# ESTIMATION OF POTENTIAL EVAPOTRANSPIRATION USING MULTIPLE LINEAR REGRESSION AND PARTICLE SWARM OPTIMIZATION

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# DEDICATION

**Al-Fatihah**

*Hajah Fatimah Binti Saenah*

(11/5/1938 – 25/4/2016)

-Wan, waking up in the morning is the hardest part in life knowing you no longer here with me-

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# ABSTRACT

Evapotranspiration (ET) is an essential element in the hydrological cycle which at the same time plays an important role in ensuring the effectiveness of the water balance system. Generally, there are two methods in obtaining ET; direct measurement and empirical model. The main objective of this study was to formulate new empirical models to estimate ET for Peninsular Malaysia. The models were developed and validated based on the sixteen years of historical meteorological data obtained from Malaysia Meteorological Department. Using the Multiple Linear Regression (MLR) algorithm, simpler potential evapotranspiration ($ET_P$) estimation models were developed for selected meteorological stations in Peninsular Malaysia. Furthermore, Particle Swarm Optimisation (PSO) was used to optimise the performance of developed models and these models were compared against $ET_P$ estimated by the Food and Agricultural Organization Penman-Monteith model. Four different measures of performance indicators were used to highlight its accuracy. The sensitivity analysis showed that air temperature, $T$ and solar radiation, $R_s$ were observed to significantly influenced ET under humid tropical climates such as Peninsular Malaysia. The proposed MLR models at all stations were able to maintain reliable and stable results with an average of 83%, 0.3%, 0.8% and 0.34 for the coefficient of determination ($R^2$), mean bias error (MBE), percentage error (PE) and root mean square error (RMSE) respectively. The accuracy of optimized MLR-PSO models was improved with a minimum of 85%. The minimum accuracy of 85% indicates that the proposed MLR models are already reliable for $ET_P$ estimation. The proposed empirical models in this study have successfully contributed to the development of $ET_P$ estimation models that is more site-specific and tailored to the Peninsular Malaysia climate due to the easy to obtain and availability of meteorological data such as air temperature and solar radiation.

# ABSTRAK

Evapotranspirasi (ET) merupakan elemen penting dalam kitaran hidrologi yang pada masa yang sama memainkan peranan penting dalam memastikan keberkesanan sistem imbangan air. Secara amnya, terdapat dua kaedah dalam mendapatkan ET; pengukuran langsung dan model empirikal. Justeru, objektif utama kajian ini adalah untuk merumus model empirikal baharu untuk menganggar ET bagi Semenanjung Malaysia. Model tersebut dibangunkan dan disahkan berdasarkan data meteorologi selama enam belas tahun yang diperoleh daripada Jabatan Meteorologi Malaysia. Dengan menggunakan algoritma *Multiple Linear Regression* (MLR) model anggaran evapotranspirasi potensial ($ET_p$) yang lebih ringkas telah dibangunkan untuk stesen meteorologi terpilih di Semenanjung Malaysia. Kemudian, *Particle Swarm Optimization* (PSO) digunakan untuk mengoptimumkan prestasi model yang dibangunkan dan model ini dibandingkan dengan $ET_p$ yang dianggarkan oleh model *Food and Agricultural Organization Penman-Monteith*. Empat ukuran penunjuk prestasi yang berbeza digunakan untuk menyerlahkan ketepatannya. Analisis sensitiviti menunjukkan bahawa suhu udara, *T* dan sinaran suria, *Rs* memberi pengaruh yang signifikan terhadap ET di bawah iklim tropika lembap seperti Semenanjung Malaysia. Model MLR yang dicadangkan di semua stesen mampu mengekalkan keputusan yang boleh dipercayai dan stabil dengan purata 83%, 0.3%, 0.8% dan 0.34 masing-masing untuk *coefficient of determination* ($R^2$), *mean bias error* (MBE), *percentage error* (PE) dan *root mean square error* (RMSE). Ketepatan model MLR-PSO yang dioptimumkan semuanya dipertingkatkan dengan minimum 85%. Fakta bahawa ketepatan telah bertambah baik dengan minimum 85% menunjukkan bahawa model MLR yang dicadangkan sudah boleh dipercayai untuk aplikasi anggaran $ET_p$. Model empirikal yang dicadangkan dalam kajian ini telah berjaya menyumbang kepada pembangunan model anggaran $ET_p$ yang lebih spesifik tapak dan disesuaikan dengan iklim Semenanjung Malaysia kerana data suhu iklim dan sinaran suria yang mudah didapati dan tersedia.

