ESTIMATION OF EVAPOTRANSPIRATION BASED ON LOCAL METEOROLOGICAL DATA, FOR PENANG ISLAND

By

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TABLE OF CONTENTS

CHAPTER 4- RESULT AND DISCUSSION

CHAPTER 5- CONCLUSION AND FUTURE RECOMMENDATION

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABL	Atmospheric Boundary Layer
ALOS-PALSAR	Advanced land Observing Satellite- Phased Array type L-band Syntetic Aperture Radar
ASL	Atmospheric Surface Layer
ATSR	Along Track Scanning Radiometer
BAS	Bulk Atmospheric Similarity
CWSI	Crop Water Stress Index
EOS	Earth Observing Systems / Earth Observatory Satellite
ET	Evaporation
ET_o	Crop/Reference evapotranspiration
FAO	Food and Agriculture Organization
Geotiff	Geographical Information System compatible formats
Glovis	Global Visualization Viewer
H	horizontal
HDF-EOS	Hierarchical Data Format -Earth Observing System
LAI	leaf area index
Landsat 7	Land Remote Sensing satellite 7
LWIR	longwave Infrared
MEASAT	Malaysian East Asean Satellite
MODIS	Moderate-Resolution Imaging Spectroradiometer
MODTRAN	Moderate spectral resolution atmospheric Transmittance algoritm
MRTWeb	MODIS Reprojection Tool Web

NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-Red
NOAA	National Oceanic & Atmospheric Administration
PBL	Planetary Boundary Layer
PET	Potential evaporation
PM	Penman-Monteith
SEBAL	Surface Energy Balance Algorithm for Land
SEBI	Surface Energy Balance Index
SEBS	Surface Energy Balance Systems
SNR	signal-to-noise
S-SEBI	Simplified Surface Energy Balance Index
SEBAL	Surface Energy Balance Algorithm for Land
SWIR	Shortwave Infrared
USGS	United States Geological Survey
UV	Ultraviolet
V	vertical

LIST OF SYMBOLS

~	estimate
°C	degree Celsius
C_p	specific heat of the air
d	displacement distance
e_a	actual vapour pressure
e_s	saturation vapour pressure
e_d	water vapour pressure
e_a-e_s	saturation vapour pressure deficit
E_{daily}	daily evaporation
ET_o	reference evapotranspiration
E_{pan}	pan evaporation
ET_{Har}	reference evapotranspiration by Hargreaves
ET_{makk}	reference evapotranspiration by Makkink
ET_{PT}	reference evapotranspiration by Priestley-Taylor,
ET_{thorn}	reference evapotranspiration by Thornthwaite
f_c	fractional vegetation cover
FET	fetch
G	soil heat flux
H	sensible heat flux
h	vegetation height

I, a	thermal indices.
K	von karman constant
$K\uparrow$	outgoing shortwave radiation
$K\downarrow$	incoming shortwave radiation
K_p	pan coefficient
$L\uparrow$	outgoing longwave radiation
$L\downarrow$	incoming longwave radiation
$NDVI_{max}$	NDVI for full vegetation coverage
$NDVI_{min}$	NDVI for bare soil
r_a	aerodynamic resistances
R_a	extraterrestrial solar radiation
r_{ah}	heat resistance
r_{ah_wet}	external resistance
RH_{mean}	mean relative humidity
R_n	Net Radiation
r_s	Bulk surface
T_a	air temperature
T_{aero}	aerodynamic temperature
T_{max}	maximum temperature
T_{min}	minimum temperature
T_{mean}	average temperature
T_o	surface temperature
u	wind speed

U_2	wind speed at 2 m height
z_{oh}	roughness length for heat transport
z_{om}	aerodynamic roughness height
z_r	relative humidity measurement height
z_w	wind speed measurement height
α	albedo or surface reflectance
β	bowen ratio
γ	psychometric constant
Δ	slope of the saturation vapour pressure
Δe	vapour pressure difference between the two measurement levels
ΔT	temperature difference between the two measurement levels
ε_a	emissivity of atmosphere
ε_s	surface emissivity.
λ	latent heat of vaporization
λE	latent heat flux
μm	Micrometer
ρ	density of air
ρ_a	mean air density at constant pressure
ρ_{air}	moist air density
Σ	Stephan Boltzman constant
Ψ	stability correction
r_c	empirical coefficient
r_s	empirical coefficient

