering the importance of ET, two methods was developed to estimate potential evapotranspiration (PET). The two ET groups there are temperature-based method and radiation-based method. About two types of PET methods were selected for each groups there are Priestly-Taylor Method and Turc Method to represent radiation-based method, meanwhile Hargreaves-Samani Method and Blaney-Criddle Method represented temperature-based method. The A2 scenario is used to represent the level of state development due to the climate projection results. The daily temperature data was provided by MMD under Ministry Science. The data provided was used in the method to estimate the future trend of PET in long term. Downscaling is a technique that have been used to predict the local meteorological condition. The SDSM is a tool that used to produce high resolution climate change scenario. The objective of the study was to quantify the performance between radiation-based method and temperature-based method and to analyse the future trend of ET at Kuantan, Pahang state. In this study, it was found that the radiation-based method gave better performance compared to temperature-based method in quantifying in calculating ET. In radiation-based method, Priestly-Taylor Methods is the most suitable method to use to find ET based on the lowest value of absolute error and higher Pearson error. Projection temperature results for minimum, mean and minimum will increase in every 30 years for interval year 2010-2039, 2040-2069 and 2099. From the projecting temperature, Turc Method under radiation-based method are suitable for projecting changing pattern of ET under climate change scenario. On the other hand, accuracy and reliability of simple PET models vary widely according to climate condition.

ABSTRAK

Penyejatpeluhan (ET) adalah istilah yang digunakan untuk menggambarkan jumlah penyejatan dan transpirasi dari permukaan tanah ke atmosfera. Memandangkan kepentingan ET, dua kaedah telah digunakankan untuk menganggarkan potensi evapotranspirasi (PET). Kedua-dua kumpulan ET terdapat kaedah berasaskan suhu dan kaedah berasaskan radiasi. Kira-kira dua jenis kaedah PET telah dipilih untuk setiap kumpulan iaitu kaedah Priestly-Taylor dan kaedah Turc yang mewakili kaedah berasaskan radiasi. Sementara itu kaedah Hargreaves-Samani dan kaedah Blaney-Criddle mewakili kaedah berasaskan suhu. Senario A2 digunakan untuk mewakili tahap pembangunan negeri berasaskan keputusan unjuran iklim. Data suhu harian telah disediakan oleh JMM di bawah Kementerian Sains. Data yang disediakan telah digunakan dalam kaedah tersebu untuk menganggar trend masa depan PET dalam jangka panjang. Penskalaan rendah adalah satu teknik yang digunakan untuk meramalkan keadaan cuaca tempatan. Model SDSM adalah alat yang digunakan untuk menghasilkan senario resolusi tinggi perubahan iklim. Objektif kajian ini adalah untuk mengukur prestasi antara kaedah berasaskan radiasi dan kaedah berasaskan suhu dan untuk menganalisis trend masa depan ET di Kuantan, Pahang. Dalam kajian ini, didapati bahawa kaedah berasaskan radiasi memberikan prestasi yang lebih baik berbanding kaedah berasaskan suhu termasuk dalam mengira ET. Dalam kaedah berasaskan radiasi, kaedah Priestly-Taylor adalah kaedah yang paling sesuai untuk digunakan untuk mencari ET berdasarkan nilai terendah ralat mutlak dan ralat Pearson lebih tinggi. Manakala suhu unjuran rendah, sederhana dan tinggi akan meningkat pada setiap 30 tahun bagi tahun selang 2010-2039, 2040-2069 dan 2099. Dari pemerhatian kajian, kaedah Turc yang mewakili kaedah berasaskan radiasi sesuai untuk mengunjurkan corak perubahan ET di bawah iklim perubahan senario. Sebaliknya, ketepatan dan kebolehpercayaan model PET mudah amat berbeza mengikut keadaan iklim.

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LIST OF SYMBOLS

ETo	Reference evapotranspiration ($mm \cdot mon^{-1}$)
$Tmean$	Mean temperature (℃)
$Tmax$	maximum air temperature (℃)
$Tmin$	Minimum air temperature (℃)
Ra	Extraterrestrial radiation (MJm^{-2} day^{-1})
R_n	Net radiation of the crop surface (MJ m^{-12} day^{-1})
Rs	Solar radiation ($MJ \cdot m^{-2}$)
G	Soil heat flux density (MJ m^{-12} day^{-1})
λ	Latent heat of vapour (MJ kg^{-1})
γ	Psychrometric constant (kPa $℃^{-1}$)
Δ	The slope vapour curve (kPa $℃^{-1}$)
p	The mean daily percentage of annual daytime hours due to the latitude of region

r^2	Variance
℃	Degree Celsius
%	Percentage

LIST OF ABBREVIATIONS

ET	Evapotranspiration
PET	Potential Evapotranspiration
SDSM	Statistical Downscaling Model
MMD	Malaysian Meteorological Department
RH	Relative Humidity
SE	Standard Error

CHAPTER 1

INTRODUCTION

1.1 Introduction

Evaporation is the process where the water from different bodies of water changes from a liquid into a gas or water vapour, and transported of to the air. This process will happen when the energy presents to change the water into water vapour. Besides that, transpiration happen when the water vapour contained in plant tissue and vapour removed to atmosphere surface. Thus, both process combine simultaneously and become evapotranspiration (ET) (Giridhar and Viswanadh, 2007).

ET is important in hydrologic cycle phase. Hydrologic cycle is a model of conceptual that describe the storage and movement of water between atmospheres. The processes of this hydrological cycle are including evaporation (Brown, 2000), condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, melting and ground water flow. Besides, the hydrological cycle is a model of the movement of water through the Earth system. ET is an important component in water balance models and irrigation scheduling (Daniel and Pringle, 2013).

The climate changes have ever been changing based on season and time (Giorgi, 2005). The internal process and variation in the sunlight can also cause the climate change. In addition, the direct impacts of climate change on Earth are mainly through ET. ET increases when the temperature, radiation and wind speed are increasing (Hazrat Ali etl al., 2000). So, the higher the temperature will produce higher ET that will affect the hydrological system. Thus, the management for long-term water resources need to be compute from the change of ET due to climate change.

Climate change, especially global warming is expected to give negative impact to the ecosystem due to the rising sea level and temperature among regions. Impact on precipitation, ET and runoff is reliable by region. The worst-case scenario for water supply when the ET is rises and receive less rainfall. ET increase due to temperature, radiation, humidity and wind speed increase. However, the reduction of rainfall amount may cause of increment of ET and reduce the percentage of humidity (Summer and Jacobs, 2005). Therefore, regional evaluation of climate change impact is necessary to evaluate impact on ET, precipitation and runoff.

ET involves a highly complex set of processes, which are influenced by many factors dependent on the local conditions. These conditions range from precipitation and meteorology to soil moisture, plant water requirements and the physical nature of the land cover (Dunn and Mackay, 1995). The primary reason for differentiating between the free-surface evaporation E and potential evapotranspiration ET is that the diffusion of water vapor into the atmosphere follows very different pathways in vegetation (transpiration) than it does from free-water-surface water. Farquhar etl al., 2007 defined potential evapotranspiration ET as the maximum quantity of water capable of being lost, as water vapor, in a given climate, by a continuous, extensive stretch of vegetation covering the whole ground when the soil is kept saturated.

1.2 Problem of Statement

Malaysia is one of the country that in progress to heading towards as a developing country. The various development programmes have been introduced to improve the standard of living of the population. This rapid development must be consistent with protect the natural cycle. The rapid uncontrolled bring negative effects such as climate change such as rising over time. The change of climate is cause by the changes of micro climate pattern which potentially an extreme climate event. Climate change has been recognizing as one of the higher challenges for ET process.

Therefore, the main aim of this study is to determine the best methods in estimating the PET value. There two type of PET methods known as radiation-based and temperature-based methods. The performance all the PET estimation were compared to the historical ET value provided by MMD as a reference. Furthermore, with this comparison future trend of potential evapotranspiration can be estimated with considered the climate change adaptation.

Energy is required to change the state of the molecules of water from liquid to vapor (Chattopadhyay and Hulme, 1997). Direct solar radiation and, to a lesser extent, the ambient temperature of the air provide this energy. The driving force to remove water vapor from the evaporating surface is the difference between the water vapor pressure at the evaporating surface and that of the surrounding atmosphere. As ET proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere. The replacement of the saturated air with drier air depends greatly on wind speed. Hence, solar radiation, air temperature, air humidity and wind speed are climatological parameters to consider when assessing the ET process.

Where the ET surface is the soil surface (Toy, 1979), the degree of shading of the crop canopy and the amount of water available at the evaporating surface are other factors that affect the ET process. Frequent rains, irrigation and water transported upwards in a soil from a shallow water table wet the soil surface. Where the soil is able to supply water fast enough to satisfy the ET demand, the ET from the soil is determined only by the meteorological conditions. However, where the interval between rains and irrigation becomes large and the ability of the soil to conduct moisture to pear the surface is small, the water content in the topsoil drops and the soil surface dries out. Under these circumstances the limited availability of water exerts a controlling influence on soil ET. In the absence of any supply of water to the soil surface, ET decreases rapidly and may cease almost completely within a few days.

There are numerous methods that exist have been developed to estimate this ET. Generally, most of the ET methods are parameter rich model and the wide ranges of data types are needed which have to expert in using various equations correctly. Thus, Xu and Singh, 2002 stated that there are very difficult to select the best ET method on data availability. Some methods are more suitable to be used at certain area.

Besides, the accuracy and reliability of model is very different according to the climate conditions of the region.

There are several equation to estimate the ET value. The method can be categoried into seven classes there are empirical, water budget, energy budget, mass transfer, combination, radiation and overview. However, performance of ET is different based on climate condition and available data (Giridhar and Viswanadh, 2007).

1.3 Objective of Study

The main objectives of this study are as follow:

i. To quantify the performance between radiationn-based method and temperature-based method in calculating ET.

ii. To estimate the future trend of potential evapotranspiration using various type of ET method.

1.4 Scope of Study

The study focused on the performance between two ET groups. There are temperature-based method and radiation-based method in calculating ET value. About two types of PET methods were selected for each groups there Priestly-Taylor Method, and Turc Method to represent radiation-based method. Meanwhile Hargreaves-Samani Method and Blaney-Criddle Method to represent temperature-based method. To obtain the best performance in estimating future trend of PET, these methods were compared to the historical data.

The A2 scenario is used to represent the level of state development due to the efficiency of the climate projection results. The daily temperature data was provided by MMD under Ministry of Science. This agency provides the results that are obtained from data based on daily scientific observation and research in natural phenomena in the fields of meteorology, hydrology, and others that’s related with scientific fields. The data provides was used in the methods to estimate the future trend of PET in the long term.

Downscaling is a technique that have been used to predict the local meteorological conditions (Hassan etl al., 2014). The Statistical Downscaling Model (SDSM) is a tool that used to produce high resolution climate change scenario. SDSM one of the tools with user-friendly software package is design to implement statistical downscaling method are used to project future maximum temperature (Tmax), minimum temperature (Tmin) and mean temperature (Tmean). Variability and changes in Tmax, Tmin and Tmean under scenarios A2 HadCM3 model was presented for future periods: 2020s, 2050s and 2080s.

1.5 Significant of Study

This study will be significant to estimate the PET value using temperature based and radiation based methods. Historical ET value as a reference to evaluate the performance of temperature-based and radiation-based. Furthermore, the climate change will affect the temperature data analysis is essential to fulfill the objectives function. There are several contributions and significant of this study are trend of future temperature, PET during flood irrigation, quantify performance on reference method, quantify performance on radiation based method and quantify performance on temperature based method.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to provide a review of past research that related to quantify the performance between temperature-based method and radiation-based method and estimate the future trend of PET. The PET concept was first introduced in the late 1940s and 50's by Penman and it is defined as the amount of water transpired in a given time by a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile (Irmak and Haman, 2003).

PET not only depending on soil moisture and plant factor, but it also depends on the changes of climate condition (Goyal, 2004). It is due to sufficient moisture that always available to completely meet the needs of the vegetation area, and then the ET happen next. There are several the factors that are extremely important in estimating PET. The PET value is requires energy from the sunlight for the evaporation process and the energy received from the Sun accounts for 80% of the variation in PET (PAPADOPOULOU etl al., 2003). Wind is the second factor affect PET which enables water molecules to be removed from the ground surface by a process known as diffusion. The rate of ET is linked to the gradient of vapour pressure between the ground surface and the layer of atmosphere receiving the evaporated water.

Evaporation is defined as a process of a substance type of vaporization of a liquid state gain energy changing to a gaseous state. Evaporation is the main way that water change from the liquid state back into the water cycle as atmosphere water vapour. The process of evaporation can be happen when the liquid in warm condition.

The ocean, seas, lakes and river are the sources that provide almost 90% of the moisture in the atmosphere by evaporation while 10% is contributed assist by plant transpiration. Transpiration happen when the water vapour that contain in the plant tissue removed to the atmosphere surface (Kosa, 2011).

