# COMPARATIVE STUDY OF FIFTY POTENTIAL EVAPOTRANSPIRATION MODELS FOR URBAN AREA IN TROPICAL REGION

UMAR FARUK LAWAN

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Hydraulics and Hydrology)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

AUGUST 2015

Specially dedicated to my father, mother, brothers and sisters, I don’t have enough words to thank you, for your immense support, care, and love.

# ACKNOWLEDGEMENT

In the name of Allah, the Most Beneficent, the Most Merciful. All praise and thanks be to the Almighty, the most Gracious the Merciful, beside which there is no other deity worthy of worship. The blessings of the Almighty be upon the Prophets from first to the last and all those noble men and women after them.

First, I will like to express my sincere gratitude and thanks to ALLAH. I am deeply thankful to my parents, brothers and sisters for their continuous support, love and prayers throughout my study.

I undoubtedly owe much to my Project Supervisor, Dr. Muhamad Askari for the guidance, constant motivation and invaluable knowledge given to me during my study.

Finally, it is difficult to mention everybody but I would like to thank Malam Gambo Haruna, Malam Muttaka Na'iya Ibrahim, Dr. Mahdi Lawan Yakub, Ibrahim Hassan, Abdulrazaq Salauddin, Mahmud Murtala Farouq, umar Musa and all my friends and colleagues who have provided assistance at various occasions generously with their knowledge and expertise in preparing this thesis. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them. I am deeply grateful to all my family members.

.

# ABSTRACT

Evaluation of potential evapotranspiration (PET) models against Penman Monteith FAO-56 has become more popular in developing countries. However, it requires complete weather variables data. To overcome this problem, we evaluated a number of PET models which were classified into fourteen-Temperature based models; twelve-Mass transfer based models; twenty one-Radiation based models and three-Combination based models against 20 years-observed pan evaporation data from Subang Jaya meteorological station. Julian day based mean imputation was used to fill the missing data. Tukey's outlier detection method was employed before estimating the PET. The performance of the models were evaluated with percentage of error (% error) in total values, % error in maximum values, % error in minimum values, % error in average values, root mean squared error (RMSE), and the paired t-test of the prediction accuracy. The results showed that Linacre, Meyer, Conchrane-Orcutt, and Kimberly Penman performed better than the other PET models among their categories. The present study also indicated that Kimberly Penman (combination based model) is decided as the best PET model. However, with considering the small difference of RMSE values and number of required weather variables, Conchrane-Orcutt (radiation based model) is recommended for future research and practical hydrological application.

# ABSTRAK

Penilaian model potensi penyejatpeluhan (PET) menggunakan Penman Monteith FAO-56 semakin popular di negara-negara membangun. Walau bagaimanapun, model ini memerlukan data pembolehubah cuaca yang lengkap. Untuk mengatasi masalah ini, beberapa model PET yang telah diklasifikasikan kepada empat belas model berasaskan suhu, dua belas model berasaskan pemindahan jisim, dua puluh satu model berasaskan radiasi, dan tiga model berasaskan gabungan dinilai menggunakan data penyejatan pan bagi pemerhatian selama 20 tahun daripada stesen meteorologi Subang Jaya. Hari Julian berasaskan imputasi min telah digunakan untuk mengisi data yang hilang. Kaedah pengesanan titik terpencil Tukey digunakan sebelum menganggarkan PET. Prestasi model dinilai dengan peratusan ralat (% ralat) dalam jumlah nilai, % ralat dalam nilai maksimum, % ralat dalam nilai minimum, % ralat dalam nilai purata, ralat min punca kuasa dua (RMSE), dan ketepatan ramalan ujian t berpasangan. Keputusan menunjukkan prestasi Linacre, Meyer, Conchrane-Orcutt, dan Kimberly Penman adalah lebih baik berbanding dengan model PET lain dalam kategori masing-masing. Kajian ini juga memberikan Kimberly Penman (model berasaskan kombinasi) diputuskan sebagai model PET yang terbaik. Walau bagaimanapun, dengan mempertimbangkan perbezaan kecil nilai RMSE dan pembolehubah cuaca yang diperlukan, Conchrane-Orcutt (model berasaskan radiasi) disyorkan untuk penyelidikan masa depan dan aplikasi hidrologi praktikal.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