ANGGARAN PENYEJATPELUHAN BERDASARKAN DATA METEOROLOGI TEMPATAN, BAGI PULAU PINANG

ABSTRAK

Penyejatpeluhan menyumbang bahagian yang besar dalam kitaran hidrologi di mana ia mengekalkan keseimbangan tenaga permukaan, kesan daripada perubahan jisim tenaga antara permukaan tanah dan atmosfera. Kebiasaannya data penyejatan dibekalkan oleh jabatan meteorologi manakala data penyejatpeluhan adalah sukar didapati. Dalam kajian ini, sistem keseimbangan tenaga permukaan (SEBS) digunakan untuk mengukur tenaga permukaan dan pecahan penyejatan bagi mengukur kadar penyejatpeluhan berpandukan data penderiaan jauh dan data meteorology tempatan. SEBS menggunakan tiga set data. Data pertama merangkumi bacaan meteorologi yang terdiri daripada bacaan halaju angin, tekanan udara, kelembapan relatif dan suhu udara. Data kedua diperolehi daripada pemerhatian imej satellite menggunakan imej MODIS/Aqua bagi menentukan pantulan permukaan, ukuran pancaran, index permukaan tumbuhan, NDVI dan pecahan kawasan tumbuhan. Persamaaan tertentu digunakan bagi menyokong imej satellite. Data set ketiga ialah maklumat mengenai sinaran matahari yang diterima dan dipantulkan semula di mana ianya penting bagi menetukan nilai jumlah sebenar sinaran yang diterima. Apabila jumlah sebenar sinaran, tenaga haba tanah, tenaga haba pendam dan tenaga haba yang dipindahkan dikenalpasti, ET dihitung menggunakan persamaan Penman-Monteith. Akhirnya keputusan menunjukkan kaedah Penman-Monteith, Priestly Taylor dan Pan evaporation sesuai digunakan bagi mengukur kadar penyejatpeluhan di Pulau Pinang tetapi persamaan Makkink, Hargreaves dan Thornthwaite tidak sesuai digunakan di kawasan kajian.

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ABSTRACT

Evapotranspiration (ET) constitute a large portion of hydrological cycle which is stabilizing energy balance at the surface as a consequence of change energy flux between land surface and atmosphere. Usually, rate of evaporation obtain from Meteorological services while data of evapotranspiration is rarely available. In this study, Surface Energy Balance Systems (SEBS) has been utilized to measure turbulent flux and evaporative fraction in order to estimate rate of evapotranspiration using remotely sensed data and meteorological observation. SEBS required three datasets. First data sets is meteorology observation consist of wind speed, air pressure, relative humidity and air temperature. Second dataset gained from satellite observation using MODIS/Aqua images to determine albedo, emissivity, leaf area index, NDVI and fractional vegetation coverage. Reliable equation need to support satellite observation image. The third data set is incoming and outgoing solar radiation which is important to determine value of net radiation. Once net radiation, soil heat flux, latent heat flux and sensible heat flux identified, ET evaluate using Penman-Monteith equation. Finally, result showed that, Penman-Monteith, Priestly Taylor and Pan evaporation method considered as the best algorithm to estimate ET in Penang Island but Makkink, Hargreaves and Thornthwaite are not suitable for the study area.

CHAPTER 1

INTRODUCTION

1.1 Background

Hydrologic cycle, or also known as water cycle is important factor for stabilizing energy balance at surface. This process is a conceptual model that describes the storage and movement of water between the biosphere, atmosphere, lithosphere, and the hydrosphere. This is the endless circulation of water vapour to precipitation, stream flow, lakes, oceans and returning to water vapour through evaporation and transpiration. Important process such as evaporation, transpiration, condensation, precipitation, deposition, runoff, infiltration, sublimation, melting, and groundwater flow occur during hydrologic cycle (Chahine et al., 1992).

One of the significant components in hydrologic cycle is Evapotranspiration (ET) process. Researchers state that in arid regions, about 90% of precipitation returns to the atmosphere through evaporation process (Rosenberg et al., 1983). On a global scale, around 65% of the precipitation on the continents is evapotranspired. Off this, 97% is evapotranspired from land surface while another 3% is come from open-water evaporation. When refer to the scale of specific zones in the world, approximately 90% of the precipitation can be evapotranspired (Varni et al., 1999).