The rate of evaporation of a substance depends on surface temperature, the pressure and humidity. Heat or energy is necessary for evaporation to occur. Energy is used to break the bonds that hold water molecules together, which is why water easily evaporates at the boiling point at 100° C. however, evaporates process much more slowly at the freezing point. Net evaporation occurs when the rate of evaporation exceeds the rate of condensation. A state of saturation exists when these two process rates are equal, at which point the relative humidity of the air is 100 per cent. Condensation, the opposite of evaporation, occurs when saturated air is cooled below the dew point where the temperature to which air must be cooled at a constant pressure for it to become fully saturated with water, such as on the outside of a glass of ice water. In fact, the process of evaporation removes heat from the environment, which is why water evaporating from your skin cools you.

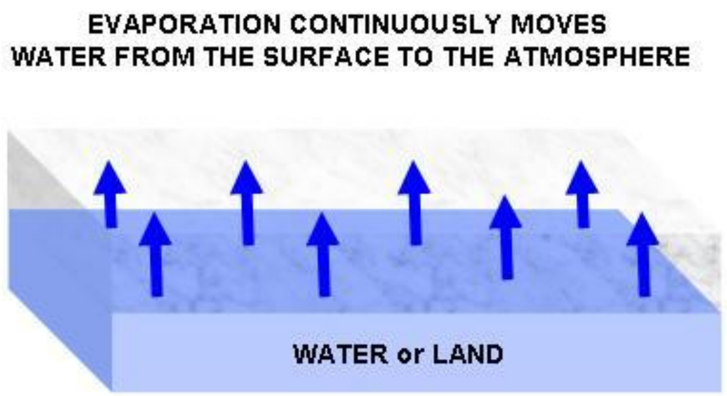

Figure 2.1: Process of evaporation

Evaporation from the oceans is the main mechanism supporting the surface-to-atmosphere portion of the water cycle. Furthermore, the large surface area of the oceans is over 70% of the Earth's surface providing the opportunity for large-scale evaporation to occur. On a global scale, the amount of water evaporating is about the same as the amount of water delivered to the Earth as precipitation. This shows the different geographically, though. Evaporation is more prevalent over the oceans than precipitation, while over the land, precipitation routinely exceeds evaporation. Most of the water that evaporates from the oceans falls back into the oceans as precipitation. Only about 10% of the water evaporated from the oceans is transported over land and falls as precipitation. Once evaporated, a water molecule spends about 10 days in the air. The process of evaporation is so great that without precipitation runoff, and groundwater discharge from aquifers, oceans would become nearly empty (Perlman, 2016).

Transpiration is the process of evaporation of water through plants from roots to small pores on the underside of leaves, where it changes to vapour and released to the atmosphere. Transpiration is basically evaporation of water from plant leaves. Transpiration also includes a process called guttation, which is the loss of water in liquid form from the uninjured leaf or stem of the plant, especially through stomata. Stomata are defined as small opening on the surface of a plant that use for gas exchange.

Plant roots in the soil draw water and nutrient up to the stems and leaves. Some of the water is returned to the air by transpiration. Transpiration rates extremely diverse depends on temperature, humidity, sunlight availability and intensity, precipitation, soil type and saturation, wind, land slope and water use and diversion by people. Transpiration assists to the loss of moisture in the upper soil zone, which can have an effect on vegetation and food-crop fields.

ET is the combination of the two processes there are evaporation and transpiration where transferring the moisture from the Earth to the atmosphere. ET also can be defined as the water lost the water lost ground surface, evaporation from the capillary fringe of the groundwater table and the transpiration of groundwater by plants whose roots tap the capillary fringe of the groundwater table. ET is important to the hydrologic cycle because it represent a huge amount of moisture lost from a watershed. This will be happen when the precipitation falls and drench into the soil, the plant absorb and transpires through leaves, stem, flowers and roots. Through ET, the location with heavily wooded area is usually decreasing the water yield. Furthermore, ET is important in many disciplines of including irrigation system design, irrigation scheduling and hydrologic and drainage studies (Irmak and Haman, 2003).

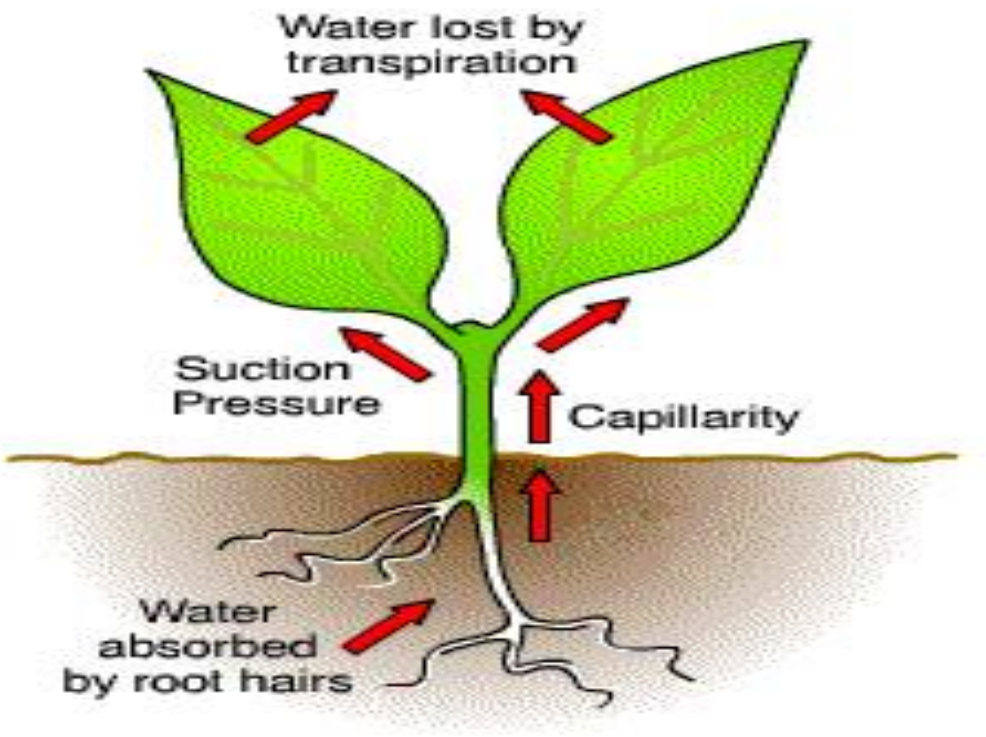

Figure 2.2: Transpiration process in plant

Temperature is the main factor that contribute to the ET value. ET rates increase when the temperature is increases. This usually happen during the vegetation season, where the air warmer due to stronger sunlight and warmer air masses. Higher temperature causes the plant cells to control the opening of the stoma. The stoma need warm temperature to open and colder to close. Second is the amount of water vapour in the air or known as relative humidity also important consideration in ET. This is due to the air become more and more saturated or less water able to evaporate into the air (Sterling, 2004). Therefore, as the relative humidity increases, transpiration decreases. Wind and air movement also play the role for the ET. Increased the movement of the air around a plant will cause in higher transpiration rate. This is related to the relative humidity of the air when water is transpires from a leaf then saturate in the air surrounding around the leaf. However, if there is no wind, the air around the leaf will not move and it will raise the humidity. The type of plant also one of the factors involved in the transpiration process. Different type of plant and different size of leaves transpires water at different rate.

2.2 The Description of Hydrological Cycle

The hydrologic or water cycle is a continuous cycle of water on, above and below the surface of the Earth. The mass of water on Earth remains fairly constant over time but the partitioning of the water into the major reservoirs of ice, fresh water, saline water and atmospheric water variable depending on a wide range of climatic variable. The water moves from one reservoir to another, such as from river to ocean, or from the ocean to the atmosphere, by the physical processes of evaporation, condensation, precipitation, infiltration runoff and subsurface flow. In doing so, the water goes through different phases including liquid, solid, and gas.

The water cycle involves the exchange of energy, which leads to temperature changes (Pike, 2015). For instance, when water evaporates, it takes up energy from its surroundings and cools the environment. When it condenses, it releases energy and warms the environment. These heat exchanges influence climate (Florides and Kalogirou, 2007).

The evaporative phase of the cycle purifies water which then resupply the land with freshwater. The flow of liquid water and ice transports minerals across the globe. It is also involved in reshaping the geological features of the Earth, through processes including, erosion, and sedimentation. The water cycle is also essential for the maintenance of most life and ecosystems on the planet (Erickson, 2010).

Hydrological cycle is a natural process which is very important in the natural cycle of nature. The cycle is able to produce sufficient water resources and process surface and in the ground of earth. The water can move in all circumstances as atmospheric such as in the air, on the earth's surface and in the ground of the earth.

Since billions of years ago, the water cycle has happened and all that life is this earth needs water as a part of life.

The water cycle is a cycle that occurs on an on-going basis. It begins at place and water retention areas such as the oceans. The sun rays are expediting process of the water cycle. The sunlight will make ocean water becomes warm, causing water vapours going up into the atmosphere. The steam-water vapour will rise higher above the atmosphere by air currents push. This will result in cold temperatures will make the water vapours gather and become a cloud. Then, the air flow will transfer the movement of the clouds surrounding the earth.

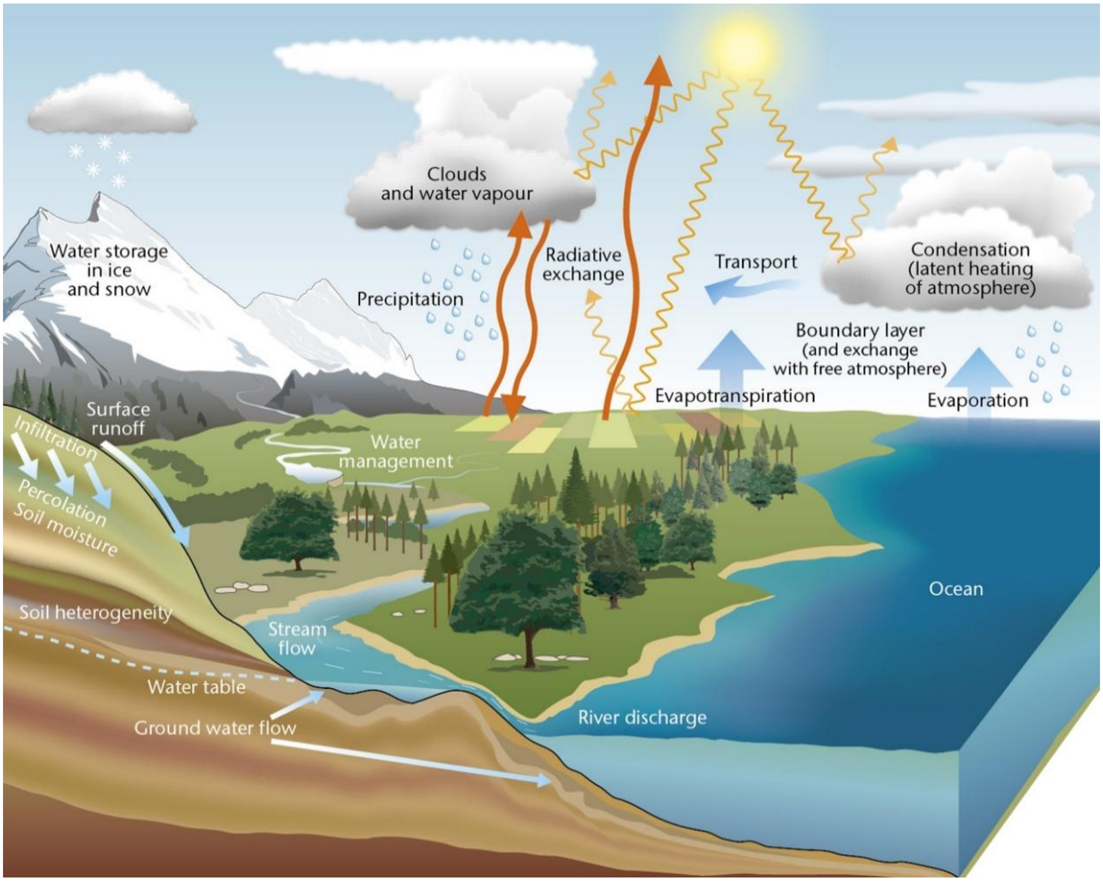

Figure 2.3: Cycle of hydrological process

Later, cloud droplet wills encounter between each other to make growing big. Once larger, it will fall out known as precipitation. The precipitation that falls through the cloud known as the rainfall (Ritter, 2006). This rainfall exists in every country in the world. Among other examples of precipitation is snow but only existing at a national country average on climate of 4 seasons only and not available on countries that are on the equator line area. Almost most of the precipitation that formed this will back down a sea or on land because of the attractiveness of the natural earth gravity. This will be the rainfall runoff surface of the earth when it fell above the land at high altitude places.

However, surface water runoff that flows is not all going back into the river. This is because the bulk of the rainfall will be absorbed back into the ground known as the infiltration (Makuch, 2008). As a result of the process of absorption by this soil, no part of this stagnant water in the ground but are close to the surface of the earth. This water flows some will absorb into the surface water source is like the ocean as a groundwater discharge. In addition, there is also water that flows from the ground outward out onto the earth's surface known as spring water comes out through the bursting land surface.