## LIST OF ABBREVIATION

| | | |
|---|---|---|
| ET | - | Evapotranspiration |
| AET | - | Actual Evapotranspiration |
| PET | - | Potential Evapotranspiration |
| ETo | - | Reference Evapotranspiration |
| FAO | - | Food and Agriculture Organization |
| DL | - | Daylight Hours |
| SDV | - | Saturated Vapour Density |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| T | - | Temperature |
| Tmax | - | Maximum Temperature |
| Tmin | - | Minimum Temperature |
| Tmean | - | Mean Temperature |
| Tdew | - | Dew Temperature |
| $^0C$ | - | Degree Celcius |
| $^0K$ | - | Degree Kelvin |
| U | - | Wind Speed |
| RH | - | Relative Humidity |
| Rs | - | Solar Radiation |
| Ra | - | Extratrerrestrail Radiation |
| Rn | - | Net Radiation |
| P | - | Rainfall |
| P | - | Atmospheric Pressure |
| J | - | Julian Day |
| Z, EL, h | - | Elevation Abive Sea Level |
| es | - | Saturated vapour Pressure |
| ea | - | Actual Vapour Pressure |
| $\lambda$ | - | Latent Heat of Vaporization |
| ɣ | - | Sychromeric Constant |
| $\Delta$ | - | Slope of the Vapour Pressure Curve |
| $\rho$ | - | Density |
| G | - | Soil Heat Flux |
| $\Theta$ | - | Latitude |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Water is the essential element for life on earth planet, where now day different regions suffer from shortages due to the large population growth and reduction of natural resources. The agricultural sector is the human activity that consumes the large amount of water in the world (about 70% of the drinking water sources) and one of the main problems of irrigated agriculture is the correct quantification of crop water requirements (Mendonça et al., 2012). In this sense there is constant search to implement sustainable practices for management of water resources, one of the more efficient of water determination of evapotranspiration (ET), which is the term used to describe the amount of water effectively ceded the land surface to the atmosphere and an important component of the hydrological cycle and used for quantifying the calculation of water balance in soil, detection water stress conditions and use as input for quantitative models of harvesting or other applications (Ferreira et al., 2011).

The process of evapotranspiration is generally considered as an essential aspect in hydrological researches. Evapotranspiration is a combination process of evaporation from the soil, open-water and transpiration from the plant vegetation which transfer water to the atmosphere. It is an important parameter in the study of hydrology, climatology, irrigation planning, and water resources management. Climate change has occurred to intensify the hydrological cycle and to change evapotranspiration (Huntington, 2006). Climatic conditions, which determine both the scale and temporal distribution of watershed hydrology may satisfy or emphasize evapotranspiration.

Evapotranspiration ET is an important part of climate and hydrological cycles (Zohren and Amin, 2013). It also has vital agricultural, ecological and hydrological roles. Three fifths of the earth solar radiation received globally is used by ET (Wang, 2012; Wild *et al.*, 2013). Also, two thirds of the water that falls on the earth surface is ET, which makes it a major part of water cycle (Baumgartner, 1975) .ET is significant in various atmospheric processes because it provides the atmosphere with water that evaporates from oceans and swamps. ET affects several atmospheric processes such as global temperature, pressure and precipitation, in magnitude and distribution (Zveryaev, 2010). Evapotranspiration (ET) is a significant factor of hydrological budgets at various spatial dimensions and is an important variable for knowing regional biological processes. ET is used in calculating actual evapotranspiration (AET) in rainfall-runoff and ecosystem modeling. It is also used in calculating the amount of water that evaporates to the atmosphere. (Band *et al.*, 1996; Hay, 2002)

Evapotranspiration is the most important variable next to rainfall in the context of irrigation to crops, and also its influence as a multivariable and multidimensional hydrological parameter (McMahon *et al.*, 2013). Evapotranspiration comes from the combination of two words, evaporation and transpiration. Evaporation describes the movement of water to air from soil, water bodies and canopy, while transpiration describes the movement of water within a plant through stomata in its leaves. Evaporation from bare ground may be strict but vaporized moisture can rapidly decline without new rainfall, which is a short phenomenon. In contrast, a dense tropical forest occupied by deep-rooted trees can continue to transpire water from deeper soil layer (Oyebande, 1998). Evapotranspiration process also described as largest loss of water from trees and grass wetlands, which has a high impacts stage and salinity of these wetlands (Hayashi *et al.*, 1998). Evapotranspiration process is one of the most important processes in designing and planning all irrigation system management. The evapotranspiration measure from the reference surface, have sufficient water level, better known as the reference evapotranspiration or reference crop evapotranspiration (Irmak, Suat *et al.*, 2006). The purpose of reference or potential evapotranspiration is to remove any specific change to vegetated crop in the process of evapotranspiration(Jensen, Marvin Eli *et al.*, 1990).

The amount of precipitation that hit the earth's surface returns to the atmosphere by evaporation and/or evapotranspiration is up to 70%. Also the precipitation returns to the atmosphere through evaporation and evapotranspiration process in arid region is 90% (Rosenberg et al., 1983). Actual evaporation is a major component in the water balance of a catchment, reservoir or lake, irrigation region, and some ground water system. For example, across all continents evapotranspiration is 70% precipitation and varies from over 90% in Australia to approximately 60% in Euroupe (Ritchie. et al., 1974). For major reservoirs in Australia, actual evaporation losses represent 20% of reservoir yield. Compare with the precipitation and stream flow, the magnitude of actual evaporation over a long term is more difficult to estimate then either precipitation or stream flow(McMahon et al., 2013). (Need Pharapres)

Evapotranspiration ET is an essential element that causes high loss of water that may lead to shortage of water and drought especially the urban region. Therefore, the research is set out to highlight and know the importance of evapotranspiration estimation process in urban catchment, and also to identify a conceptual model that is expected to serve as a guide toward the effectiveness of evapotranspiration estimation for tropical urban region especially in the areas where complete data is lacking.