## TABLE OF CONTENTS


| | TITLE | PAGE |
|---|---|---|
| | **DECLARATION** | **iii** |
| | **DEDICATION** | **iv** |
| | **ACKNOWLEDGEMENT** | **v** |
| | **ABSTRACT** | **vi** |
| | **ABSTRAK** | **vii** |
| | **TABLE OF CONTENT** | **viii** |
| | **LIST OF TABLES** | **xii** |
| | **LIST OF FIGURES** | **xiv** |
| | **LIST OF ABBREVIATIONS** | **xvi** |
| | **LIST OF SYMBOLS** | **xvii** |
| | **LIST OF APPENDICES** | **xix** |
| **CHAPTER 1** | **INTRODUCTION** | **1** |
| 1.1 | Introduction | 1 |
| 1.2 | Problem Statement | 3 |
| 1.3 | Objectives of study | 4 |
| 1.4 | Scope of study | 4 |
| 1.5 | Significant of study | 5 |
| 1.6 | Structure of thesis | 6 |
| **CHAPTER 2** | **LITERATURE REVIEW** | **7** |
| 2.1 | Introduction | 7 |
| 2.2 | Water balance | 7 |
| | 2.2.1 Watershed Water Balance | 8 |
| | 2.2.2 Reservoir Water Balance | 9 |
| | 2.2.3 Soil Water Balance | 10 |
| | 2.2.4 Irrigation Water Balance | 11 |
| 2.3 | Natural Cycle | 13 |

| | | | |
|---|---|---|---|
| | 2.3.1 | Hydrological Cycle | 13 |
| | | 2.3.1.1 Evaporation | 14 |
| | | 2.3.1.2 Transpiration | 14 |
| | | 2.3.1.3 Evapotranspiration | 15 |
| 2.4 | Meteorological Parameters | | 23 |
| | 2.4.1 | Solar radiation | 23 |
| | 2.4.2 | Temperature | 24 |
| | 2.4.3 | Relative humidity | 25 |
| | 2.4.4 | Wind speed | 26 |
| 2.5 | Evapotranspiration Measurement | | 27 |
| | 2.5.1 | Direct Measurement | 27 |
| | 2.5.2 | Estimation Approach | 30 |
| | 2.5.3 | Other Approach | 30 |
| 2.6 | Evapotranspiration Estimation Model | | 37 |
| | 2.6.1 | Temperature Based Model | 37 |
| | 2.6.2 | Radiation Based Model | 39 |
| | 2.6.3 | Pan-Evaporation Based Model | 39 |
| | 2.6.4 | FAO-Penman Monteith Model | 40 |
| 2.7 | Regression Analysis | | 42 |
| 2.8 | Application of Artificial Intelligence (AI) | | 44 |
| | 2.8.1 | AI forecasting | 44 |
| | 2.8.2 | AI optimization | 48 |
| 2.9 | Particle Swarm Optimization Application | | 52 |
| 2.10 | Data Preparation | | 54 |
| | 2.10.1 | Outlier Detection | 55 |
| | 2.10.2 | Data Imputation | 55 |
| 2.11 | Chapter Summary | | 57 |
| **CHAPTER 3** | **RESEARCH METHODOLOGY** | | **59** |
| 3.1 | Introduction | | 59 |
| 3.2 | Study Area | | 62 |
| | 3.2.1 | Data availability | 64 |
| 3.3 | Data Processing | | 65 |