The water resources that are formed at nearly the earth's surface will be absorbed by the plant roots and will be released through the surface of the leaves of this plant, which is known as the process of transpiration. The excess water which is in the ground will be absorbed into the soil and growing in will fill the aquifers space (sub-surface rocks). This aquifers is formed and is able to store large quantities of water storage which very much for a very long period of time. However, if too long period times, the water flow will also be moving on its own due to the attractiveness of the natural earth gravity and will flow naturally to lower altitude areas such as into the ocean. When the water flows back to the ocean, this means the water flow process terminates or also back starting cycle.

In addition, the hydrology cycle will also move hydrosphere which is the area that contains the quantity all of air, water and the ground surface (Caswell, 1987). This cycle a process is the movement of water through hydrosphere. This makes the whole process easier to move water. This process easier is divided into five sections, it is condensation, infiltration, runoff, evaporation and precipitates.

This process of this cycle will begin with the first process that is known as the condensation process. This happened as a result of condensation process of water vapour condenses in the air and became more and converging to become cloud formation (Cheng, 2009). This condensation process occurs as a result of the existence of air at temperature difference layer and the earth's surface. As a result of this temperature difference, water will change shape and properties. This water changes occur from the unstable temperature conditions and there is a temperature level decreased or upgrading. When the surrounding air sufficiently in cold, water vapour will condense on the particles found in the air to make cloud formation. This process is easily observed in plants that are surrounded by drops of dew during the time this happened.

When the cloud began to form, wind movement also will start moving across the globe and causes the water vapour will be clutter. When this situation occurs, the contents of the cloud will also achieve a level no longer able to accommodate the rate of water moisture, then this will change water vapour and will produce recognized is known as distribution of rainfall, snow, hail, winter, dew or others.

Next, for explaining the next process is the have three processes. Those processes are infiltration, runoff and evaporation. This process can happen simultaneously. This occurs when the process of breast feeding has been seeping into the soil moisture. This process is closely related to the permeability of the ground conditions. The structural properties of soil permeability to be measured in a state of flow speed through the water will pass a particular type of soil. Then, the more the permeability properties of the soil surface, the more moisture it will absorb water into the soil.

In addition, if the deposition is faster than the flow of running water permeability properties of the soil, then the water flow will be ground surface runoff flows. This runoff will flow capacity is lower. The part of the runoff flow will flow to watercourses such as the river. The river flows will converge at a place more water reservoir known as lake and the ocean. Meanwhile, the infiltration of flow of water under the ground will move also simultaneously and will flow into rivers and eventually back to wider areas.

After that, after this happened with the second process resulting from the energy of sunlight radiation then the cycle will make reason of the evaporation process. This evaporation process is the process of structural change in the form of liquid water to water vapour. This sunlight radiation will make temperature measurements will be the growing liquid water as temperatures because ocean or lake will also be on the rise. When the level of liquid water temperature rising, the water molecules will change will be released into the air. Meanwhile, the hot air will begin to rise higher into the atmosphere and started to change turns into water vapour slowly resulted condensation process.

In addition, the water storage is very important because water supplies for life that animate above earth include plants, humans and animals. The water storage for humans at this point is very adequate because the level of use is still manageable for the long term. Through, the hydrological cycle process will also ensure the process of the movement of water resources will move and maintain a clean environment and healthy. After that, the expected count almost 100 billion gallons of water a year and have been filtered and recycled through the process. If the process was halted, then life will suffer tribulation and perish impossible to remain a living surface of the earth. This process must be continued so that the life of the universe able to function naturally. Without water supply, sure difficult for life to continue to survive.

Furthermore, the definition of hydrology can be a termed as a soil science. The hydrology includes all movements of hydrology, occurrence, distribution and features in this world and relation with nature. The hydrological related fields are as geology, the study of weather and climate, meteorology and study marine scientific research.

In addition, the basic components of the hydrological cycle include the groundwater flow, stream flow, runoff, infiltration, evapotranspiration, evaporation and precipitation. The flow of water movement through several phases in will process hydrological cycle was in terms of time and space (Ismail, 2009).

After that, the movement of the water cycle process begins from the oceans into the atmosphere and then end up being part of the rainfall distribution over the surface of the earth. Where, the water is formed and accumulated in the river or lake area will flow naturally toward the ocean. This process is understandable as the hydrological cycle process. In hydrological processes can be seen the existence of water through 3 state changes in the properties with solid, liquid and gas. The concept of hydrological cycle process is so easy to understand but must recognize the process happened during the hydrological cycle. The quantity of rainfall distribution has a close relationship with the runoff flow can be seen using the hydrological cycle significantly as in Figure 2.3.

Meanwhile, the evaporation of ocean water will suffer as a result of the heat radiation of sunlight and then a cloud formed from water vapour will move across the earth's surface. This rainfall which fall earth surface is part of the surface of the leaves on affected plants. This water will be evaporating back into the atmosphere before reaching the surface of the ground. The some of this rainfall will continue to fall on the ground and led to the infiltrate process known as groundwater. The stagnant water at the ground surface will be in the form of steam evaporates back into the atmosphere and the rest move flows into the river as surface runoff.

The process of the water cycle will occur when water is used repeatedly in the process of the cycle runs continuously. The total quantity of water in this cycle will always be at the rate of the same size. Meanwhile, there will be water stored either at sea, in the air or in the ground. Then, there is also a quantity of water to be transferred in accordance with the process during this cycle occurs.

The sun, which drives the water cycle, heats water in oceans and seas. Water evaporates as water vapour into the air. Ice, rain and snow can sublimate directly into water vapour. ET is water transpired from plants and evaporated from the soil. Water vapour molecule H^2O, has less density compared to the major components of the atmosphere, nitrogen and oxygen, N^2 and O^2 (Shakhashiri, 2011). Due to the significant difference in molecular mass, water vapour in gas form gain height in open air as a result of buoyancy. However, as altitude increases, air pressure decreases and the temperature drops.

The lowered temperature causes water vapour to condense into a tiny liquid water droplet which is heavier than the air, such that it falls unless supported by an updraft. A huge concentration of these droplets over a large space up in the atmosphere become visible as cloud. Fog is formed if the water vapour condense near ground level, as a result of moist air and cool air collision or an abrupt reduction in air pressure. Air currents move water vapour around the globe, cloud particles collide, grow, and fall out of the upper atmospheric layers as precipitation. Some precipitation falls as snow or hail, sleet, and can accumulate as ice caps and glaciers, which can store frozen water for thousands of years.

Most water falls back into the oceans or onto land as rain, where the water flows over the ground as surface runoff. A portion of runoff enters rivers in valleys in the landscape, with stream flow moving water towards the oceans. Runoff and water emerging from the groundwater may be stored as freshwater in lakes. Not all runoff flows into rivers, much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes aquifers, which can store freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies and the ocean as groundwater discharge. Some groundwater finds openings in the land surface and comes out as freshwater springs. In river valleys and flood-plains there is often continuous water exchange between surface water and ground water in the hypothetic zone. Over time, the water returns to the ocean, to continue the water cycle.

2.3 The Description of Climate Change

Climate change will increase or decrease the dry conditions in the dry area of the world by increasing or decreasing PET (Huoa etl al., , 2013). Climate change in (IPCC, 2007) refers to a change in the state of the climate that can be identified by using statistical tests. The changes obtain in the mean or the variability of its properties, and continue for an extended period, generally in decades or longer. There is the different between weather and climate. Weather is the changes we see in the temperature, precipitation, humidity and wind in a short term period in a region or a city. Addition, weather can differ from day to day or even in on the same day (NASA, 2011). In the afternoon the weather may be sunny and warm while it will change to cloudy and cool during the evening. The climate of a region and or city for a weather average is different for different season. It is shown that the region or city may warm during summer and may tend to be cold and snowy during winter. This climate changes happen very slowly around tens, hundreds and thousands of years.

The Earth's climate is continually changing. Before, Earth's climate has experienced hotter and cooler periods, each enduring a huge number of years. Observations show that Earth's climate has been warming and the average temperature has increase more than one degree Fahrenheit during the past 100 years. Thus, this amount may not seem like much, however the small changes in Earth's average temperature can lead to big impacts (NASA, 2011).

The Earth’s climate to change are natural, however there are also factors causing it. Different factors work on different period of time and not all the factors charge of changes in earth's climate in the far off past are significant to contemporary climate change. Factors that cause climate change can be separated into two classes that are natural processes and human activity.

The Earth's climate due to the natural factors that is external to the climate system, such as changes in volcanic activity, solar output, and the Earth's orbit around the Sun. Of these, the two factors relevant on timescales of contemporary climate change are changes in volcanic activity and changes in solar radiation. In terms of the Earth's energy balance, these factors primarily influence the amount of incoming energy. Volcanic eruptions are episodic and have relatively short-term effects on climate. Changes in solar irradiance have contributed to climate trends over the past century but since the Industrial Revolution, the effect of additions of greenhouse gases to the atmosphere has been over 50 times that of changes in the Sun's output.

Climate change can also be caused by human activities, such as the burning of fossil fuels and the conversion of land for forestry and agriculture. Since the beginning of the Industrial Revolution, these human influences on the climate system have increased substantially. In addition to other environmental impacts, these activities change the land surface and emit various substances to the atmosphere. These in turn can influence both the amount of incoming energy and the amount of outgoing energy and can have both warming and cooling effects on the climate. The dominant product of fossil fuel combustion is carbon dioxide, a greenhouse gas. The overall effect of human activities since the Industrial Revolution has been a warming effect, driven primarily by emissions of carbon dioxide and enhanced by emissions of other greenhouse gases.

The build-up of greenhouse gases in the atmosphere has led to an enhancement of the natural greenhouse effect. It is this human-induced enhancement of the greenhouse effect that is of concern because ongoing emissions of greenhouse gases have the potential to warm the planet to levels that have never been experienced in the history of human civilization. Such climate change could have far-reaching and/or unpredictable environmental, social, and economic consequences.

2.4 General Climate of Malaysia

Malaysia has uniform temperature, high humidity and high rainfall climate characteristic features. Generally light of wind and having clear sky for whole day although there is period of serious drought. Besides that, there are a few days with no sunshine except during the northeast seasons.

The wind flow in Malaysia is usually light and variable, there are however the wind pattern will change based on some uniform period. Four changes can be well-known as the southwest monsoon, northeast monsoon and two periods of inter-monsoon seasons. The southwest monsoon season usually start between May or early June and will ends in September and the northeast monsoon season will start in early November and ends in March. Thus, during the two inter-monsoon season, the wind also light and variable and lies over Malaysia.

Figure 2.4: Malaysia topography map (Source: Graphic Maps, 2016)

Malaysia is primary a maritime country, the general wind flow pattern is very marked especially during the days with clear skies effect by the land and sea breezes. During clear night, the reverse process will took place and the land breeze of weaker strength will develop across the coastal area.

The rainfall distributions patterns are because the seasonal wind flow patterns that combine together with the local topographic features. The exposed area like the east coast of Peninsular Malaysia, Western Sarawak and the northeast coast of Sabah will have a heavy rain during the northeast monsoon season. Besides that, at mountain or inland area mostly free from the influence. The best way to describe the rainfall of the country is by according to the seasons.

There are three main types of the seasonal variation of rainfall in Peninsular Malaysia.

a) The months with maximum rainfall over the east coast stated start from November to January, while driest months are from June to July.

b) The southeast coastal area over the Peninsula shows two periods of maximum rainfall separated by two periods of minimum rainfall. Generally the primary occurs in October to November while the secondary maximum occurs in April to May. However, the primary minimum occurs in January to February and the secondary minimum in June to July over the northeast-western region.

c) The rainfall pattern over the southeast coastal area is can see by early in the morning from May to August with results that the double maxima and minima pattern is no longer detectable. Besides that, during October and November are the months with maximum rainfalls while February the month with the minimum rainfall. Last, during the months March to May maximum and the June to July minimum rainfall are not present.

Malaysia naturally has abundant sunshine and thus solar radiation because of the maritime county that close to equator. However, Malaysia will not having a full day with clear sky even in severe drought. Addition information, Malaysia receives about six hour of sunshine per day while Kuantan, Pahang receive four to seven hour per day.

2.5 Projection of Climate Trend

2.5.1 The statistical downscaling model (SDSM)

SDSM is one of the statistical climate models. This model is the most popular model among the researchers because the potential of the model to generate the reliable results while having limited sources (Khan et al, 2006). The accuracy of the SDSM simulation is depended on the appropriate selections of predictor variables that should have better correlation relationship with the predictand site in the equal sub-grid scale. The predictor variables are refers to the large scale of atmospheric characteristics consist of sea level pressure, geopotential height, wind fields, temperature variables, specific and relative humidity presented in numerical parameters. Meanwhile the predictand is refers to the local climatic stations consists of temperature and rainfall stations in the specific grid box.

The selection of predictors is referred to some of the criteria and behaviors. Inaccuracies during the calibration and validation processes are expected to produce suspicious results in the climate modeling. Recent previous studies have explored several methods to achieve the closest calibration of predictor and predictand relationships such as Multiple Linear Regression (MLR), Nonlinear Programming (NLP) and Canonical Correlation Analysis (CCA) (Gangopadhyaya, 1966; Benestad, 2005; Huth, 1999). The adaptation during the screening process in the SDSM model is very important to sustain the reliability of the climate generation.