A land use changes have a direct effect on hydrology all the way through its connection with the evapotranspiration feature and in river basin there may be significant variation in both climate and land used across the region. The impact of the difference in the evapotranspiration characteristic assessed for the Tyne Basin in north east England (Taha, 1997). It's also recognized that urban climate vary from those of rural areas and that the absolute of difference can be relatively large at times depending on weather conditions, urban thermo physical and geometrical characteristics, anthropogenic moisture and heat sources nearby in the area. Therefore, this research is set out to identify the importance of evapotranspiration urban catchment which will be used to identify a conceptual model that is expected to serve as a guide toward the effective evapotranspiration for the urban climate region.

Global water and global warming crises were connected and exacerbated by unprecedented global pressure from over-consumption, population growth, globalization of economic system and trade, reduction in development assistance, and the failure to enact viable policy, legal and traditional reforms (Duda and El-Ashry, 2000). The recurrent themes of the dominant global water crises are the sectoral competition between irrigation and industrial use, between urban and rural area. Therefore, estimation of evapotranspiration is one of the first significant steps for evaluating crop water requirement that will have a special economic importance in rationing of water consumption in the agricultural field under current and future climate conditions.

The fundamental problem of hydrological modeling activities on terrestrial water cycle is the effects of climate change. Climate analysis at various climate stations reveals increase in temperature over a century and fluctuation in precipitation. IPCC predicts a continuation in this trend in future (IPCC, 2007). Law of clausius-clapeyron (Clapeyron., 1834; Krysanova *et al.*, 2008) , assumed that the water holding capacity of the atmosphere will increase in future, arising from mean temperature. From this law, an increase in saturation vapor pressure of 6-7% per degree Celsius can be derived. Hence, a spontaneous increase in evapotranspiration (ET) is obtained. The effect of climate change on ET is estimated using Hydrological model since it cannot be obtained by climate observations and predictions (Bormann, 2011).

Few studies conducted on evapotranspiration estimation in Malaysia (Md. Hazrat Ali and Teang, 2009; Najim *et al.*, 2003; Yusop *et al.*, 2008). Najim *et al.* (2003) examined the sensitivity of evapotranspiration to climate change using eight evapotranspiration estimation methods with thirty years' daily climate data from seberang park paddy estate, meteorological station, they concluded that the tropical climate was characterized by a high rainfall. Md. Hazrat Ali and Teang (2009) simulates daily time series of evaporation using the Penman equation and potential evapotranspiration using penman montieth. The evaporation and evapotranspiration was predicted under temperature change in muda catchment, Malaysia as an influence by climate data variables. Yusop *et al.* (2008) estimate evapotranspiration rate in the catchment area of oil palm in Johor, Malaysia with three different types of catchments using short time period water budget (SPWB) and catchment water balance (CWB).

## 1.2 Problem Statement

Evapotranspiration estimation now a day has given more considerable attention by pervious researchers. Thus most of the researchers limited there number of ET equations or models, such as (Bormann, 2011) used 18 ET models while (Tabari et al., 2013) used 31 ET models. Much software also was used in the estimation of ET, which include; EmPest, ETo calculator, AFSIR, AWSET, Cropwat, but they also used limited number of ET equations. This study provide new insight into evapotranspiration estimation, 49 models will be use for the estimation.

Several approaches has been used by previous researchers in estimating evapotranspiration (ET) in Malaysia which include; sensitivity of estimates of evapotranspiration due to change in climate (Najim et al., 2003), rate of evapotranspiration in catchment area of oil palm in Johor, Malaysia (Yusop et al., 2008), estimating evapotranspiration in historical and projected future evapotranspiration in Muda irrigation scheme (Tukimat et al., 2012). However, these studies were localized to agricultural catchments. Noticeably, evapotranspiration estimation is still lacking in the urban region.

Also Selangor is one of the state in Malaysia have a history of water shortage, in which several argument has been made about this issue of shortage of water in the area. The Government saying that this issue of water crises is due to demand growth in the state, while other expertise are saying is due to weather changes (pattern of rainfall has been change) (Yin, 2014). In 2014 Selangor water crises causes multi-million ringgit losses, and at least 30 companies in the state suffer great losses (Zachariah, 2014 ). Tajuddin (2014) mention that the demand for the state water grow between 3% - 4% annually, He added that in 2014 daily demand for Selangor reach 4,907, million liters, where as the effective supply capacity is only 4,431 million liters, which clearly indicates that Selangor facing water shortage by almost 500 million liters per day, but the government says that the water rationing was due to dry spell season. As a result of this it is very essential for the managers of water resources to know the amount of water loss for necessary measures to reduce or to avoid shortage of water in the urban area now and in the feature time.