| | | | |
|---|---|---|---|
| | 3.3.1 | Outlier Detection / Tukey's boxplot | 66 |
| | 3.3.2 | Data Imputation / EM Method | 67 |
| 3.4 | Data Correlation | | 68 |
| 3.5 | ET Benchmark Estimation | | 69 |
| 3.6 | Evapotranspiration Models | | 78 |
| 3.7 | Multiple Linear Regression | | 85 |
| 3.8 | Particle Swarm Optimization Implementation | | 88 |
| 3.9 | Performance Indicators | | 92 |
| **CHAPTER 4** | **RESULTS AND DISCUSSIONS** | | **95** |
| 4.1 | Introduction | | 95 |
| 4.2 | Data and Its Descriptive Analysis | | 95 |
| 4.3 | Correlation of Data | | 101 |
| 4.4 | Sensitivity Analysis | | 103 |
| 4.5 | ET Benchmark Data | | 109 |
| 4.6 | ET Empirical Models Evaluation | | 112 |
| 4.7 | Multiple Linear Regression Analysis | | 124 |
| 4.8 | MLR Model Optimization by PSO | | 133 |
| **CHAPTER 5** | **CONCLUSIONS AND RECOMMENDATIONS** | | **139** |
| 5.1 | General | | 139 |
| 5.2 | Conclusions | | 139 |
| | 5.2.1 | Sensitivity Analysis | 139 |
| | 5.2.2 | ET Empirical Evaluation | 140 |
| | 5.2.3 | MLR Empirical Models | 141 |
| | 5.2.4 | MLR-PSO Empirical Models | 141 |
| 5.3 | Recommendation for Future Works | | 142 |
| **REFERENCES** | | | 143 |
| **Appendix A** | | | 163 |

**Appendix B** 167
**Appendix C** 169
**Appendix D** 177
**LIST OF PUBLICATIONS** 181

## LIST OF TABLES


| TABLE NO. | TITLE | PAGE |
|---|---|---|
| Table 2.1 | ET values correspond to the type of major crops in Malaysia | 21 |
| Table 2.2 | List of advantage and disadvantage correspond to ET measurements (Allen et al., 2011) | 33 |
| Table 2.3 | Summary of AI application in forecasting | 47 |
| Table 2.4 | Summary of AI application in optimization | 51 |
| Table 2.5 | PSO Parameter Description | 52 |
| Table 2.6 | Method Suggested Based on Missing Data Rate (Presti et al., 2010) | 56 |
| Table 3.1 | Proposed Model Description | 60 |
| Table 3.2 | Meteorological station location description | 64 |
| Table 3.3 | Details of meteorological parameter recorded correspond to its years | 65 |
| Table 3.4 | Interpretation of Pearson Correlation (Schober, Boer, and Schwarte, 2018) | 69 |
| Table 3.5 | Adapted PSO Algorithm used in this study | 89 |
| Table 3.6 | The various cross validation stage | 91 |
| Table 4.1 | Percentage of Missing Value | 96 |
| Table 4.2 | Descriptive statistics of meteorological parameters for each stations | 98 |
| Table 4.3 | Pearson Product Moment Correlation Coefficient between independent variables and dependent variable at AS station | 102 |
| Table 4.4 | The average of sensitivity of ET to climatic change | 104 |
| Table 4.5 | Existing ET Empirical Models Ranking | 113 |
| Table 4.6 | The Durbin-Watson value showing residuals independence | 124 |
| Table 4.7 | Correlations independent and dependent variables | 126 |
| Table 4.8 | Collinearity statistics for variables mean air temperature and solar radiation | 126 |

Table 4.9 Cook’s distance value as indicator of no outlier 127

Table 4.10 Developed ET estimation model using MLR approach for each stations 128

Table 4.11 Developed ET estimation model using MLR approach for each region 132

Table 4.12 MLR and PSO Model for All Stations 137

## LIST OF FIGURES


| FIGURE NO. | TITLE | PAGE |
| --- | --- | --- |
| Figure 2.1 | Schematic diagram of watershed water balance (Hobbins, and Huntington, 2016) | 8 |
| Figure 2.2 | Schematic diagram of reservoir water balance (Mekonnen, 2005) | 10 |
| Figure 2.3 | Schematic diagram of soil water balance (Chowdary, Rao, and Sarma, 2003) | 11 |
| Figure 2.4 | Schematic diagram of irrigation water balance for paddy field (Yoshida, Masumoto, Horikawa, et al., 2016) | 12 |
| Figure 2.5 | Schematic illustration of general hydrological cycle | 13 |
| Figure 2.6 | Variation of stomatal shape in terms of plant species (a) the eudicots, (b) the grass (Aono, Nagai, Dickel, et al., 2021) | 15 |
| Figure 2.7 | The subordinate relationships between ET-related concepts (Xiang et al., 2020) | 16 |
| Figure 2.8 | Typical description of Class-A pan evaporation equipment (Allen et al., 1998) | 17 |
| Figure 2.9 | General Kc value for agricultural crop correspond to its season (Allen et al., 1998) | 20 |
| Figure 2.14 | Average Solar Radiation in Malaysia ($MJ/m^2/day$) (Makaremi, Salleh, Jaafar, et al., 2012) | 24 |
| Figure 2.11 | Typical design for lysimeter (Howell, 2004) | 29 |
| Figure 2.18 | Vertical cross section of a stem for stem heat method of sap flow approach (Smith, and Allen, 1996) | 31 |
| Figure 2.13 | Meta-heuristic algorithm[a] classification (Mirjalili, and Lewis, 2016) | 49 |
| Figure 3.1 | Research Flow Chart | 61 |
| Figure 3.2 | Selected Meteorological Station in Peninsular Malaysia with its corresponding main region | 63 |
| Figure 3.3 | Tukey’s Boxplot Schematic Diagram | 66 |
| Figure 3.4 | Flow chart for ET estimation using FAO-PM model | 74 |
| Figure 3.5 | Basic flowchart of PSO | 90 |