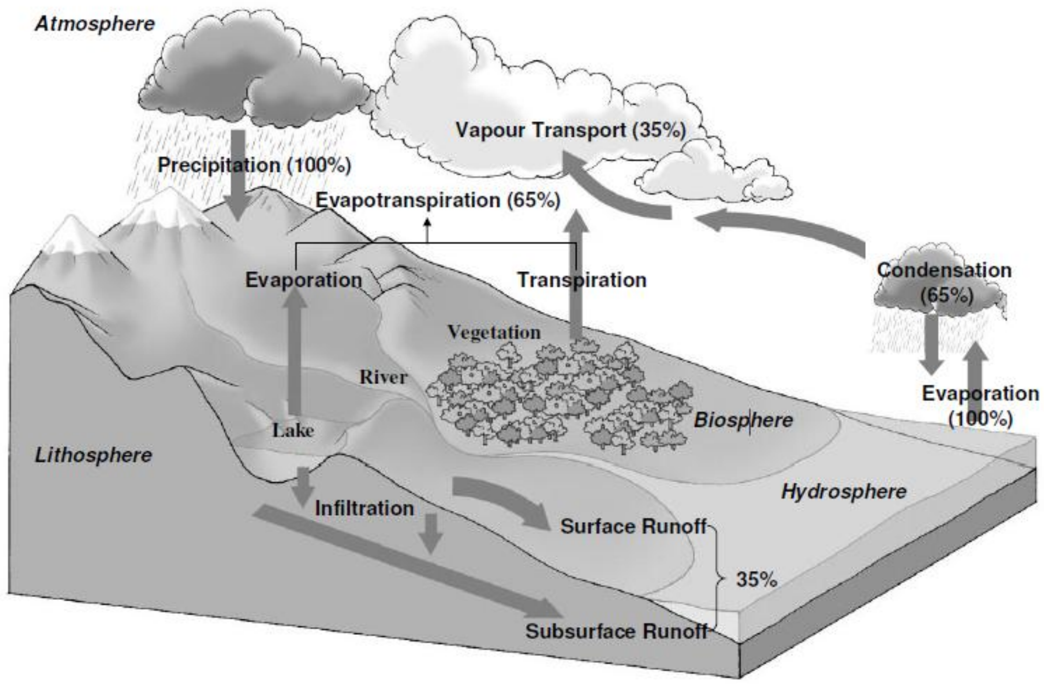

Figure 1.1: Hydrologic cycle

(Source of International Institute Geoinformation Science and Earth Observation Enshede Netherlands)

Evapotranspiration is refers to the combine process of evaporation and transpiration whereby water is lost from the soil surface by evaporation and water is lost from plants by transpiration (Shan Xin et al., 2007). Evaporation and transpiration occur simultaneously and there is difficult to distinguish both processes (Allen and Smith, 1998). Rate of Evapotranspiration determine by a few factors that is soil moisture, plants type, stage of plant development and also weather. While weather identified by most of meteorology parameters such as solar radiation, wind speed, atmospheric pressure, humidity and temperature. Furthermore, Evapotranspiration varies seasonally according to the climatic condition, environmental surrounding, land cover and also land use. Because of the variability, understanding of evapotranspiration process and knowledge about the spatial and temporal rate is necessary with support by water resource modelling and dynamic crop weather modelling.

Evaporation is defined as a process of transformation water from liquid to gas phases and moves from the ground to atmosphere. These processes only happen on the surface of the liquid and not involve the whole water body and must be supported by energy. The source of energy for evaporation is primarily solar radiation. In addition, it is related to the behaviour of environmental surrounding. Meteorological conditions become the crucial impact to the rate of evaporation and also amount of energy available plays a main role in regulating evaporation from vegetation.

Apart from the water availability in the topsoil, evaporation from a cropped soil is mainly determined by the fraction of solar radiation which is reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process (Allen, Periera, Raes and Smith, 1998).

Accurate estimating ET plays a significant role in assessing groundwater recharge, predicting crop yield and planning land use. The importance becomes even greater in semi-arid area where a series of severe problem occurred for example shrinkage of rivers and lakes, increased desertification caused by decreased vegetation covers, reduced biodiversity due to changes in hydrological cycle and worst conflict of water demands for the nature and the highly increased of human activities (Shan Xin et al., 2007).

Terms of potential evapotranspiration (PET) always been used in evapotranspiration measurement. Potential evapotranspiration refers to amount of water that could be evaporated and transpired if sufficient water available. It is the rate at which water is removed from the soil surface or profile if available. It always refers to the plants adequately supplied with water and usually not limited by disease or fertility (Burman and Pochop, 1994). Potential evapotranspiration defined simply as the amount of water that would be lost from the surface to evapotranspiration if the soil or vegetation mass had an unlimited supply of water available (Hansen et al.,1980; Dingman et al., 1994, Watson and Burnett, 1995). Since PET assumes that water availability is not an issue, vegetation would never reach the wilting point (the point in which there is not enough water left in the soil for a plant to transpire). Therefore, the only limit to the transpiration rate of the plant is due to the physiology of the plant and not due to any atmospheric or soil moisture restrictions (Watson and Burnett, 1995). PET is considered as the maximum ET rate possible with a given set of meteorological and physical parameters (Dingman et al., 1994). Thus, any irrigation that supplies more water than PET can accommodate is simply wasted.

Other family of evapotranspiration is reference crop evapotranspiration or reference evapotranspiration and denoted as ET_o. It is similar to PET with exception that it is applied to an identifiable crop such as alfafa or grass (Burman and Pochop, 1994). The reference surface is not short of water and it is a hypothetical grass reference crop with specific characteristics (Allen, Periera, Raes and Smith, 1998).