## 1.3 Aim and Objectives

The aim of this research is to study the PET with reference to the relationship between PET model and climate data. The models are categorized to be (Temperature-based model, Mass transfer-based model, Radiation based model and combination model). The study will identify the model that can serve as a guide toward the effectiveness of PET estimation for tropical urban region where complete climate data is lacking. Specifically, the objectives of the study are:

i. To estimate evapotranspiration values for tropical urban region based on the different groups of equations.

ii. To compare the performance of various ET models according to their groups (Temperature-based method, Mass transfer-based method, Radiation based method and combination method).

iii. To examine the applicability of the PET models among the groups.

## 1.4 Scope and Limitation

The study was conducted in Subang a district in a state of Selangor Malaysia. And for the purpose of this study, daily meteorological data for Subang which is an urban area will be used, 50 PET models were apply for the computation, data included are maximum temperature, minimum temperature, wind speed, relative humidity, rainfall and pan evaporation data, while other variables that were not measured will be computed with certain method or equations using the record data. The study is applicable for Subang; 20 years (1985 to 2004) daily meteorological data will be use for estimation of PET.

## 1.5 Significant of the Study

The present study updates the number of PET models usedfor PET estimation, with climatic data of Subang, Malaysia. Knowledge of this study can be a better tool for water resources managers, government, individual and private organizations to plan for mitigation measures. To ensure the effectiveness on utilization and management of the water resource, water availability and productivity which affect the processes of biomass accumulation and ground water recharge.

However, lack of proper estimation of PET using PET models for urban areas has an implication in knowing the actual loss of water caused by PET. Therefore it is very essential for the managers of water resources to know the amount of water loss for necessary measures to reduce or to avoid shortage of water in the urban area now and in the feature time.

# REFERENCES


Abtew, W., Obeysekera, J., Irizzary-Ortiz, M., Lyons, D. and Reardon, A. (2003). Evapotranspiration estimation for south Florida. *Bridges*, 10(40685), 235.

Allen, R.G., Tasumi, M. and Trezza, R. (2007). Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)-model. *J. Irrig. Drain. E*, 133, 380-394.

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO, Rome*, 300(9).

Allen, R. G., Pruitt, W. O., Wright, J. L., Howell, T. A., Ventura, F., Snyder, R., et al. (2006). A recommendation on standardized surface resistance for hourly calculation of reference ET o by the FAO56 Penman-Monteith method. *Agricultural Water Management*, 81(1), 1-22.

Ashktorab, W. H., Pruitt, K., Paw, U. and George, W. (1989). Energy balance determinations close to the soil surface using a micro-Bowen ratio system. *Agricultural and forest meteorology*, 46(3), 259-274.

Band, L. E., Mackay, D. and Creed, I. (1996). Sensitivity to Potential Climate Change. *Journal of the American Water Resources Association*, 41(5):928-938.(5 Limnol. Oceanogr), 41.

Barnett, N., Madramootoo, C. and Perrone, J. (1998). Performance of some evapotranspiration. *Canadian Agricultural Engineering*, 40(2), 89.

Baumgartner, W. C., Reichel, E.,. (1975). The world water balance. Mean Annual Global, Continental and Marine Precipitation. *Elsevier, Amsterdam.*

Blaney, H. and Criddle, W. (1950). Determining water requirements in irrigated areas from climatological and irrigation data. *Soil Conservation Service TP*, 96, 48 pg.

Bogawski, P. and Bednorz, E. (2014). Comparison and Validation of Selected Evapotranspiration Models for Conditions in Poland (Central Europe). *Water Resources Management*, 28(14), 5021-5038.

Bormann, H. (2011). Sensitivity analysis of 18 different potential evapotranspiration models to observed climatic change at German climate stations. *Climatic Change*, 104(3-4), 729-753.

Bronswijk, J. J. B. (1988). Modeling of water balance, cracking and subsidence of clay soils. *Journal of Hydrology*, 97(3), 199-212.

Brunsell and N.A., G., R.R.,. (2003). Scale issues in land-atmosphere interactions: implications for remote sensing of the surface energy balance. . *Agricultural and Forest Meteorology*, 117, 203-221.

Cai, J., Liu, Y., Lei, T. and Pereira, L. S. (2007). Estimating reference evapotranspiration with the FAO Penman–Monteith equation using daily weather forecast messages. *Agricultural and Forest Meteorology*, 145(1), 22-35.

Carlson, T.N.;, Capehart, W.J.;, Gillies and R.R. (1995). A new look at the simplified method for remote sensing of daily evapotranspiration. *Remote Sens. Environ.*, 54, 161-167.

Clapeyron. (1834). Puissancemotrice de la chaleur. *Journal de l'École Royale Polytechnique*, XIV(Vingttroisième
cahier, Tome), 153-190.