| | | |
|---|---|---|
| Figure 3.6 | Integrated MLR model in PSO algorithm flow chart | 91 |
| Figure 4.2 | Average Pearson Product Moment Correlation Coefficient between ET and meteorological variable for all station | 103 |
| Figure 4.3 | Sensitivity analysis of ET by percent changes in meteorological variables | 106 |
| Figure 4.4 | Monthly mean daily ET for selected station in Peninsular Malaysia form 1st January 1987 to 31th December 2003 | 111 |
| Figure 4.5 | Total ET (mm) for 24 models at 17 stations over the period of January 1987 till December 2003 | 115 |
| Figure 4.6 | Scatterplot showing linear relationship between (a) ET and solar radiation, (b) ET and mean air temperature | 125 |
| Figure 4.7 | Scatterplot of standardized residuals against standardized predicted values | 125 |
| Figure 4.8 | Normal P-P plot for residuals error | 127 |
| Figure 4.9 | The average of Performance Indicator for MLR-ET estimation model | 130 |
| Figure 4.10 | MLR and PSO $R^2$ Performance | 134 |
| Figure 4.11 | MLR and PSO RMSE Performance | 135 |
| Figure 4.12 | MLR and PSO Accuracy Performance | 136 |

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ABC | - | Artificial Bee Colony |
| ACO | - | Ant Colony Optimization |
| AI | - | Artificial Intelligence |
| ANFIS | - | Adaptive Neuro-Fuzzy Inference Systems |
| CFO | - | Central Force Optimization |
| CIMIS | - | California Irrigation Management Information System |
| CSS | - | Charged System Search |
| DE | - | Differential Evolution |
| ES | - | Evolution Strategy |
| FFA | - | Firefly Algorithm |
| GA | - | Genetic Algorithm |
| GEP | - | Gene Expression Programming |
| GP | - | Genetic Programming |
| GRNN | - | Generalized Regression Neural Networks |
| GSA | - | Gravitational Search Algorithm |
| GSO | - | Group Search Optimizer |
| HS | - | Harmony Search |
| MLP | - | Multilayer Perceptron |
| MVRVM | - | Multivariate Relevance Vector Machine |
| PSO | - | Particle Swarm Optimization |
| RBFN | - | Radial Basis Function Network |
| RBNN | - | Radial Basis Neural Networks |
| SA | - | Simulated Annealing |
| SBA | - | Social Behaviour Algorithm |
| SVM | - | Support Vector Machine |
| TLBO | - | Teaching Learning Based Optimization |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| a | - | coefficient min RH in Eq. (2.11) |
| as , bs | - | FAO-PM coefficient as =0.25 and bs = 0.75 |
| atm | - | atmospheric pressure kPa |
| b | - | coefficient wind speed in Eq. (2.11) |
| c1 | - | constant for Eq. (2.9) |
| c2 | - | constant for Eq. (2.9) |
| Cr | - | coefficient depending on the relative humidity and wind speed Eq. (2.12) |
| d | - | day time length Eq. (2.9) |
| $d_r$ | - | inverse relative distance Earth-Sun |
| E | - | evaporation |
| $e_0$ | - | viscosity of saturated water vapor |
| $e_a$ | - | Actual Vapor Pressure (kPa) |
| $E_{aero}$ | - | aerodynamic component |
| $e_d$ | - | vapour pressure in the atmosphere Eq (2.8) |
| Epan | - | Class A pan evaporation |
| $e_s$ | - | vapour pressure at the evaporating surface Eq (2.8) |
| ET | - | evapotranspiration in mm/day |
| $ET_a$ | - | actual ET (mm/d) |
| $ET_o$ | - | reference ET (mm/d) |
| $ET_p$ | - | potential evapotranspiration in mm/day |
| F | - | upwind distance fetch of low-growing vegetation (m) |
| f(u) | - | function of the horizontal wind velocity Eq (2.8) |
| G | - | Soil Heat Flux (MJ/$m^2$/day) |
| Gsc | - | solar constant;0.082 MJ/$m^2$/min |
| I | - | I is a thermal index imposed by the local normal climatic temperature regime Eq(2.10) |
| J | - | Julian day in the year |
| Kc | - | crop coefficient |
| Kpan | - | Class A pan evaporation coefficient |
| LAI | - | Leaf area index |
| n | - | actual duration of sunshine |
| N | - | Maximum duration of sunshine or daylight (hours) |
| $R_a$ | - | Extraterrestrial shortwave radiation (kJ/$m^2$/day) |
| RH | - | daily relative humidity, % |
| RHmin | - | minimum relative humidity |
| $R_n$ | - | net radiation (mm/d) |