However, the predictor selections will become complicated when the selection of predictor set is represented for many climate stations. It may take longer time to analyse the predictor-predictand relationships one by one. The M-CM analysis is a regression method that is widely used to explain the variables association. It has the potential to screen the multiple predictor-predictand relationships in a single sheet that will interpret their associations in the form of positive or negative correlation values. The application M-CM analysis in the SDSM model can reduce the time in making the best selection on the random correlations. In this study, the M-CM analysis is proposed as a screening tool of the SDSM model to get the best predictors that will fit to all multiple local predictand (climate stations).

The overall technical details of the statistical model (SDSM) is normally used in downscaling tool that provided by (Wilby et al., 2002). For the development of downscaling models, the SDSM is used because the technique multiple linear regression. As a first step, the statistical relationship between predictands and predictors is established by develops each model and by using the predicted data from general circulation model, GCMs, is stimulate the future series of predictands. To determine the occurrence and the amount of conditional meteorological variables like precipitation, the SDSM is use two separate sub-models. The SDSM can be restricted as a conditional weather generator in which regression equation are used to measure the parameters of daily precipitation occurrence. Therefore, the SDSM is more practical than a straightforward regression model.

According to the Wilby et al., 2002 the SDSM is best explain as a regression based method and hybrid of stochastic weather generator because atmospheric moisture variables and regional circulation pattern are used to conditional local weather parameters such as precipitation occurrence and intensity at individual sites.

2.5.2 Predictors and Predictants

Downscaling methods can be classified into two major categories which are dynamic downscaling and statistical downscaling. Due to the higher on demand and cost, statistical downscaling methods (e.g. NCEPs) are available for limited areas and studies. Moreover, the outputs of NCEPs are in grid resolution for NCEPs is 50km for most practical applications, such like hydrological studies. The statistical downscaling methods are developed to overcome these challenges. Compared to dynamic downscaling methods, statistical downscaling methods are normally easier and cost efficient to implement, and can link the state of some variables representing a large spatial scale and the state of other variables representing a smaller scale by using computationally efficient ways (Chen at al., 1991). Therefore, statistical downscaling methods are the more user friendly methods and widely used in hydrological impact studies under climate change scenarios (Khan et al., 2006; Wu et al., 2014).

In SDSM, choosing of the model parameter is important things. The parameters of the regression equation are estimated using an ordinary Least Squares algorithm. Rainfall is set as the condition process because there is an intermediate process between the regional forcing and local weather, which the local precipitation amount is correlated with the occurrence of wet days. Temperature is state as the unconditional process, where a direct link between the large scale predictors, and local scale predictand already assuming.

NCEP data is reanalyses data sets from National Centre for Environmental Prediction, which re-gridded and normalize toward the grid-system HadCM3. Both of

NCEP and HadCM3 data sets contain predictor variables, which used as input in SDSM. Selection of predictor variables from 26 variables, as Table 1 from each data set is the most difficult part of SDSM. Different atmospheric predictors control with different local variables and the outcome of predictand will affected. Therefore, the predictor(s) is selected from sensible, strongly and consistence correlated with predictand, and accurately modelled by GCMs.

2.5.3 Calibration and Validation of SDSM Model

The calibration model process form downscaling models based on multiple regression equations, given daily weather data (the predictand) and regional-scale, atmospheric (predictor) variables (Wilby et al., 2007). It is selected based on the select predictor variables that were derived from the NCEP data set. The temporal resolution of the downscaling model for precipitation and temperature downscaling are specified as monthly for each station. Some of the SDSM setup parameters for bias correction and variance inflation are adjusted during calibration to obtain a good statistical agreement between the observed and simulated climate variables. For event threshold, a value of 0.5 is used. Result of the calibration process in SDSM contains reports on the explained variance (r^2) and standard error (SE) for each regression model type. The predictor variables were selected based on the criteria such as physically related to the predictand, produce the highest explained r^2 and the lowest SE, which give the significance results of downscaling. The high correlation values indicate that there is a strong predictor predictand relationship of all the twelve months.

Table 2.1: Predictor variables from 26 variables

No	Predictor Variables	Predictor Description	No.	Predictor Variables	Predictor Description
1	mslpaf	Mean sea level pressure	14	p5zhaf	500 hpa divergence
2	p_faf	Surface air flow strength	15	p8_faf	850 hpa airflow strength
3	p_uaf	Surface zonal velocity	16	p8_uaf	850 hpa zonal velocity
4	p_vaf	Surface meridional velocity	17	p8_vaf	850 hpa meridional velocity
5	p_zaf	Surface vorticity	18	p8_zaf	850 hpa vorticity
6	p_thaf	Surface wind direction	19	p850af	850 hpa geopotential height
7	p_zhaf	Surface divergence	20	p8thaf	850 hpa wind direction
8	p5_faf	500 hpa airflow strength	21	p8zhaf	850 hpa divergence
9	p5_uaf	500 hpa zonal velocity	22	p500af	Relative humidity at 500 hpa
10	p5_vaf	500 hpa meridional velocity	23	p850af	Relative humidity at 850 hpa
11	p5_zaf	500 hpa vorticity	24	rhumaf	Near surface relative humidity
12	p500af	500 hpa geopotential height	25	shumaf	Surface specific humidity
13	p5thaf	500 hpa wind direction	26	tempaf	Mean temperature at 2m

CHAPTER 3

METHODOLOGY

3.1 Introduction

Period of progress must be recognized in this way so the objective of the study can be achieved easily and efficiently. The aim for this study is to quantify the performance between radiation-based method and temperature-based method with historical data from MMD and to estimate the future trend of temperature and PET at Kuantan, Pahang state. For the following step, when the topic and objective were identified, literature review has been led to gather data information so more understanding about this study will be easier for the next step. From the literature review and discussion with the supervisor, scope of study had been identified.

Temperature data is required for this study, to project future temperature trend. Downscaling model or SDSM was developed by Wilby et al. 2002 used to downscale the GCM output at regional scale that can project the future temperature of the study area. Addition, GCM just can predict future changes only in mean temperature (Tukimat, 2012).

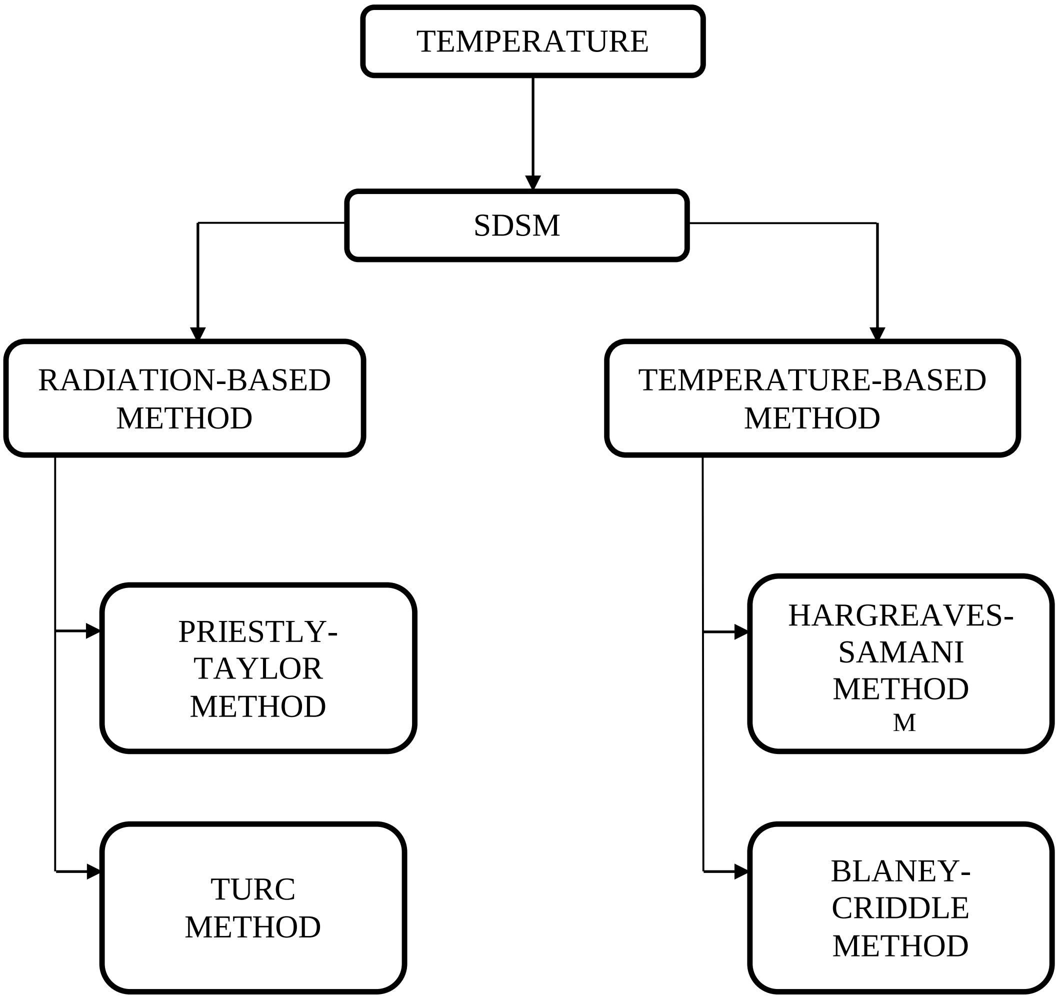

Figure 3.1: Flow chart of methodology

3.2 Statistical Downscaling Model (SDSM)

SDSM (Wilby et al., 2002) is a freely software tools that facilitates the scenarios of daily surface weather variables under present and future climate forcing. The investigation mainly includes the calibration and validation of SDSM model on downscaling daily precipitation, the validation of modelling extreme precipitation indices using independent period of the NCEP reanalysis data, and the projection of future regional scenarios of extreme precipitation indices (Huang et al, 2011). The SDSM is a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution global climate models (GCMs). Typically, GCMs have a resolution of 150-300 km. Many impacts models require information at scales of 50 km or less, so some method is needed to estimate the smaller-scale information.

Statistical downscaling first derives statistical relationships between observed small-scale variables and larger scale variables, using either circulation typing, regression analysis, or neural network methods. Future values of the large scale variables obtained from GCM projections of future climate are then used to drive the statistical relationships and so estimate the smaller-scale details of future climate.

Figure 3.2 show the SDSM software that reduce the task of statistically downscaling daily weather series into seven discrete processes

1) quality control and data transformation;

2) screening of predictor variables;

3) model calibration;

4) weather generation (observed predictors);

5) statistical analyses;

6) graphing model output;

7) scenario generation (climate model predictors).

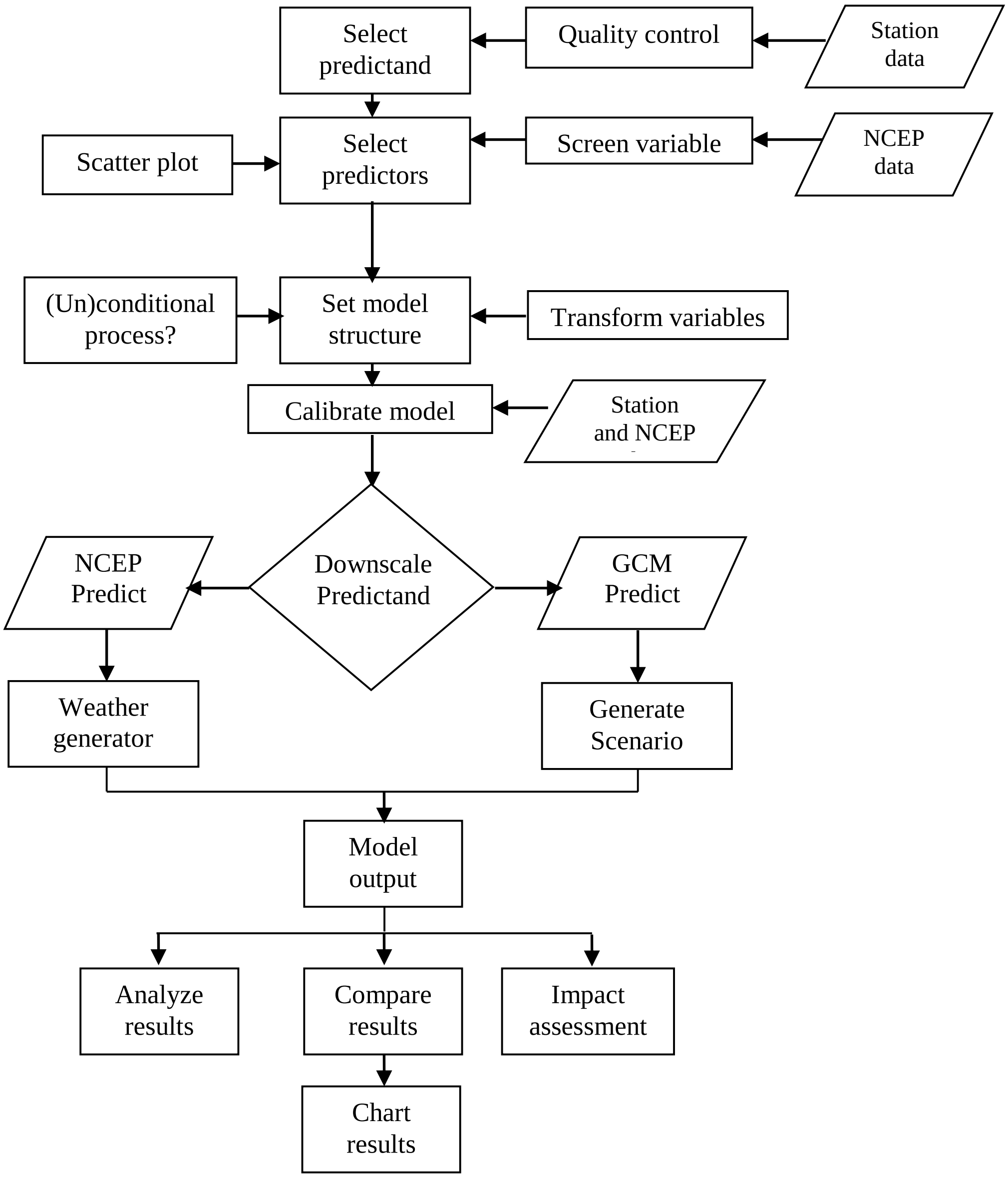

Figure 3.2: SDSM climate scenario generation (Source: Wilby et al., 2007)

3.3 Radiation-Based Method

The radiation-based were widely applied in estimation the ET and PET at various land area and condition. This method is suitable for areas where available climate data include measured air temperature and radiation (Giridhar et al., 2007). Two popular radiation based equations were evaluated and compared in this study. There are Priestly-Taylor equation and Turc equation.