DeAngelis, A., Dominguez, F., Fan, Y., Robock, A., Kustu, M. D. and Robinson, D. (2010). Evidence of enhanced precipitation due to irrigation over the Great Plains of the United States. *Journal of Geophysical Research: Atmospheres (1984–2012)*, 115(D15).

Dehghani Sanij, H. e. a. (2004). Assessment of evapotranpiration estimation models for use in semi-arid environments. *Agricultural water management*, Vol. 123, pp. 200-210.

Dempster, A. P., Laird, N.M., Rubin, D. (1977). Maximum likelihood from incomplete data via the EM algorithm. *J. of Royal Statistical Society Series*, 39, 1–38.

Dingman, S. L. (2015). *Physical hydrology*. Prentice-Hall, Inc: Waveland press.

Doorenbos, J. (1977). Guidelines for predicting crop water requirements. *FAO irrigation and drainage paper*, 24, 15-29.

Doorenbos, J. P., WO. (1977). Crop Water Requirements, Irrigation and Drainage Paper. No. 24. *FAO, Rome*.

Droogers, P. and Allen, R. G. (2002). Estimating reference evapotranspiration under inaccurate data conditions. *Irrigation and drainage systems*, 16(1), 33-45.

Duda, A. M. and El-Ashry, M. T. (2000). Addressing the global water and environment crises through integrated approaches to the management of land, water and ecological resources. *Water International*, 25(1), 115-126.

Eagleman, J. R. (1967). Pan evaporation, potential and actual evapotranspiration. *Journal of Applied Meteorology*, 6(3), 482-488.

Federer, C. A. a. D. L. (1983). A Hydrologic Simulation Model for Eastern Forests. In R. R. 19 (Ed.), *Water Resource Research Center*. Durham, New Hampshire.: University of New Hampshire.

Ferreira, E., Toledo, J. H. d., Dantas, A. A. and Pereira, R. M. (2011). Cadastral maps of irrigated areas by center pivots in the State of Minas Gerais, using CBERS-2B/CCD satellite imaging. *Engenharia Agrícola*, 31(4), 771-780.

Fetter. (1994). *Applied Hyrology*. New Delhi: McGraw Hill.

Fortier, S. (1907). Evaporation losses in irrigation. *Engineering News*, 58(12), 304-307.

Gary, K., Honaker, J., Joseph, A., Scheve, K.:. (2000). What to do about missing data in political science. *GKing.Harvard.edu.*

Ghandhi, S. K. and Principles, V. F. (1983). John Wiley & Sons. *New York*, 422-424.

Gocic, M. and Trajkovic, S. (2010). Software for estimating reference evapotranspiration using limited weather data. *Computers and Electronics in Agriculture*, 71(2), 158-162.

Gowda, P.H., Chavez, J. L., Colaizzi, P. D., Evett, S. R., Howell, T. A., et al. (2007). Evapotranspiration mapping for agricultural water management: present status and challenges. *Irrig. Sci.,*, 26, 223-237.

Green, I. and Stephenson, D. (1986). Criteria for comparison of single event models. *Hydrological Sciences Journal*, 31(3), 395-411.

Grismer, M., Orang, M., Snyder, R. and Matyac, R. (2002). Pan evaporation to reference evapotranspiration conversion methods. *Journal of Irrigation and Drainage Engineering*, 128(3), 180-184.

Gurney, R. J., Camillo, P.J. (1984). Modelling daily evapotranspiration using remotely sensed data. *J. Hydrololgy*, 69, 305-324. .

Hansen, V. E., Israelson, O. and Stringham, G. E. (1980). Irrigation principles and practices. *Irrigation principles and practices. 4th edition.*

Hargreaves, G. H. (1973). The estimation of potential and crop evapotranspiration. Proceedings of the 1973,

Hargreaves, G. H. and Allen, R. G. (2003). History and evaluation of Hargreaves evapotranspiration equation. *Journal of Irrigation and Drainage Engineering*, 129(1), 53-63.

Hargreaves, G. H., Samani, Z.A.,. (1985). Reference crop evapotranspiration from temperature. *Appl. Eng. Agric*, 2, 96-99.

Hartmann, D. (1994). Global Physical Climatology. In S. Diego (Ed.), *Hydrlogical Cycle*. CA: CA:Acadamic Press.

Hay, L., and GJ. McCabe,. (2002). Spatial Variability in Water Balance Model Performance in the Conterminous United States. *Journal of the American Water Resources Association (JAWRA)*, 3(3), 38.

Hayashi, T., Kojima, T. and Saigo, K. (1998). Specification of Primary Pigment Cell and Outer Photoreceptor Fates byBarH1Homeobox Gene in the DevelopingDrosophilaEye. *Developmental biology*, 200(2), 131-145.

Helsel and Hirsch, R. (2002). *Statistical Methods in Water Resources* (Vol. 4). U.S: U.S. Geological Survey.

Huntington, T. G. (2006). Evidence for intensification of the global water cycle: review and synthesis. *Journal of Hydrology*, 319(1), 83-95.