Furthermore, the terms of potential evapotranspiration have been replaced by the term "reference evapotranspiration" in current engineering usage (Doorenbos and Pruitt, 1975, 1977; Wright et al.,1982; Burman et al., 1990; Burman et al., 1983). Jensen defined reference evapotranspiration as the rate at which water, if available, would be removed from the soil and plant surface of a specific crop, arbitrarily called a reference crop (Jensen et al., 1990). Although any crop could be a reference crop, clipped grass (~0.12 m tall) or alfalfa (~0.5 m tall) has been the most widely used as the reference crop definitions (Jensen et al., 1990).

Assuming that moisture is always available, evapotranspiration depend primarily on the availability of solar energy to vaporize water. Evapotranspiration therefore varies with latitude, season of the year, time of the day, and cloud cover estimation. Warmer air can hold more water vapour, thereby will increased evapotranspiration rates. Minimum evapotranspiration generally occur during the coldest months of the year and vice versa. Drier air can accept much more water vapor than air that is nearly saturated, and windy conditions generally accelerate evaporation with the increment of speed. When air is saturated with water vapour, it condenses into droplets of water, and forming clouds. When the droplets gain enough mass, they fall to the ground as rain or snow causing evaporation and evapotranspiration occur again. This process will never stop as long as water and solar energy exist in this world.

Nowadays, the estimation of evapotranspiration become easier because there are a lot of method and techniques base on equilibrium surface using energy balance equation. One of famous methods is using Penman-Monteith equation. These method is most general and widely used appropriate with recommendation by Food and Agriculture Organization (FAO) irrigation and drainage paper 56. It is developed from original Penman-Monteith method together with equation of aerodynamic and surface resistance. The equation use standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed which consume all of meteorology aspect. This reason creates the stability of the equation. Although there are many other methods directly or indirectly proposed for estimating potential ET, Penman-Monteith method still considered as a universal standard to estimate ET (Jensen et al., 1990). By investigating around 20 different methods, Penman-Monteith equation shows the most accurate result from well-watered grass or reference crop evaporation under varied climatic conditions, humid and arid regions after measurement using certain equipment at area selected (Jensen and Burman, 1990). To get the best accurate data, some modification of the Penman-Monteith equation needs to calculate energy balance equation.

1.2 Problems Statement

Currently, global warming effects contribute to the huge concern and influence the whole world climate including study area. Any climatic changes will affect rate of evapotranspiration. The water budget in any region will be altered and this causing major consequences to the earth. The emission and absorption of green house gases such as carbon dioxide, radioactive gases and aerosol, modified the climate and create a big concern towards temperature's increment. The future global warming is predict to increase from 0.1°C to 0.3°C over the period of a decade (Raper et al., 1996). As Penang state known among the most rapidly developing, industrializing and also most populated island in Malaysia, it is indirectly affecting weather scale received by the island. The development of Penang Island will cause warmer environment in urban areas than its surrounding rural areas. Most of the areas expose to the Urban Heat Island (UHI) phenomenon which is contributing to the significant thermal discomfort among urban dwellers. Urban area has higher thermal conductivity and radiation heat budget. By changing the vegetation areas become impervious surfaces such as roads, building, concrete and modification of terrestrial ecosystem, the urban areas tends to bring out the higher surface temperature. Finally, temperature difference between urban and surrounding rural area contribute to the development of UHI (Hanafiah and Weng, 2001).

There are many useful algorithm can be implement to estimate evapotranspiration rather than use certain equipment at field measurement. SEBS application is one of the famous techniques which consider some equation to measure energy balance at the surface. It is supported by using FAO Penman-Monteith equation. The equation built in complex algorithm which is approved since a few decades ago. From principle of energy conservation: $R_n+G+H+\lambda E=0$, it is assumed that R_n and G are known or may be easily computed for most remote sensing-based energy balance studies. The two remaining terms, H and λE, are turbulent flux quantities and difficult to estimate. Application of remote sensing technique is useful in this study, to obtain necessary parameter in Penman-Monteith equation. Furthermore, remote-sensing provided data to regional scale and not only focus to the point measurement as meteorological station did. In this study, estimation of evapotranspiration from Penman-Monteith equation will compare with a few reference evapotranspiration models.

1.3 Objective

The main objective of this study is to evaluate rate of evapotranspiration in Penang Island by using meteorological observation and remote sensing data. Detail of objectives represent as the following:

1. To estimate Evapotranspiration for Penang Island by using meteorology and satellite observation.
2. To estimate Evapotranspiration based on Penman-Monteith equation through application of Surface Energy Balance Systems (SEBS).
3. To determine the accuracy of ET estimation with various reference model.

Once objectives have been achieved, the listing research question of this study can be elaborate clearly:

1. How far the importance of Surface Energy Balance Systems towards Penman-Monteith equation?
2. Is the parameter of SEBS such as emmisivity, albedo and fractional coverage can obtain directly or need a specific way to do so?
3. What is the necessary condition to apply in Penman-Monteith equation?
4. Which other reference ET yield the best accurate result as Penman-Monteith equation?