3.3.1 Turc Method

Turc method estimates monthly ETo based on measurements of maximum and minimum air temperature and solar radiation (Fisher and Pringle, 2013) using the equation

When RH < 50%

$$ET_o = 0.0133 \frac{T_m}{T_m+15}(R_s + 50) \quad (1)$$

When RH > 50%

$$ET_o = 0.0133 \frac{T_m}{T_m+15}(R_s + 50)(1 + \frac{50-RH}{70}) \quad (2)$$

where

ETo = reference evapotranspiration ($mm \cdot mon^{-1}$)
Rs = solar radiation ($MJ \cdot m^{-2}$)
Tm = average air temperature (˚C) calculated as (Tmax + Tmin)/2
RH = relative humidity (%)

3.3.2 Priestley-Taylor Method

Priestly-Taylor (1972) found that the actual ET is 1.26 times greater than the PET and replace the aerodynamic terms with constant value of 1.26. This method just needs long-wave radiation and temperature to estimate ET. These equations can express as

$$ET_0 = 1.26 \frac{\Delta}{\Delta+\gamma}(R_n - G)\frac{1}{\lambda} \quad (3)$$

where

Δ = the slope vapour curve (kPa ℃$^{-1}$)
γ = psychrometric constant (kPa ℃$^{-1}$)
R_n = net radiation of the crop surface (MJ m^{-12} day^{-1})
G = soil heat flux density (MJ m^{-12} day^{-1})
λ = latent heat of vapour (MJ kg^{-1})

3.4 Temperature-Based Method

ET estimation methods that's only need temperature as an input variable are considered as temperature-based method in this study (Xu and Singh, 2002). Temperature based method one of the earliest to estimate ET and for the temperature based method, two popular equations are compared and each represent typical form namely Hargreaves-Samani (1948) and Blaney-Criddle (1950).

3.4.1 Hargreaves-Samani Method

The Hargreaves-Samani equation estimate ET based on the maximum and minimum temperature. This equation also derived from regression of temperature reduction and relative humidity factor. The equation is expressed as:

$$ETo = 0.023\ (0.408)(Tmean + 17.8)(Tmax - Tmin)^{0.5} Ra \qquad (4)$$

where

$Tmax$ = maximum air temperature (℃)
$Tmin$ = minimum air temperature (℃)
Ra = extraterrestrial radiation (MJm^{-2} day^{-1})

3.4.2 Blaney-Criddle Method

Blaney-Criddle methods is one of the simple method used to calculate ET. This equation was widely used before Penman-Monteith equation occurs. These equations only need temperature changes at a particular region for measuring reference ET and it can express as

$$ET_0 = p(0.46T_{mean} + 8) \quad (5)$$

where

p = the mean daily percentage of annual daytime hours due to the latitude of region

$Tmean$= mean temperature (℃)

Temperature based method required only temperature as an input variable are considered for estimation potential evapotranspiration (PET) in this study. The temperature based methods are one of the earliest methods in estimating potential evapotranspiration (PET).

Due to widen inconsistency in meteorological data collection procedure and standard, a lot of different evaporation equations have been used for different study. Performance of the empirical equation usually differ from study area.

3.5 Study Area

Kuantan is located between 3°49′00″N, 103°20′00″E in Pahang state lies in the East coast Peninsular Malaysia. It is near with Kuatan River and faces the South China Sea. Kuantan is considered the social, economic and commercial hub for the East Coast of Peninsular Malaysia due to its strategic location. Rapid development has transformed and modernised Kuantan. Since 2005, Kuantan has many development projects, including Putra Square, Mahkota Square, Bukit Gambang Water Resort, Kuantan Sentral, Pahang Tech Park and Kuantan Port City under the Kuantan District Locality Plan 2004-2015. Recently, the introduction of Malaysia's first Special Economic Zone (SEZ) at Kuantan is designed to boost the regional economy, tourism and growth. In an effort to catalyse the growth of the Kuantan Metropolitan Precinct, the government has cited a petroleum manufacturing area in Pekan, a neighbouring town.

Kuantan's climate is classified as tropical. Kuantan is a city with a significant rainfall. Even in the driest month there is a lot of rain. This location is classified as Af by Köppen and Geiger. The average annual temperature in Kuantan is 26.6 °C. The average annual rainfall is 2887 mm.

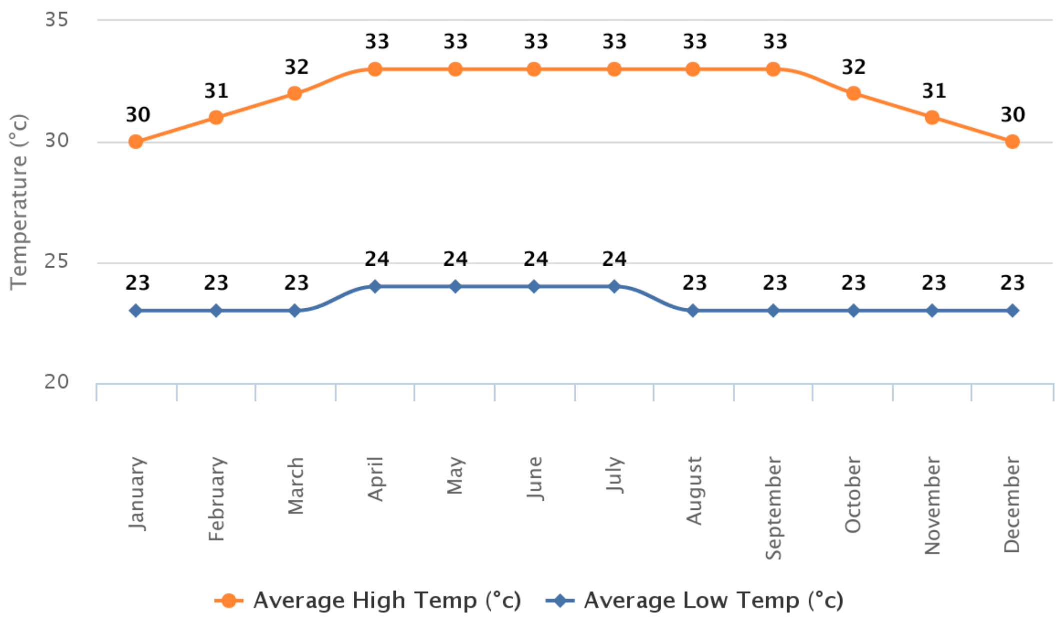

Figure 3.3: Average temperature graph for Kuantan

The rainy season runs from October to March, with north-easterly winds bringing heavy rain and often causing floods in the region, especially along the Kuantan River. From November through January, the north-east monsoon elevates humidity levels to uncomfortable heights, with daily thunderstorms and similar weather.

Strong winds and high seas make travelling to offshore islands dangerous during this time, and there is little sunshine. During the rainy season, actual temperatures can fall to around 27°C / 81°F, but increased humidity will affect the heat index. The air quality in Kuantan is affected during the drier months by a haze of pollution from slash-and-burn agricultural activities in Indonesia.

Seasonal variations between hot and dry, and wet and humid, affect the climate and temperatures here, as the cooling effect of the monsoon rains and thunderstorms may be largely negated by excessive humidity forcing up the heat index. Grey skies and strong winds are the norm for the months of November, December and January, and, combined with the possibility of flooding, make this season not the best time to visit.

High summer brings high temperatures combined with the haze, meaning that visitors with weak chests and those prone to asthma-related illnesses should perhaps choose another time to visit. The best months of the year are in the shoulder seasons approximating spring and autumn, thus avoiding the fierce heat and pollution in summer, and the grey skies and torrential winter rains. Pleasantly hot days with lots of sunshine and balmy evenings during these months will make sure your holiday is an unforgettable experience for all the right reasons.

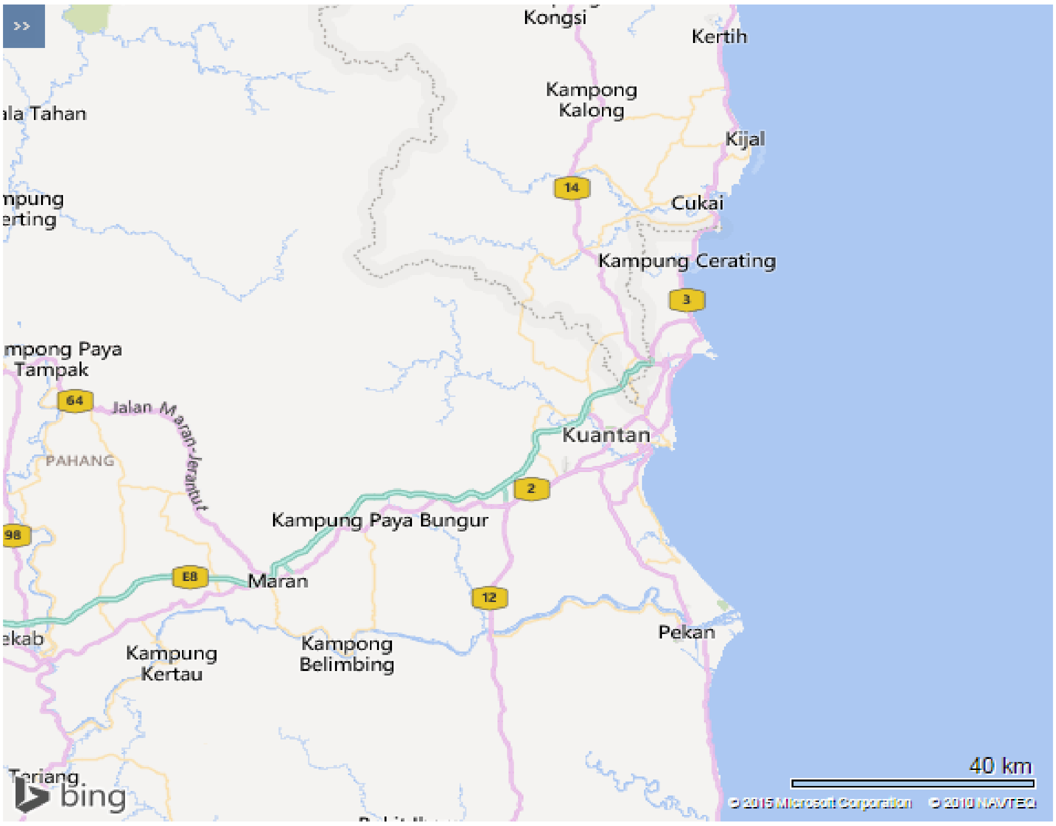

Figure 3.4: Maps of Kuantan, Pahang

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The historical temperature was conducted on a monthly and annual temperature for a station at Kuantan, Pahang. The overall area of the Pahang state is about 36137 km^2. In general, the area of Kuantan is 2,960 km^2 and this study only covered Kuantan district area only. Historical temperature data from the Malaysia Meteorological Department (MMD) were obtained to quantify the performance between temperature-based method and radiation-based method in calculating ET. Next, to analyze the future trend of potential evapotranspiration using various type of ET methods.

Two type of each group methods were selected there are Hargreaves-Samani Method and Blaney-Criddle Method to represent the temperature-based meanwhile Priestly-Taylor method and Turc Method to represent the radiation based. Every equation that had been used for this study having their own parameters that need to be considered. Table 4.1 presented the monthly of meteorological parameter for Kuantan,Pahang. All these parameters were used in calculating the PET using temperature-based method and radiation-based method.

The projection climate trend at the study site during year 2010 to 2099 has been produced by using SDSM model. The SDSM model used the relationship between local climate pattern and information of the atmospheric circulation at specific sub-grid in predicting future change of climate. The SDSM tools has generated the synthetic daily temperature at the study area and used multiple regression technique to construct the predictor-predictand relationship.