IPCC. (2007). the physical science basis. Contribution of Working Group I to the Fourth Assessment. *Report of the IPCC*, 4(Cambridge University Press), 996 pg.

Irmak, S., Haman, D. and Jones, J. (2002). Evaluation of Class A pan coefficients for estimating reference evapotranspiration in humid location. *Journal of Irrigation and Drainage Engineering*, 128(3), 153-159.

Irmak, S., Irmak, A., Allen, R. and Jones, J. (2003). Solar and net radiation-based equations to estimate reference evapotranspiration in humid climates. *Journal of irrigation and drainage engineering*, 129(5), 336-347.

Irmak, S., Payero, J. O., Martin, D. L., Irmak, A. and Howell, T. A. (2006). Sensitivity analyses and sensitivity coefficients of standardized daily ASCE-

Penman-Monteith equation. *Journal of Irrigation and Drainage Engineering*, 132(6), 564-578.

Jensen, D., Hargreaves, G., Temesgen, B. and Allen, R. (1997). Computation of ETo under nonideal conditions. *Journal of Irrigation and Drainage Engineering*, 123(5), 394-400.

Jensen, M. E., Burman, R. D. and Allen, R. G. (1990). Evapotranspiration and irrigation water requirements. Proceedings of the 1990,

Jensen, M. E. and Haise, H. R. (1963). Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of the Irrigation and Drainage Division*, 89, 15-41.

Jones, H. G. (1992). *A quantitative approach to environmental plant physiology* ((2nd ed). ed.). UK: Cambridge University Press.

Kairu, E. N. D. R. (1991). A review of methods for estimating evapotranspiration particularly those that utilize remote sensing. *Geo. Journal*, 25, 371-400.

Kirkham, M. B. (2005). *Potential evapotranspiration*.

Krysanova, V, Buiteveld H, H. D., Hattermann FF, v. N. K., Roest K, M.-. and Santos P, S. M. (2008). Practices and lessons learned in coping with climatic hazards at the river-basin scale: loods and drought. *Ecol Soc*, 2(http://
www.ecologyandsociety.org/vol13/iss2/art32/), 13.

Lage, M., Bamouh, A., Karrou, M. and El Mourid, M. (2003). Estimation of rice evapotranspiration using a microlysimeter technique and comparison with FAO Penman-Monteith and Pan evaporation methods under Moroccan conditions. *Agronomie*, 23(7), 625-631.

Landeras, G., Ortiz-Barredo, A. and López, J. J. (2008). Comparison of artificial neural network models and empirical and semi-empirical equations for daily reference evapotranspiration estimation in the Basque Country (Northern Spain). *Agricultural water management*, 95(5), 553-565.

Lean, J. and Rowntree, P. (1993). A GCM simulation of the impact of Amazonian deforestation on climate using an improved canopy representation. *Quarterly Journal of the Royal Meteorological Society*, 119(511), 509-530.

Leuning, R. and Moncrieff, J. (1990). Eddy covariance CO2 flux measurements using open-path and closed-path CO2 analyzers-corrections for analyzer water vapor sensitivity and damping of fluctuations in air sampling tubes. *Boundary-Layer Meteorology*, 53, 63-76.

Li, D., Deogun, J., Spaulding, W. and Shuart, B. (2004). Towards Missing Data Imputation: A Study of Fuzzy K-means Clustering Method. In S. Tsumoto, R. Słowiński, J. Komorowski & J. Grzymała-Busse (Eds.), *Rough Sets and Current Trends in Computing* (Vol. 3066, pp. 573-579): Springer Berlin Heidelberg.

Li, Z. L., Tang, R., Wan, Z., Bi, Y., Zhou, C., Tang, B., et al. (2009). A Review of Current Methodologies for Regional Evapotranspiration Estimation from Remotely Sensed Data. *Journal of Sensors*, 9, 3801-3853.

Little, R. J., Rubin, D.B.:. (1987). Statistical Analysis with Missing Data. *Wiley, New York*, (New York).

Lu, J., Sun, G., McNulty, S. G. and Amatya, D. M. (2005). A comparison of six potential evapotranspiration methods for regional use in the southeastern United States1: Wiley Online Library.

Marlyn, L. S. (2009). *Hydroclimatology* (first ed.). UK: Cambridge University Press.

McCabe, M. F., Wood, E.F. (2006). Scale influences on the remote estimation of evapotranspiration using multiple satellite sensors. *Remote Sens. Environ.*, 105, 271-285.

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. and McVicar, T. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis. *Hydrology and Earth System Sciences*, 17(4), 1331-1363.

Md. Hazrat Ali and Teang, S. L. (2009). Potential Evapotranspiration Model for Muda Irrigation Project, Malaysia. *Water Resources Management*, 23(1), 57-69.

Mendonça, J. C., da Silva, B. B., de Sousa, E. F., de Jesus Ferreira, N. and André, R. G. B. (2012). *Assessment of evapotranspiration in North Fluminense Region, Brazil, using Modis products and Sebal algorithm*: INTECH Open Access Publisher.