$R_{nl}$ - outgoing net longwave radiation(MJ/$m^2$/day)

$R_{ns}$ - incoming shortwave radiation(MJ/$m^2$/day)

Rs - total solar radiation (in calories per square centimetre per day

$R_s$ - solar radiation (MJ/m2/d)

$R_{so}$ - clear-sky radiation (MJ/$m^2$/day)

s - temperature- and altitude-dependent weighting factor

T - air temperature (°C)

Tmax - Maximum air temperature (°C)

Tmin - Minimum air temperature (°C)

Tdew - dewpoint air temperature

Tmax, K - Maximum temperature in Kelvin

Tmean - average air temperature

Tmin, K - Minimum temperature in Kelvin

u - mean daily wind speed at 2m height m/s

x - the independent variable for Regression method

y - the dependent variable for Regression method

z - elevation (m)

α - Albedo taken as 0.23

$\beta_0$ - the intercept for Regression method

β1 - the slope of independent variable

γ - psychometric constant (mb/C)

Δ - slope of saturation vapor pressure-temperature relationship in kPa/°C

δ - Solar decimation

ε - the error for Regression method

λ - the latent heat of vaporization (in calories per gram)

σ - Stefan-Boltzman constant (MJ/K4/m-2/day)

ϕ - Latitude in radian

$\omega_s$ - sunset hour angle in rad

# LIST OF APPENDICES


| APPENDIX | TITLE | PAGE |
|---|---|---|
| Appendix A | Percent change for sensitivity analysis | 161-163 |
| Appendix B | Average daily Et estimated using FAO-PM | 165 |
| Appendix C | Correlation coefficient between independent and dependent variable | 167-174 |
| Appendix D | Sample of calculation for FAO-PM model | 175-178 |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Hydrology is one of Earth Science and civil engineering study that is easily be forgotten. Water cycle or hydrological cycle study is a root in tackling water crisis issue. With only 3% of freshwater available in this planet, dare to say that water is important and yet taken for granted. The importance of hydrology assessment especially for water cycle can be clearly seen lately as the world is perplexed with the arise of ‘water scarcity’, ‘water rationing’ and ‘blue gold’ issues and it is a never ending issue. Today’s world population has reached 7.7 billion and has increased 1.8% since 1950 (Daily, Dasgupta, Bolin, et al., 1998).As in 2018, population in Malaysia has reached 32.6millions according to Department of Statistics Malaysia and received approximately 2000mm to 4000mm precipitation annually yet facing water crisis. On average, Malaysian consume 201litres per person per day according to National Water Service Commision (SPAN), which is 36 litres higher than recommended by World Health Organization (WHO) (Bernama, 2020).

The issue of water scarcity in Malaysia surprisingly has spike the attention not only by the government but also among hydrologists. Water scarcity leads to the water rationing and in 2014, Selangor faced the worst water rationing event that affected 300,000 households of the state (The Star, 2014). Seven out of eight dams in Selangor has gone dry due to El Nino from December 2013 till February 2014. Consider this is as a wake-up call for researchers in all aspects; economics, water resources, environmental, ecologists and even in social and health field since 29 death cases were reported during the dry spell.