Table 4.1: Average monthly parameters used in different methods for estimating ET at the study area. Meteorological data are collected from the Kuantan, Pahang

Parameter	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Nov	Dec	Nov	Dec
Max Temp (oC)	31.1	30.9	30.6	30.7	31.3	32.1	32.7	33.0	32.9	32.9	32.42	31.87
Min Temp (oC)	23.0	23.1	22.9	23.0	23.1	23.4	23.6	23.8	23.7	23.6	23.55	23.34
Rainfall (mm)	139.48	87.40	148.34	158.69	158.97	123.56	124.46	148.91	169.25	218.26	234.48	227.20
Avg. RH (%)	72.90	73.00	76.60	81.50	86.30	86.30	86.40	87.00	85.00	79.70	77.80	74.70
Sunshine, n (h/day)	8.70	9.00	8.50	8.70	6.60	6.70	5.70	5.70	6.10	7.00	7.20	8.10
Net Radiation (MJ/m2/day)	19.09	20.78	20.84	21.20	17.27	17.77	16.28	15.94	15.67	16.39	15.90	16.40
Vapor Pressure (kPa/ oC)	0.21	0.22	0.22	0.22	0.21	0.21	0.21	0.21	0.2	0.2	0.22	0.21
Latent Heat (MJ/kg)	2.44	2.44	2.43	2.43	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44
Psychrometric (kPa/ oC)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Solar radiation (MJ/m2/day)	21.46	23	22.74	22.52	18.89	19.62	18	17.24	17.02	18.2	22.54	22.29

4.2 Performance of SDSM

4.2.1 Calibration and Validation of SDSM

The temperature data for this study was obtained from the meteorological station at Kuantan. It is assumed the temperature data obtained from the Kuantan meteorological station represent the temperature trend in Pahang state. In SDSM, the screening process was done to determine the most relevant predictor variables with linear correlation analysis between the predictors and the predictand variables. The empirical relationship between predictors such as sea level pressure and predictands such as temperature and rainfall were developed to generate the future climate.

Normally, the predictor variables should be in physically and conceptually sensible with respect to the predictands that have strongly and consistently correlated with the predictands. Besides, predictor variables should be ready available from the observed data and GCM output and accurately modelled by GCMs. It is also recommended that the candidate predictor suite contain variables describing atmospheric circulation, thickness, stability and moisture content.

The temperature simulation only involves single-site temperature record known as Kuantan meteorological station. Based on the temperature trends in Malaysia, the monthly temperature range is very small and has a small variation at different areas. Besides, the temperature data was well correlated to the atmospheric characteristics and the selection of predictor can be easily done. For this study, each local predictands was calibrated in 15 years starting from year 1984 to 1999 and continue with following 15 years validated starting from year 1999 to 2013 using the selected NCEP predictors to evaluate the performance of the simulated result compared to the observed data. Then, the GCM-derived predictors were used to generate the daily weather series using equal NCEP predictor variables for the future year.

Based on the correlation value in the screening process, five predictors were selected from the one-shot analysis result to simulate with local climate characteristics.

Five predictors were selected there are surface vorticity (p_z), 500 hPa geopotential height (p500), relative humidity at 500 hPa (r500), relative humidity at 850 hPa (r850) and mean temperature at 2m height (temp) to project the temperature trends at study site.

Figures 4.1 present the simulated results produced for calibration from year 1984 to 1998 and validation starting from year 1999 to 2013 processes using predictors set from NCEP for three conditions temperature there are maximum, mean and minimum. In general, to project the future temperature trend in the same grid box, the constant predictors were used that were provided by HadCM3 type A2 scenario.

The performances of calibration and validation results that were presented in Table 4.2 consists of correlation coefficient (r) and mean absolute error (MAE). Based on the results, the MAE for the maximum temperature show the lowest value in the whole analysis, between 0.0 to 0.5 ^{o}C. On the other hand, mean and minimum temperature showed higher value of MAE, between 1.0 to 2.0 ^{o}C. Higher correlation values were estimated in the calibrated and validated results for minimum, mean, and maximum temperature simulation closer to 1.0. It shows the calibrated and validated values were in a good agreement with historical records and produced reliable data for the future projection.

Table 4.2: Performance of calibration and validation results for temperature using SDSM model

Temperature	Correlation, r	MAE
Max	0.99	0.36
Mean	0.99	1.24
Min	0.99	1.99

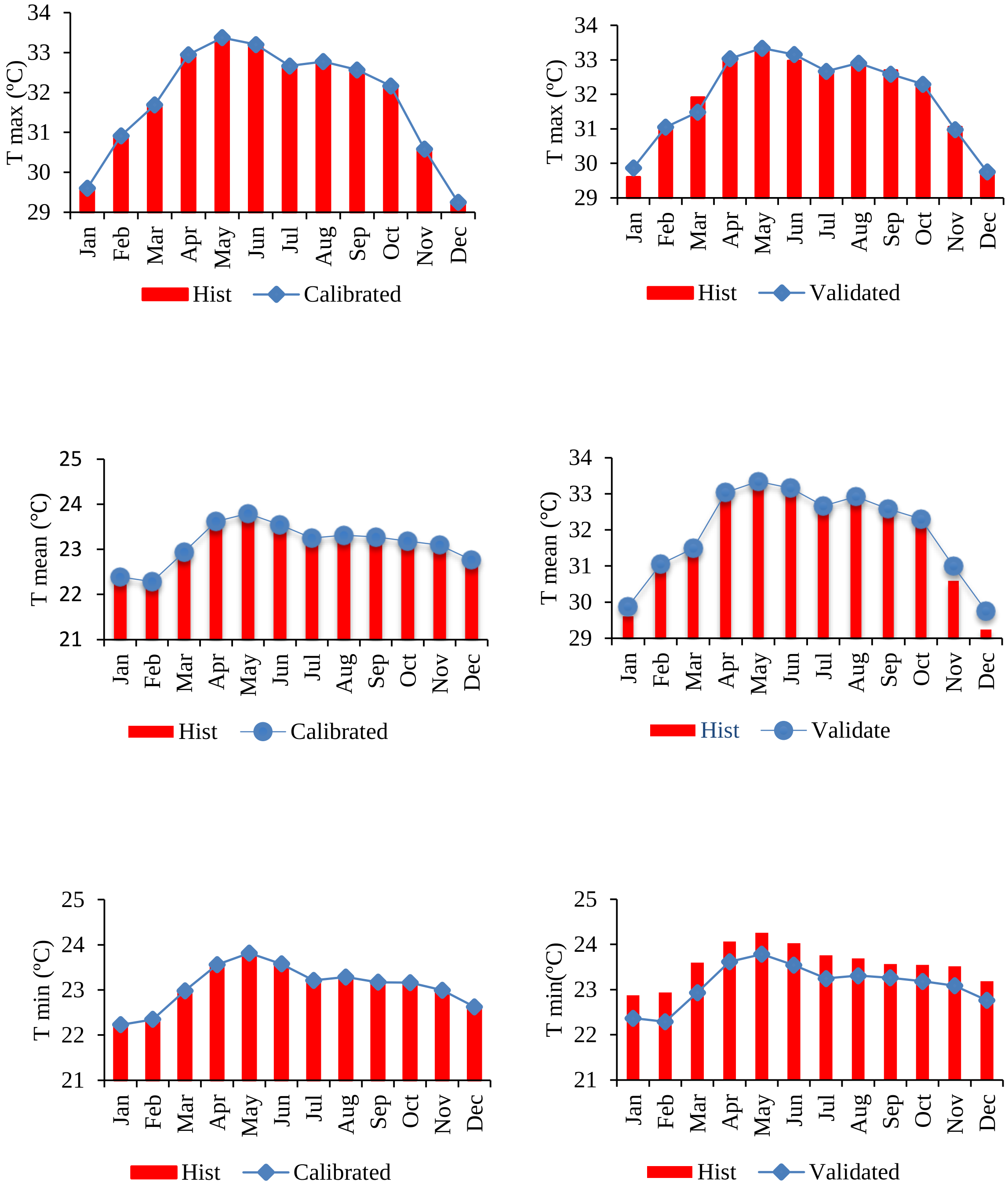

Figure 4.1: Calibrated (1984 to 1998) and validated (1999 to 2013) results for minimum, mean, maximum for Kuantan using SDSM model

4.2.3 Temperature Projection in Study Area

The magnitude and rate of future climate change will primarily depend on the following factors the rate at which levels of greenhouse gas concentrations in our atmosphere continue to increase and how strongly features of the climate (e.g., temperature, precipitation, and sea level) respond to the expected increase in greenhouse gas concentrations. Besides, natural influences on climate (e.g., from volcanic activity and changes in the sun's intensity) and natural processes within the climate system (e.g., changes in ocean circulation patterns) also the factor of future climate change.

The SDSM model is applied to simulate and generate future scenario at Kuantan station for the mean, min, and max of daily temperature data over the period year 2010-2099. Figure shows the generated monthly temperature (minimum, mean and maximum) for every interval period year 2010 - 2039, 2040 - 2069, and 2070 – 2099 by using SDSM tools.

Generally, the results show that the temperature will increases in every 30 years starting from January to August due to the high sun hours during the period. Based on the Figure 4.2, the highest minimum temperature during the period year 2010-2039, 2040-2069, and 2070-2099 is in May achiving 24 ^{o}C to 27 ^{o}C compared to the historical temperature data of 24 ^{o}C in the same month. It is expected to increase about 12%. However, the lowest minimum temperature is between 22 ^{o}C to 23 ^{o}C is expected occurred in January and February. The average increment for the minimum temperature is reaching until 3.45% at the end of century.

Figure 4.3 present the projection for mean temperature projection. The result shows that at the beginning of the months from January to August show that the projection mean temperature increase evenly during period 2010-2039, 2040-2069 and 2070-2099. However, start from September to December the projection mean temperature fluctuated. The highest mean temperature is in April and May between 27 ^{o}C to 31 ^{o}C compared to the historical temperature data. On the other hand, the lowest minimum temperature is between 25 ^oC to 27 ^oC and having the average increment in minimum temperature projection reach until 3.50% at the end of century.

Figure 4.4 refer to the projection for maximum temperature projection. Based on the figure, during the month April to July show that the projection maximum temperature increase evenly during period 2010-2039, 2040-2069 and 2070-2099 between 33 ^oC to 36 ^oC. However, during December the projection maximum temperature having the lowest temperature between 29 ^oC to 32 ^oC. The results also shown that the increment of maximum data increase to 3.48% at the end of century.

The temperature results show the increment in the minimum, mean and maximum temperature readings. Precaution is highly recommended even though the estimated temperature in the future year not extremely high. It is because the temperature raises may encourage the loss of volume of soil moisture and evapotranspiration rate especially at open surface like paddy fields. Thus, the irrigated demand is expected to inconsistent and possibly increase affected by changes of climate variability in the future year.