Myrtveit, I., Stensrud, E., Olsson, U.H.:. (2001). Analyzing data sets with missing data: an empirical evaluation of imputation methods and likelihood-based methods. *IEEE Transactions on Software Engineering*, 27, 999–1013.

Najim, M. M. M., Aminul Haque, M. and Lee, T. (2003). Estimation of evapotranspiration and climate change in the west coast of peninsular

Malaysia. Proceedings of the 2003 *Malaysian Science and Technology Congress*, 194-200.

Oudin, L., Hervieu, F., Michel, C., Perrin, C., Andréassian, V., Anctil, F., et al. (2005). Which potential evapotranspiration input for a lumped rainfall–runoff model?: Part 2—Towards a simple and efficient potential evapotranspiration model for rainfall–runoff modelling. *Journal of Hydrology*, 303(1), 290-306.

Oyebande. (1998). *Effect of forest in water yeild*. Singapore: press, Singapore.

Ozgur, K. (2014). Comparison of Different Empirical Methods for Estimating Daily Reference Evapotranspiration in Mediterranean Climate. *Journal of Irrigation and Drainage Engineering*, 140(1), 04013002.

Penman, H. L. (1948). Natural evaporation from open water, bare soil and grass. Proceedings of the 1948 *Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 120-145.

Pereira, L. S., Perrier, A., Allen, R. G. and Alves, I. (1999). Evapotranspiration: concepts and future trends. *Journal of Irrigation and Drainage Engineering*, 125(2), 45-51.

Qiu, G. Y., Miyamoto, K., Sase, S., Gao, Y., Shi, P. and Yano, T. (2002). Comparison of the three-temperature model and conventional models for estimating transpiration. *Japan Agricultural Research Quarterly*, 36(2), 73-82.

Rácz, C., Nagy, J. and Dobos, A. C. (2013). Comparison of Several Methods for Calculation of Reference Evapotranspiration. *Acta Silvatica et Lignaria Hungarica*, 9(1), 9-24.

Revheim., K.J.A. and Jordan, a. R. B. (1976). Precision of evaporation measurements using the Bowen ratio. *Boundary Layer Meteorol*, 10, 97-111.

Ritchie., and J.T. (1974). Evaluating irrigation need for southeasttern U.S.A., Proc. *irrigation and drianage spec.*, (ASCE).

Rosenberg, N., B., B., and and Verma, S. (1983). The biological environment,. *Microclimate:*, (wiley, New york).

Rosenberry, D., Stannard, D., Winter, T. and Martinez, M. (2004). Comparison of 13 equations for determining evapotranspiration from a prairie wetland, Cottonwood Lake Area, North Dakota, USA. *Wetlands*, 24(3), 483-497.

Schrödter, H. (1985). Verdunstung. Anwendungsorientierte Messverfahren und Bestimmungsmethoden. *Springer Berlin*, 186pp.

Seguin, B. I., B.,. (1983). Using midday surface temperature to estimate daily evaporation from satellite thermal IR data. *Int. J. Remote Sens*, 4, 371-383.

Shahidian, S., Serralheiro, R., Serrano, J. and Teixeira, J. L. (2013). Parametric calibration of the Hargreaves–Samani equation for use at new locations. *Hydrological Processes*, 27(4), 605-616.

Singh, V. P., Xu, C.Y.,. (1977). Evaluation and generalization of 13 mass-transfer equations for determining free water evaporation. *Hydrological Processes*, 11, 311-323.

Smithson, P., et.al.,. (2002). *Fundamentals of the physical environment* ((3rd ed), ed.). New York: Routledge.

StatSoft, I. (2007). Statistica data analysis software system. *Computer software*, (Tulsa, OK).

Tabari, H. (2010). Evaluation of Reference Crop Evapotranspiration Equations in Various Climates. *Water Resources Management*, 24(10), 2311-2337.

Tabari, H., Grismer, M. E. r. and Slavisa. (2013). Comparative analysis of 31 reference evapotranspiration methods under humid conditions. *Irrigation Science*, 31(2), 107-117.

Tabari, H. and Talaee, P. H. (2011). Local calibration of the Hargreaves and Priestley-Taylor equations for estimating reference evapotranspiration in arid and cold climates of Iran based on the Penman-Monteith model. *Journal of Hydrologic Engineering*, 16(10), 837-845.

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and buildings*, 25(2), 99-103.

Tajuddin, R. (2014, June 28, 2014). Water Crisis in Selangor. *MatRodi, June 28, 2014*.

Thirukumaran, S. and A, S. (2015). An alternate imputation technique of a mean method for missing values and comparative study with neighbor methods. *International Journal of Applied Engineering Research*, 10(4), 9969-9982.

Thornthwaite, C. W. (1948). An approach toward a rational classification of climate. *Geographical review*, 55-94.