1.4 Thesis Outline

This study encompass with complex algorithm base on combination of a few formula describing by many other researcher. Some of theoretical aspects then being discuss to impart basic idea regarding the action of energy balance at the Earth. For purpose of presentation outlines, this thesis divides into five chapters.

Chapter one includes an overview of the thesis from beginning and consist of introduction to the research background, problem statements, main objective together with essential question based on this topic and finally viewing overall thesis's outline.

Chapter two focus more about literature review. Some of previous study related also discuss in here. It is includes the history of Penman-Monteith Equation, the importance of remote sensing for this study and also elaborate all criteria coverage. Furthermore, theoretical basis of evapotranspiration process and reference model of ET for validation purpose also being touched clearly. Details of Pan-method, Priestley-Taylor, Hargreaves, Makkink and Thornthwaite highlighted with describing all important criteria for each model and necessary condition to apply the models.

Chapter three provides methodology criteria beginning with explanation on the study area including climatology aspect continuing with brief introduction on how to gather all data from meteorology and satellite observation. It also elaborating the application of satellite MODIS towards getting the images. In addition, this chapter explain SEBS application towards Penman-Monteith equation. It is focusing on how to get value of net radiation, soil heat flux, sensible heat flux, latent heat flux and also describes reliable equation with this topic.

Chapter four consist of result and discussion. All finding results elaborate clearly. Here, rate of evaporation estimated using algorithm compare with ground truth data. Meanwhile, rate of ET estimated using Penman-Monteith equation compare with measurement from different algorithm.

Chapter five or last chapter summarizing the important evaluation and conclude the obtained result after all calculation made. The aspects discuss is related to the main anticipate objective as mention in the previous section. Future recommendation and constructive idea also suggested so that others can improve the quality of these topic next time.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Estimation of evapotranspiration based on remote sensing data has been rapidly developed since the last twentieth and several methods have been adopted by different research groups and used in related study area successfully. Among those methods, some are little bit simple, only multi-wave band data were used to calculate the available radiation on the surface then by applying conventional Priestley-Taylor equation or other model to calculate ET. Some are complicated when use method that include detail process about sensible heat flux calculation. Some only use synchronous meteo-satellite data, although image resolution is lower (Weinjing et al., 2006).

Method calculating evapotranspiration as proposed by Dalton et al., (1802), enhance the observation technologies and deep understanding of radiation transmission between land surface and atmospheric boundary layer (Gieske et al., 2003). For global, regional and local scale, there are some methods currently applied for monitoring ET either direct and indirect method. These models used in estimating actual and reference ET, which depend on the type of applications and available data (Gieske et al., 2003).

Direct method of ET is more difficult which is need specific device and measurements of soil water balance by using lysimeter requirement. Normally, direct methods need expertise with Eddy covariance technique which correlating with fast fluctuation vertical wind speed and water vapour density. This method are often expensive, demanding in term of accuracy and only can be handle by professional (Allen et al., 1998). The mass transfer method of computing ET examines the movement of air parcels above a generally homogenous surface (Allen et al. 1998). These parcels, also known as eddies, transport water vapor, heat, and momentum to and from an evaporating surface (Dingman et al., 1994; Allen et al., 1998; Geiger et al., 2003). Aside from lysimeters and mass transfer techniques, several other methods exist for measuring ET directly, such as eddy covariance (Massman and Grantz, 1995; Scott et al., 2004; Testi et al., 2004) and scintillometric techniques (Daoo et al. 2004). However, these methods require very high-resolution equipment that is generally cost-prohibitive and labor intensive. Because of the difficulty in direct measurement, ET commonly estimated by indirect method. Generally, indirect methods represent base on three famous techniques: Catchment water balance which involve the equation of water balance, hydrometeorological equation which is use Penman-Monteith method and lastly, energy balance study.

John Monteith, elaborated as "because Penman got the physics right, his formula has provided a basis for many theoretical and experimental studies" (Monteith et al., 1985). Penman idea is really useful and acceptable, all over the world. FAO Penman–Monteith (PM) yields after a few modifications towards Penman method. It was introduced as a standard model to estimate ET (Allen et al., 1998). However, in some cases, the use of FAO PM Method is restricted by lack of input variables. Concerned about that, Allen et al., (1998) suggested procedures for estimating missing climatic parameters, like net radiation, vapour pressure deficit and wind speed.

FAO Penman-Monteith has two advantages in comparison with other methods which is well documented method in comparison by using lysimeters under a wide range of climate conditions and yield good results under a variety of climate scenarios (Droogers and Allen, 2002). In the absence of lysimetric data Penman-Monteith equation is appropriate to find error of other method (Landeras and Lopez, 2008). Many researchers has recommended the standardization of the Penman-Monteith equation for estimation ET (Allen, Pereira, Rais, Smith, 1998). It is acquire air temperature, relative humidity, wind speed and solar radiation to compute ET (Droogers and Allen, 2002). Lack of one or more, climatic variable physically related to evaporation and transpiration processes will inescapably reduces the accuracy of evapotranspiration estimation.