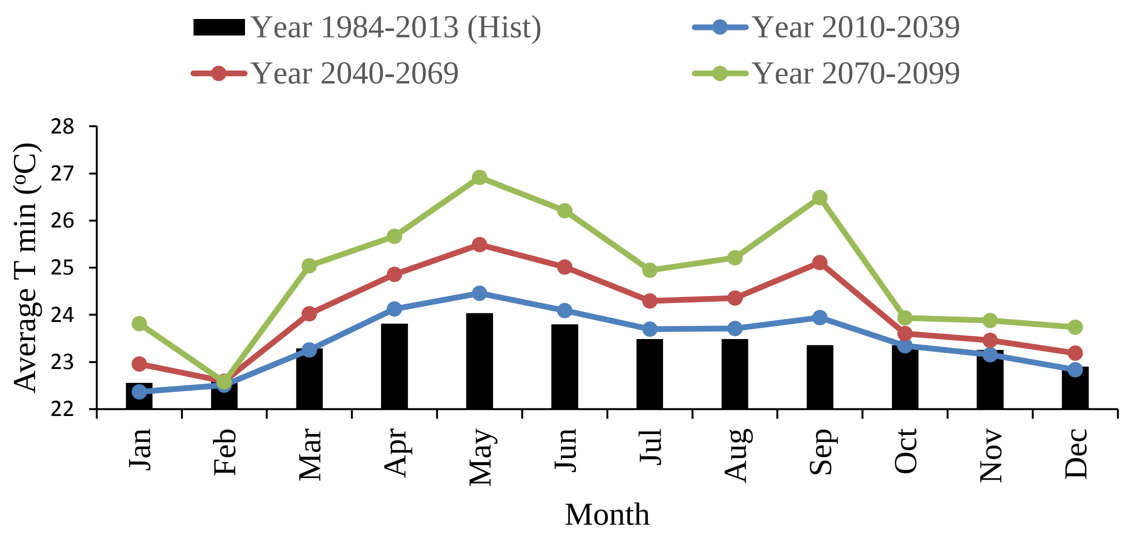

Figure 4.2: Projected minimum monthly temperature at different time intervals

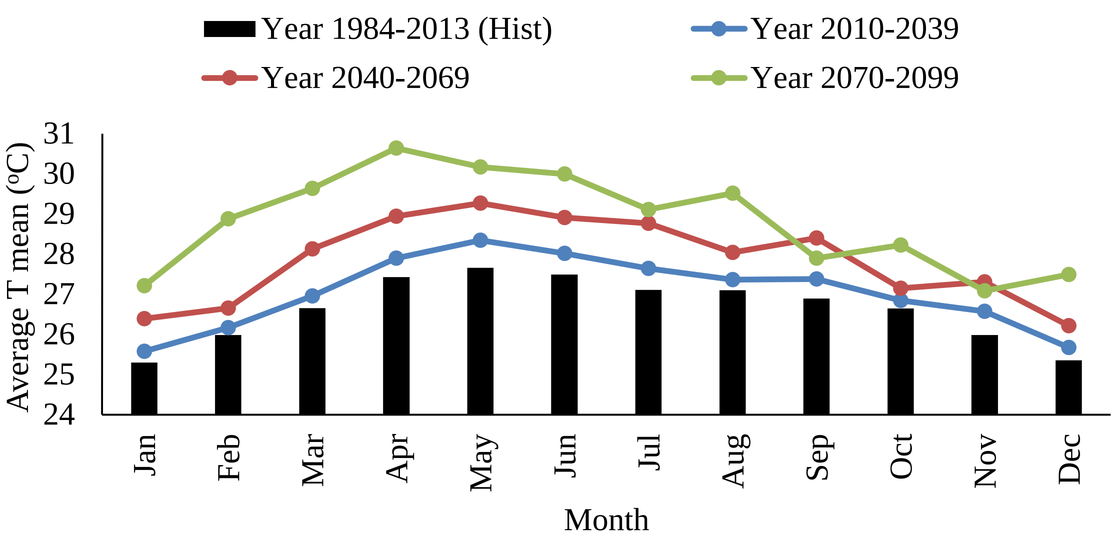

Figure 4.3: Projected mean monthly temperature at different time intervals

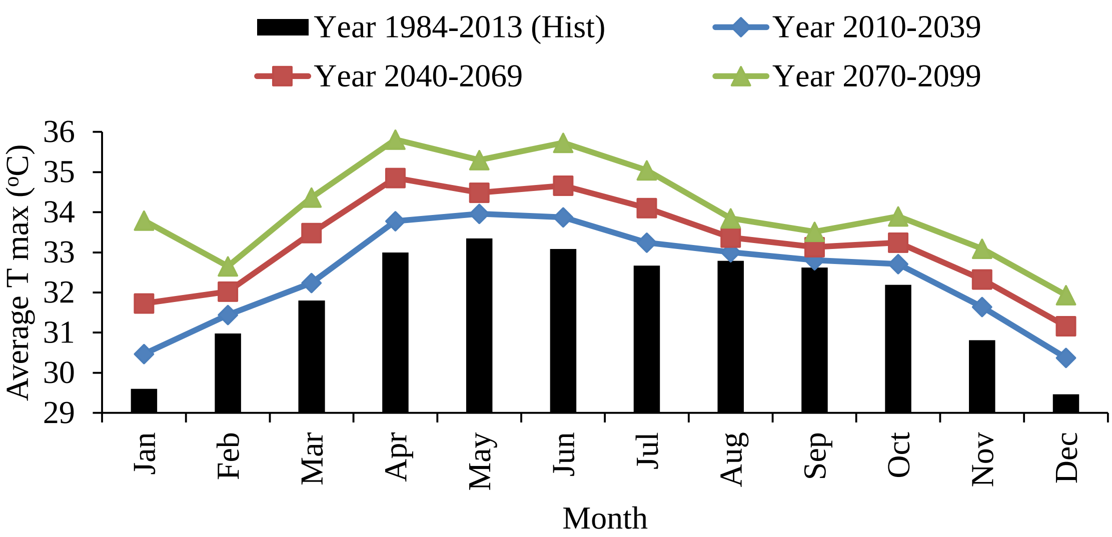

Figure 4.4: Projected maximum monthly temperature at different time intervals

The temperature results show the increment in the minimum, mean and maximum temperature readings. Precaution is highly recommended even though the estimated temperature in the future year not extremely high. It is because the temperature raises may encourage the loss of volume of soil moisture and evapotranspiration rate especially at open surface like paddy fields. Thus, the irrigated demand is expected to inconsistent and possibly increase affected by changes of climate variability in the future year.

4.3 Comparison of PET Methods

Potential evapotranspiration (PET) defined as the amount of evaporation that would occur if a sufficient water source were available. However, the actual evapotranspiration is considered the net result of atmospheric demand for moisture from a surface and the ability of the surface to supply moisture, then PET is a measure of the demand side. Surface and air temperatures, insolation, and wind all affect this. A dry land is a place where annual potential evaporation exceeds annual precipitation.

To measure the accuracy and reliability of ET methods, estimated ET value produced by each method were compared with the historical ET that obtained from MMD. Performances of ET methods in this study were measured by comparing two parameters there mean absolute error, which gave the amount of physical error in the measurement and Pearson correlation coefficients which gave a measure of association between ET estimates.

Table 4.3 shows the error of absolute and Pearson with ET methods that used in this study there are radiation-based methods (Priestley-Taylor Method and Turc Method) and temperature-based method (Hargreaves Mtehod and Blaney-Criddle Method). From the error in the table, the higher value of Pearson correlation and the lowest value of the absolute error that compared with historical data can find the best method of ET.

The correlation coefficients of temperature-based method were much higher more than 0.8 compared to radiation based method that less than 0.8. However, the absolute error were least for the Priestly-Taylor method and highest for Blaney-Criddle method. As the correlations between radiation-based methods and historical data are high, it can be remarked that radiation-based method can efficiently selected the actual ET pattern.

Relative error gives an indication of how good a measurement is relative to the size of the thing being measured. Figure 4.5 show the relative error among four simple ET methods. From the figure below, show that the Blaney-Criddle method has the highest value of relative error compare to Hargreaves-Samani method, Preistly-Taylor method and Turc method. Hargreaves-Samani and Turc methods still show the higher value of relative error which still not the best method to use in this study. However, Priestly-Taylor method has the lowest value of relative error that classify the best method of ET for this study. The comparative accuracy of these measurements can be determined by looking at their relative errors.

The mean daily ET values estimated by different methods are shown in Figure 4.6 and the monthly pattern produced by different methods is not similar. In general, the ET values at Kuantan, Pahang are in the range of 2.0 mm/day to 5.0 mm/day. The highest values of ET are found in April (4.21 mm/day) and followed by August (4.19 mm/day) as the temperature and sun hours are high during this months. Besides, the lowest of ET value is predicted occurred in November to January due to Northeast Monsoon. The Blaney-criddle method produced the highest values of ET (6.0 mm/day) with average increment value 1.5 mm/day and followed by Turc method with average increment value 1.32 mm/day. The Priestley-Taylor method as the lowest increment with an average 1.15 mm/day and produced similar pattern to the historical data.

Table 4.3: Error and correlation between historical data and ET model under study

PET	Method Type		Error	
	Temperature	Radiation	Absolute	Pearson
Hargreaves Samani	X		1.00	0.90
Priestly-Taylor		X	0.36	0.73
Blaney-Criddle	X		1.77	0.83
Turc		X	1.15	0.71

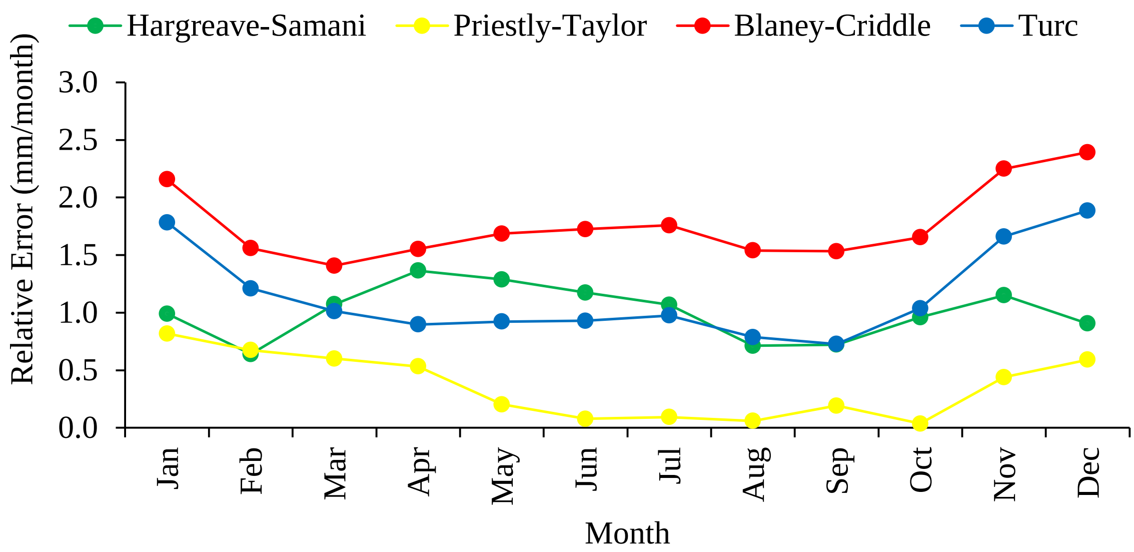

Figure 4.5: Relative error between historical data and ET model under study

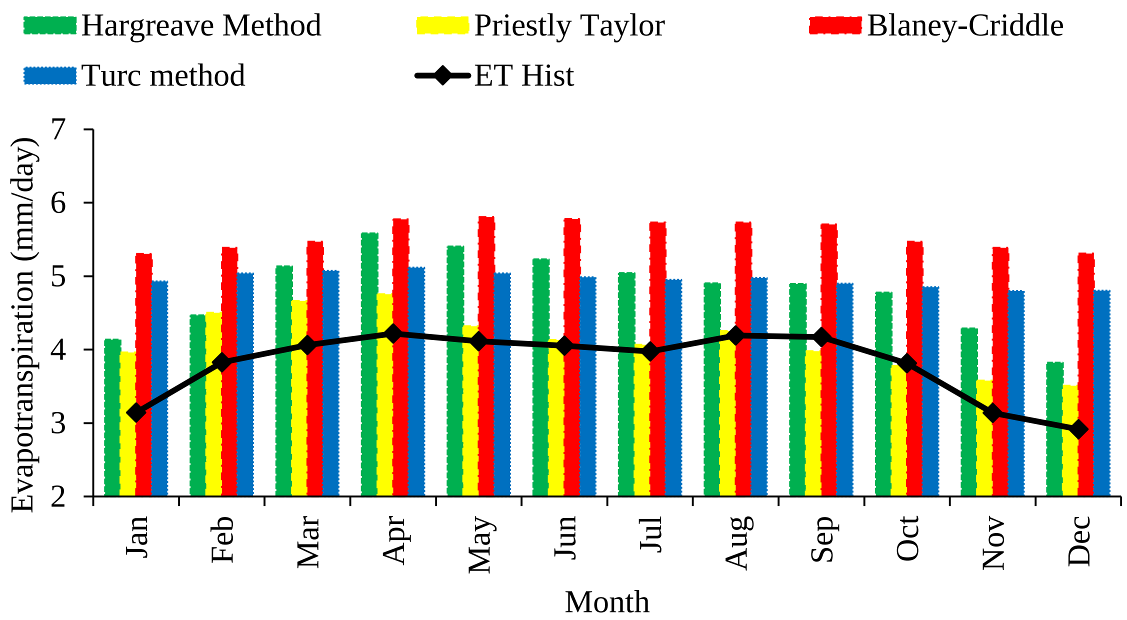

Figure 4.6: Comparison performance of ET value of each methods with the historical data

4.4 Future Projection of ET in study area

Figure 4.7 shows the changing pattern of PET by year predicted by historical data, Turc Method, Blaney-Criddle Method and Hargreaves-Samani Methods for the time period 2010–2099. The ET values were estimated based on the future temperatures projected results produced by SDSM model. It was considered that all meteorological other parameters are not be affected by climate change and therefore, all parameters would remain constant. In general, all the methods estimate the increment of ET in the area over the time period 2010–2099 due to increment of temperature ready in the future year. This was acceptable as the SDSM also projected a sharp rise of temperature which would certainly accelerate the evaporation and transpiration processes.

The Blaney-Criddle method predicted the highest changes in PET (2000 mm/year to 2147 mm/year) with average ET 1813 mm/year. This method predicted an increment of ET by 1.7% per year on average and increment about 1.5% compare to historical ET. Turc method is the second method predicted that have the higher changes of ET compare to other three methods (1780 mm/year to 1860 mm/year) with average ET 1813 mm/yer. This method predicted an increment of ET by 1.47% per year on average and increment about 1.32% compared to historical ET.

The Hargreaves method that have the higher changes in PET (1610 mm/year to 1779 mm/year) after Turc method. It have average ET 1690 mm/year. Besides, this method predicted of ET by 1.37% per year on average and increment about 1.23% compare to historical ET. On the other hand, Priestly-Taylor method show that it have similar trend with historical ET with have lowest increment 1.22% per year on average and lowest increment about 1.10% compared to historical ET. The changes of ET between 1468 mm/year to 1549 mm/year with average ET 1506 mm/year.