Trajkovic, S. (2007). Hargreaves versus Penman-Monteith under Humid Conditions. *Journal of Irrigation and Drainage Engineering*, 133(1), 38-42.

Trajkovic, S. and Kolakovic, S. (2009). Evaluation of Reference Evapotranspiration Equations Under Humid Conditions. *Water Resources Management*, 23(14), 3057-3067.

Tukimat, Aqilah, N. N., Harun, S. and Shahid, S. (2012). Comparison of different methods in estimating potential evapotranspiration at Muda Irrigation Scheme of Malaysia. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, 113(1), 77–85.

Tyagi, N., Sharma, D. and Luthra, S. (2000). Determination of evapotranspiration and crop coefficients of rice and sunflower with lysimeter. *Agricultural water management*, 45(1), 41-54.

Verma, S. B. (1990). Micrometeorological Methods for Measuring Surface Fluxes of Mass and Energy. *Remote Sensing Reviews*, 5(1), 99-115.

Wang, K., Dickinson, R.E. (2012). A reviewof global terrestrial evapotranspiration: observation, modeling, climatology, and climatic variability. *Rev. Geophys. org/10.1029/2011RG000373.*, 50.

Ward, R. C. (1967). *Principles of hydrology*: Tata McGraw-Hill Education.

Watson, I. and Burnett, A. (1995). Hydrogeology. *An environmental approach: CRC Press, Boca Raton, Florida*.

Wiesner, C. J. (1970). Climate, irrigation and agriculture. *Climate, irrigation and agriculture.*

Wild, Martin, F., Doris, S., Christoph, , Loeb, N., Dutton, E. G., König- and Langlo, G. (2013). The global energy balance from a surface perspective. *ClimateDynamics*, 40.

Willmott, C. J., Ackleson, S. G., Davis, R. E., Feddema, J. J., Klink, K. M., Legates, D. R., et al. (1985). Statistics for the evaluation and comparison of models. *Journal of Geophysical Research: Oceans (1978–2012)*, 90(C5), 8995-9005.

Wilson, B.K. and et al. (2001). A comparison of methods for determining forest evapotranspiration and its components: sap-flow, soil water budget, eddy covariance and catchment water balance. *Agricultural and Forest Meteorology*, Vol. 106, , pp 153-168.

Xi, J. (2008). Outlier detection algorithms in data mining. Proceedings of the 2008 *Intelligent Information Technology Application, 2008. IITA'08. Second International Symposium on*, 94-97.

Xing, Z., Chow, L., Meng, F.-r., Rees, H. W., Monteith, J. and Lionel, S. (2008). Testing reference evapotranspiration estimation methods using evaporation pan and modeling in Maritime region of Canada. *Journal of Irrigation and Drainage Engineering*, 134(4), 417-424.

Xu, C.-Y. and Singh, V. (2002). Cross comparison of empirical equations for calculating potential evapotranspiration with data from Switzerland. *Water Resources Management*, 16(3), 197-219.

Xu, Y. P., Pan, S., Fu, G., Tian, Y. and Zhang, X. (2014). Future potential evapotranspiration changes and contribution analysis in Zhejiang Province, East China. *Journal of Geophysical Research: Atmospheres*, 119(5), 2174-2192.

Xystrakis, F. and Matzarakis, A. (2011). Evaluation of 13 Empirical Reference Potential Evapotranspiration Equations on the Island of Crete in Southern Greece. *Journal of Irrigation and Drainage Engineering*, 137(4), 211-222.

Yin, Y. B. (2014, April 30, 2014). 5 mistakes Khairy made on the Selangor water crisis. *Kinibiz*.

Yoder, R., Odhiambo, L. and Wright, W. (2005). Evaluation of methods for estimating daily reference crop evapotranspiration at a site in the humid Southeast United States. *Applied engineering in agriculture*, 21(2), 197-202.

Yusop, Z., Chong, M. H., Garisu, G. J. and Ayob, K. (2008). Estimation of evapotranspiration in oil palm catchments by short-time period water-budget method. *Malaysian Journal of Civil Engineering*, 20(2), 160-174.

Zachariah, E. (2014 November 10, 2014). Selangor water crisis caused millions in losses to industries. *Malaysian Insider, November 10, 2014*.

Zhou, M.C. and et al. (2006). Estimating potential evapotranspiration using Shuttleworth-Wallace model and NOAA-AVHRR NDVI data to feed a distributed hydrological model over the Mekong River basin. *Journal of Hydrology*, Vl. 327, pp. 151-173.

Zohren, I. and Amin, E. (2013). *Data Driven Techniques and Wavelet Analysis for the Modeling of Actual Evapotranspiration*. Jeneza Tredine 9, 51000 Rijeka, Crotia: Dejan Grgur.

Zveryaev, I. I., Allan, R.P. (2010). Summertime precipitation variability over Europe and its links to atmospheric dynamics and evaporation. *J. Geophys. Res. D: Atmos. 115*, 12((art. no. D12102).).