Refer to the history of Penman- Monteith equation, it is base on equation for ET as derived by Penman et al. (1948). It was built by combining energy balance equation and aerodynamic equation for vapour transfer and then finally modified by Monteith et al., (1965) to include a canopy resistance for vapour diffusion out of stomata. ET has been studied for centuries. For more reviews of the history, refer to Brutsaert et al., (1982) and Jensen et al., (1990). Major progress in processes of energy exchange came about twentieth century. The classic work of Penman (1948) laid the foundation for relating ET to meteorology variables. Penman combined the energy balance components to sustain the evaporation with a mechanism to remove water vapor or known as sink strength. Many of researchers including Penman, continued expand the theory of the combination equation since 1950 with special emphasis of aerodynamic aspects. A detail summary in 1950's and early 1960's was presented by Rijtema et al. (1965) and Monteith et al. (1965).

Currently, equation base on PM model is widely use as a reference methodology, with adopted parameterization for surface and aerodynamic resistances to obtain reference ET from meteorological data (Allen et al., 1998). This method considers many parameters related to the evapotranspiration process such as net radiation, air temperature, vapour pressure deficit and wind speed. It was shown good results when compared with data from lysimeters. Some methods of estimating ET depend on atmospheric and thermodynamic parameters such as density of air, vapour pressure and air pressure. The significant usage of PM equation normally estimate from well-watered and stressed canopies, depend on the surface resistance but the measurement is little bit complex. Furthermore, PM equation capable substituting surface temperature with air temperature and energy balance (Monteith and Unsworth, 1990).

The estimation of atmospheric turbulent flux at the land surface has long been recognized as the most important process in the determination of the exchanges energy and mass among hydrosphere, atmosphere and biosphere (Bowen 1926, Penman 1948, Monteith 1965). Compare to all previous remote-sensing algorithms for heat flux estimation, SEBS developed by Su et al., (2002) has most important advantage for estimation of roughness height for heat transfer which is most critical parameter in parameterization of heat flux at land surface. Based on SEBS algorithm, some validations have been done successfully in different place with different scale (Su and Jacob, 2001). Since last twenty years, many researchers struggling to find out the best technique for calculating ET. For summary, they finally conclude that there are three types of methodology base on turbulent heat flux and ET estimation can be used in this study. There are analytical approaches, semi-empirical approaches and empirical approaches.

For analytical approaches, the former takes into consideration detailed physical processes at the scale of interest but usually involve complicated relationships and demands various input variable which can be observed directly by radiometric measurement and meteorological variables at proper reference height. Representative works of the first type including Jackson et al. (1981, 1988) that derived the so-called Crop Water Stress Index (CWSI) by applying the Penman-Monteith equation to radiometric measurements (Monteith et. al., 1981).

The foundation of analytical approaches which is related with this study were laid by Menenti et al. (1984) proposing a two layer combinational equation for a drying soil which was later shown by Menenti et al. (1993) to be able reduce combination equation by Penman-Monteith. In a further attempt, Menenti and Choudhury (1993) used the Surface Energy Balance Index (SEBI) approach. Because of the limited usage of SEBI which is parameterization not universal and cause some unexplain scatters in the result Menenti et al. (2001), Su et al. (2001, 2002) proposed the surface energy balance systems (SEBS) by extending the SEBS concept with a dynamic model for thermal roughness and the Bulk Atmospheric Similarity (BAS) theory of Brutsaert et al. (1999).

SEBS can be used for both local scaling and regional scaling providing a link for radiometric measurements and atmospheric models at various scales. By using SEBS, Jia et al. (2001) has successfully coupled large scale Numerical Weather prediction model fields to radiometric measurements from Along Track Scanning Radiometer (ATSR). Rauwerda et al. (2002) has extended SEBS to a parallel source model and has show significant improvement in estimation turbulent heat fluxes. On the application side, SEBS has been used to generate daily, monthly and annual evaporation in semi-arid environment and for drought monitoring (Su et al. 2001, 2002). On the empirical side, Bastiaansen et al., (1995) proposed the Surface Energy Balance Algorithm for Land (SEBAL) that required simultaneous presence of absolute dry and wet pixels and has been used for many irrigation studies. Later on, Su et al. (1999) has made correction in SEBAL for theoretical problem. Then, Simplified Surface Energy Balance Index (S-SEBI) present by Roerink et al. (2000) by fitting dry and wet cases present in spatial radiometric data and showed reasonable success for application to semi-arid areas (Roerink et al., 2000).

2.2 Previous study

Previous study of ET estimation recognized all around the world since a few decades ago. Different equation normally contributes to the different result. A method suitable for estimation at one place does not give the same result when applied to a different place which expose to the different climatic condition.