Figure 4.8 to 4.10 show the projected mean monthly PET during 2010-2040, 2041-2070 and 2071-2099 period. From the figure, it show that the Blaney-Criddle method have the highest PET during every three interval period. Next follow by Turc method, Hargreave method and Priestly-Taylor method. However, Priestly-Taylor shown the same trend with historical data.

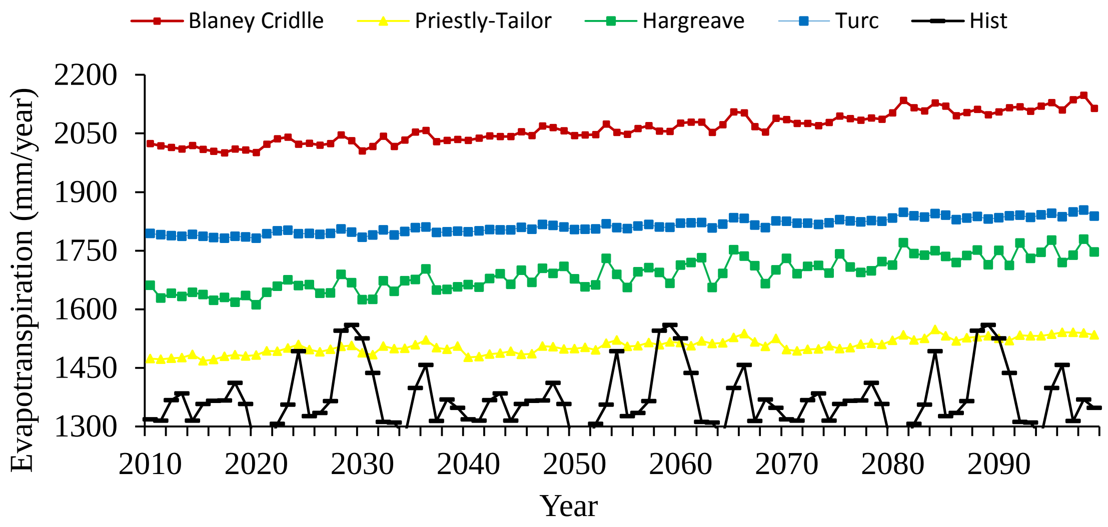

Figure 4.7: Estimation of PET value at different time interval

Figure 4.8 to 4.10 show the changing pattern of ET by day predicted by historical data from MMD, Turc Method, Blaney-Criddle Method and Hargreaves-Samani Methods for the time period 2010–2099. In general, all the methods showed an increase of the ET in the study area over the time period 2010-2099. This acceptable as the SDSM also projected a sharp rise of temperature which would certainly accelerate the evaporation and transpiration processes.

Figures below showed that the Blaney-Criddle method predicted the highest changes in PET (5.0 mm/day to 7.0 mm/day) follow by Turc, Hargreave-Samani and Priestly-Taylor methods. In addition, correlation error for Blaney-Criddle method quite higher 0.7-0.9 shown in Table 4.4.1 compared to historical data. Hargreave-Samani and Priestly method showed the fluctuated correlation error that not suitable for projecting changing pattern of ET under climate change scenario. However, Turc method showed the lowest correlation error between 0.61 and 0.72 which suitable method for projecting future changes of ET due to temperature rise.

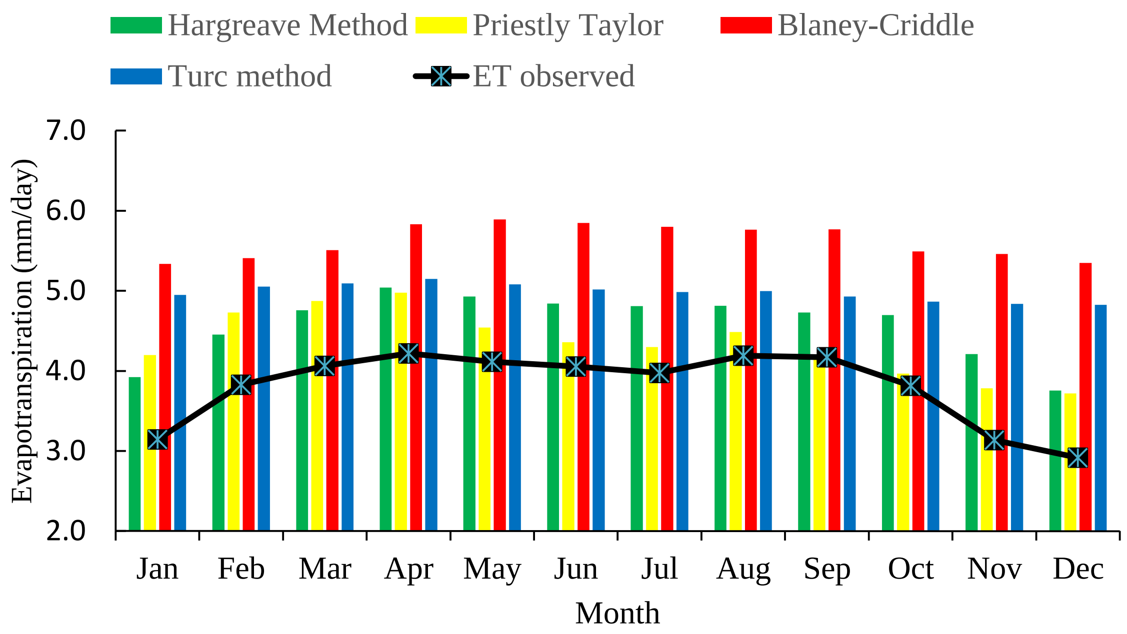

Figure 4.8: Estimation mean monthly PET in interval period Δ2020

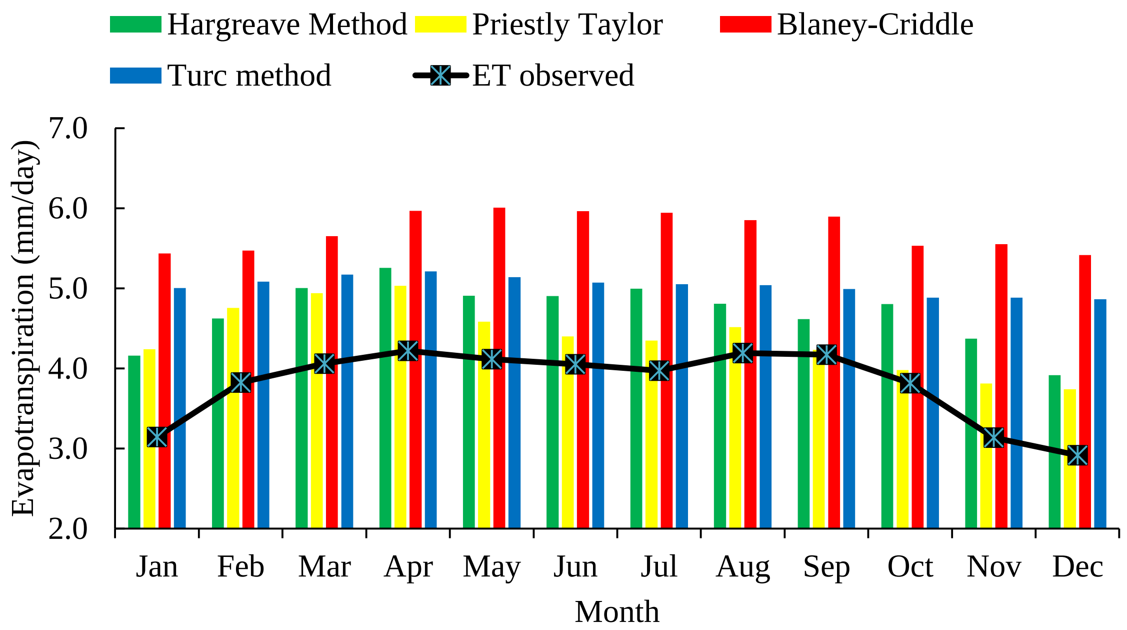

Figure 4.9: Estimation of mean monthly PET in interval period Δ2050

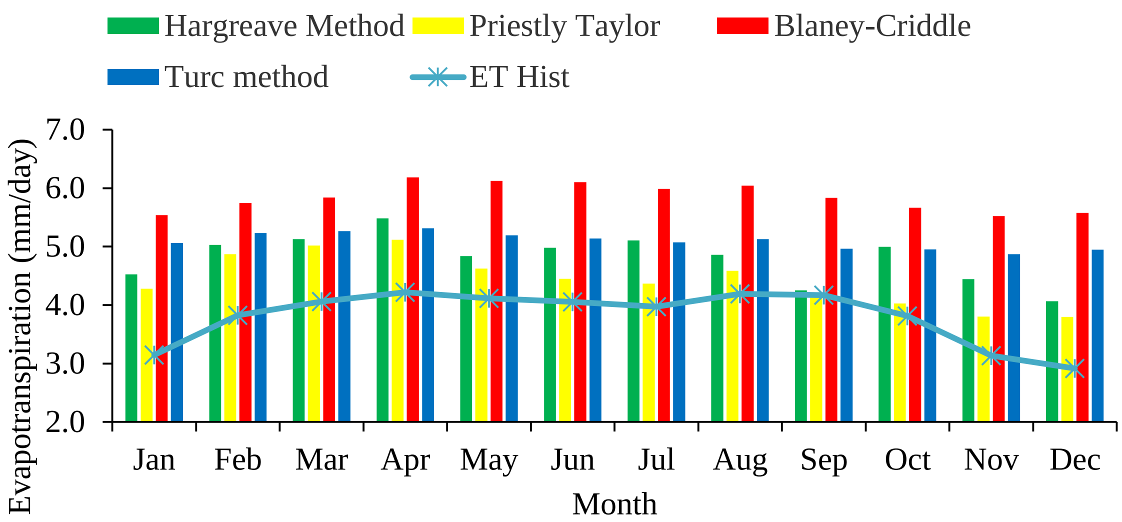

Figure 4.10: Estimation of mean monthly PET in interval period Δ2080

Table 4.4: Correlation between historical data and ET at different time interval

PET	Year		
	2010-2039	2040-2069	2070-2099
Blaney-Criddle	0.80	0.79	0.85
Hargreave-Samani	0.96	0.89	0.66
Turc	0.72	0.71	0.61
Priestly-Taylor	0.72	0.71	0.69

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objective of the study is to determine the best performance in estimating PET value using temperature-based method (Hargreaves-Samani Method and Blaney-Criddle Method) and radiation-based method (Priestly-Taylor Method and Turc Method). To obtain the best method in estimating PET, these methods were compared with the historical data from MMD. Downscaling is a technique by which properties of the free atmosphere are used to predict local meteorological conditions. The Statistical Downscaling Model (SDSM) is a tool that used to produce high resolution climate change scenario. The climate change will affect the temperature with decrease or decrease. However, this temperature data analysis is essential to fulfilling the objectives function.

5.2 Quantifying the Performance of Temperature-Based Method and Radiation-Based Method in Calculating ET

1) Radiation-based method is the best method in estimating ET for the study area. In radiation-based method (Priestly-Taylor Method and Turc Method), Priestly-Taylor method is the most suitable method to use to find ET followed by the Turc method.

2) From the results, Priestly-Taylor method had the lowest value of absolute error (0.36) and higher and Pearson error (0.73).

3) In temperature-based method, Hargreaves-Samani Method is the best compared to Blaney-Criddle Method. This is because Hargreaves-Samani Method have the lowest in absolute error (1.00) and highest in Pearson error (0.90).

4) From the results, it can classify that the best method to find ET for the study area are Priestly-Taylor Method followed by Hargreaves-Samani Method, Turc Method and Blaney-Criddlle Method.

5.3 Estimating PET Due to the Climate Change Impact

1) Projection of temperature results for minimum, mean and maximum will increase in every 30 years starting from January to August for interval year 2010-2039, 2040-2069 and 2070-2099.

    a) The highest minimum temperature occurred in May achieving 24 ^{o}C to 27 ^{o}C and the lowest minimum temperature occurred in January and February between 22 ^{o}C to 23 ^{o}C. The average increment reaching 4.35% the end of the century.

    b) The highest mean temperature occurred in April to May achieving 27 ^{o}C to 31 ^{o}C and the lowest minimum temperature between 25 ^{o}C to 27 ^{o}C. The average increment reaching 3.50% the end of the century.

    c) The highest maximum temperature occurred in April to July achieving 33 ^{o}C to 36 ^{o}C and the lowest minimum temperature occurred in December between 29 ^{o}C to 32 ^{o}C. The average increment reaching 4.35% the end of the century.

2) Radiation-based method are suitable for projecting changing pattern of ET under climate change scenario.

3) In the radiation-based method, Turc method is the most suitable method for projecting future changes of ET duet to temperature rise. Turc method had the lowest correlation error between 0.61% to 0.72% in projecting the future changes compare to the historical data.

5.4 Recommendations

Several recommendation are provided in enhancing the study purpose:

a) The Priestly-Taylor Method can be tested at various location in Malaysia to determine the performance and suitability of this method.

b) Consider many temperature meteorological stations surrounding Pahang state to obtain the distribution and fluctuation of PET value at different topography.

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