McKenny and Rosenberg (1993) used Penman-Monteith, Thornthwaite, Hargreaves and Priestley-Taylor in the North American Great Plains which is found that Thornthwaite produced the lowest annual values and Penman give the highest. Rosenberg et al., (1983) together with McKenny and Rosenberg (1993) reported that Thornthwaite, a highly empirical method, tends to greatly underestimate potential evapotranspiration.

Chabda et al. (1986) reported that reference evapotranspiration modified by Penman method and Hargreaves method has been found to be highly significant in Maharashtra, India.

Priestley and Taylor (1972) also found to underestimate potential evapotranspiration, particularly under advective conditions. This equation is similar to the Penman and Penman-Monteith formulations, with the exception that mass transfer effects are represented by a constant value, rather than computed from information of wind speed, humidity, and vegetation characteristics.

Gunston and Batchelor (1983) applied Priestley-Taylor and Penman methods to estimate evapotranspiration within the latitude zone of 25°N to 25°S. They found that estimation from these two methods agree closely when monthly rainfall exceeded monthly evapotranspiration.

Research by Amatya et al., (1995) compared Hargreaves-Samani et al., (1985), Priestley-Taylor et al., (1972), Makkink et al., (1957) with FAO Penman-Monteith in North Carolina. Priestley-Taylor and Makkink give the best estimation. He also found that Makkink generally underestimated ET during peak months, while Hargreaves-Samani model tended to overpredict ET. Yet, the Makkink model shows excellent results in Western Europe where it was designed, both in comparisons to FAO Penman-Monteith and measured ET data (de Bruin and Lablans 1998, Xu and Singh 1998de Bruin and Stricker 2000).

Barnett et al. (1998) and Irmak et al. (2003) support this observation as well. Xu and Singh (2000) examined several models including Priestley-Taylor and Makkink against pan evaporation data in Switzerland. These findings support the possibility that each parameter of the model may need to be properly adjusted for the local climate, particularly if the model is not designed explicitly for that climate.

Most relevant geographically to this study is research by Shah and Edling (2000) predicted daily ET in Crowley, Louisiana. They compared three forms of the Penman equation namely Penman-Monteith, FAO-Penman (by Doorenbos and Pruitt 1977) and Penman (Penman et al., 1963) to ET data derived from water balance method and finally found that The Penman-Monteith model underreported ET by 3.7%, which was found acceptable for irrigation purposes.

Lee et al., (2003) in his research regarding estimation of evapotranspiration in a rice irrigation scheme in Peninsular Malaysia shows that Penman-Monteith and pan method give the best accurate result for the west coast, Peninsular Malaysia meanwhile, Priestley-Taylor shows the lowest estimations of evapotranspiration followed by the Hargreaves method. This previous studies chose as a close reference to this research because the study area located in a same region and expose to the same climatic condition.

2.3 The importance of Remote Sensing

Remote sensing defined as the collection data of an object from a distance. Remote sensors or remote sensing devices has a greatly improve the ability to receive and record information about an object without any physical contact. It involves measurement of the electromagnetic spectrum that can be use to characterize any of information data need. Photography in the visible wavelengths is one of the first remote sensing techniques to be use. Over the years, remote sensing technique has expanded to provide the capability of making measurements over the entire electromagnetic spectrum (Colwell et al., 1983). Different sensors can provide many types of information. For example, measurement of reflected solar radiation give information on albedo, thermal sensors which is measure surface temperature and microwave sensors which is measure the dielectric properties of surface soil.

Satellite remote sensing such as NOAA/AVHRR, METEOSAT and LANDSAT program monitoring land surface process since past twenty years and develop to the great extent to a number of such programs. Recently launched is Terra satellite with on-board ASTER and MODIS sensors and mark a new phase in monitoring process occur near the earth surface and lower atmosphere. With increasing capability to estimate land surface parameter such as surface reflection and land surface temperature using remotely sensed data, researchers has developed a variety of method to compute the actual evapotranspiration particularly based on energy balance method. SEBAL (Bastiaanssen et al., 1998), S-SEBI (Roerink et al., 2000) and SEBS (Jia et al., 2003) are a few examples of energy balance algorithm developed to estimate ET base on Remote Sensing data (Weligepolage et al., 2005).

This study needs the application of remote sensing using MODIS satellite image to find the value of albedo, emissivity, NDVI and fractional coverage of interested area. This is the only way to find out the parameter value correctly. Basically, ET process relate to the energy exchange at the surface. Because of the limitation to achieve enough energy for this process, remote sensing used as surrogate to estimate the rate of ET. It is possible to predict regional actual ET by applying the principle of energy conservation. Meteorology services only measure at one point measurement compare to the remote sensing instrument which is measure until large regional scale. Furthermore, remote sensing technique has developed rapidly. From satellite observation, spectral reflectance and emittance of radiation at land surface easily estimate by combining remote sensing data with solar radiation observation based on surface energy balance model (Norman and Kustas, 1995, Su et al., 2002).

Nowadays, remote sensing currently use as an important source of data and information for hydrological, meteorological and other water resources management.

Satellite remote sensing is the best equipment to get information on radiation balance and energy balance surrounding. The other significant usage is to detect change anomalies across landscape and target field (Boegh et al., 2002). It also helpful in extended models to regional scale where no meteorological data provided. The tool has enable scientists to study the global hydrologic cycle in a quantitative way and study some of the previously insoluble problems of spatial variability. While remote sensing imagery has many applications in mapping land use and land cover, agriculture, soils mapping, forestry, city planning, archaeological investigations, military observation, and geomorphological surveying. Multi-functional purpose of remote-sensing should be announced to the whole world so that the usage will widely spread out.

2.4 Theoretical basis of Evapotranspiration

Theoretical basis of evapotranspiration refers to the energy balance equation as the following:

$$R_n - G - H - \lambda E = 0 \qquad 2.1$$

Where:

R_n = net radiation (Wm^{-2})
G = soil heat flux (Wm^{-2})
H = sensible heat flux (Wm^{-2})
λE= latent heat flux (Wm^{-2})
(λ is latent heat of vaporization and E actual evapotranspiration).

The energy receive by surface must equal the energy leaving the surface for the same time period. All fluxes of energy should consider when derive an energy balance equation. All terms are in units of Wm^{-2} and may be positive (i.e., R_n is receive by surface and the other fluxes are directed away from the surface) or negative (i.e., R_n is lost from the surface and the other fluxes are directed toward the surface). In other words, a positive R_n indicates an input of energy into the surface system (the typical daytime condition), and positive values for all other terms indicate a loss from the surface system (Dingman et al.,1994; Allen et al., 1998; Geiger et al., 2003). The magnitude and sign of the energy balance terms depend on several factors, such as day of the year, time of the day and condition of atmosphere (Allen et al., 1998; Geiger et al., 2003). The equation only measure vertical flux gradients while neglecting the horizontal and should be use in areas of generally homogeneous land cover (Allen et al., 1998).

Each component in the equation has a various amounts which depend on weather condition, vegetation cover and soil moisture criteria. For example, soil heat flux can rise up net radiation from 5% to 50% (Brutsaert et al., 1982). Net radiation and soil heat fluxes can estimate from climatic parameters. Measurements of the sensible heat flux however complex and cannot easily obtained. It requires accurate measurement of temperature gradients above the surface. The latent heat flux representing ET fraction which is can derive from energy balance equation if all other components are known. (Allen and Smith, 1998).

Further development of these model then apply using remote sensing method because the difficulty and limitation of the equation using traditional method. The improvement more focus on latent heat flux and the result obtain is consistent with meteorological observation data. The latent heat flux in many physical models is written as:

$$LE = R_n - G - H \quad 2.2$$

Where G can be calculate using R_n and H calculate using this following formula:

$$H = \frac{\rho C_p (T_{aero} - T_a)}{r_{ah}} \quad 2.3$$

Where:

ρ = density of air
C_p= heat capacity of dry air
T_{aero} = aerodynamic temperature
T_a = air temperature at reference height
r_{ah}= heat resistance (depend on wind speed and surface roughness)

FAO Penman-Monteith represents the evaporating surface as a single "big leaf" (Raupach and Finnigan, 1988) with two parameters; (r_{av}) which is influenced only slightly by the crop canopy architecture; and (r_s) depends on the biological behavior of the crop canopy surface and related to both crop specific parameters (light attenuation, leaf stomatal resistances, etc.) and environmental parameters (irradiance, vapor pressure deficit, etc.). Original Penman-monteith equation expressed by Monteith et al., (1965):

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a C_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \quad 2.4$$

Where:

λ = latent heat of vaporization

Rn = net radiation

G = soil heat flux

es - ea = vapour pressure deficit of the air

ρ_a = mean air density at constant pressure

C_p = specific heat of the air

Δ = slope of the saturation vapour pressure

γ = psychrometric constant

r_s = Bulk surface

r_a = aerodynamic resistances

2.5 Reference Evapotranspiration Equation

2.5.1 Introduction

Accurate determination of reference evapotranspiration is very essential for precise computation of crop water use. Several models have been used in computing reference evapotranspiration and they require local calibration in order to validate their usage. Nowadays, there are various methods for estimating evapotranspiration. Several of them primarily use remote sensing data for ET estimation (Jiang and Islam, 2001; Nishida and Norman et al., 2003). Some of these methods need a lot of weather parameters as model input and difficult to calculate while the rest is easier to determine because only involve one or two parameters. Many equations available to estimate reference evapotranspiration but normally, easiest equations give inconsistent values due to their different weather data requirements or because they were developed for specific climatic regions (George et al., 2002; Nandagiri and Kovoor, 2006; Lu et al., 2005;Temesgen et al., 2005; Trajkovic et al., 2005; Xu and Singh, 2002). Therefore it is important to understand the input requirements of the