In designing and managing water resources, knowledge on magnitude and variation of evapotranspiration (ET) is required. ET is one of the process in hydrological cycle is defined as the combination of water evaporates to the air and transpiration from plants. The accurate estimation of ET helps in irrigation design (Tegos, Malamos, and Koutsoyiannis, 2015; Wang, and Dickinson, 2012) and scheduling as well as domestic water resources management (Jovic, Nedeljkovic, Golubovic, et al., 2018; Ortega-Farias, Irmak, and Cuenca, 2009). As study done by (Inman-Bamber, and Smith, 2005) found that the irrigation of sugarcane crop can be classified into three phase; (1) early canopy development, (2) late canopy development and stalk elongation and (3) maturing phase. More water is required during later canopy development rather than early development and less water is required during maturing phase. This study is one of the examples of the necessity knowing ET in order to optimize the crop production.

The study on ET has undergone since 1802 where Dalton discovered way to calculate combination of water losses by transpiration of plants and evaporation of Earth’s land to the atmosphere. The urgency to study ET has gradually increases with the increasing of public awareness of climate change that alters water resources in conjunction with domestic water demand. ET study mainly focuses on obtaining the accurate of its qualitative result for further analysis such climate change and watershed resources management. ET data is required not only for water balance model but also used in land surface energy balance model. Numerous methods have been proposed for ET estimation since actual measurement of ET; lysimeter consumes time, cost and laborious. Alternative methods are preferable like scintillometers, bowen ratio energy balance, eddy covariance flux partitioning and most favourite method is the empirical method.

Till dates there are more than 50 ET empirical models and most of them procreate based on calibration from pioneer empirical models; Penman (1948), Hargreaves and Samani, (1985), Makkink (1957), Turc (1961), and Jensen and Haise (1963). These models were derived from various climate regions and the coefficient/parameters needs calibration before it can be used at selected study region.

Meteorological data has been taken as the main input in obtaining estimation of ET based on empirical models.

## 1.2 Problem Background

In previous literature, the importance of ET are constantly mentioned and various study related with ET can easily be found especially related to the application of ET estimation models. Although the Food and Agricultural Penman-Monteith 56 (Allen, Pereira, Raes, et al., 1998) (herein after FAO-PM) model has been decided as the most accurate ET estimation model, this model is not applicable at data scarce region like Malaysia. Although meteorological data can be purchase from the Malaysia Meteorology Department (MMD), the data are often incomplete and sometimes the parameter needed is not measured such as evaporation. This situation can be cause the model to work improperly. As mentioned by (Paparrizos, Maris, and Matzarakis, 2016), each of the estimation models developed for specific climatic regions and hence to ensure satisfactory result, few models needs to be testified before they can be used at own region.

Annually in Malaysia, water rationing has become a normal routine for citizen in west coast of Peninsular Malaysia. Consider the urge in need of better model to estimate ET for future development of water balance system in managing domestic water demand, Malaysia needs to have ET estimation model that is more site specific that applies influential parameter affecting ET.

To author’s knowledge, studies on reservoirs management system, water resources management prior to solve problems on water scarcity in Malaysia exceed adequate level. As part of the hydrology study branch, ET is not the first choice for young researchers and ET study in Malaysia is still distressing. The importance of ET in water balance system is undeniable and known by all. The accuracy of FAO-PM model in estimating ET is also undeniable but it is also known as data demanding model which for certain region, this model is not applicable. With that, how is the ET been estimated? Other simpler empirical model such as Hargreaves, Makkink, Turc and Priestley-Taylor can also be used after calibration. This creates a non-uniform application of ET estimation model for Peninsular Malaysia.

The urge to contribute ET literature review and provides better, more applicable ET estimation model for Peninsular Malaysia driven the execution of this study. The statistical analysis of ET corresponds to meteorological parameters, development of empirical model and comprehensive ET review is done in this study.

## 1.3 Objectives of the study

The principal objectives of this study is to derive a simpler empirical model that is more realistic, site specific and practical implementation under Peninsular Malaysia climate. The specific objectives of this study are outlined as follows;

1. To examine the essential meteorological parameters in affecting ET by using sensitivity analysis

2. To evaluate the performance of empirical models for estimating ET in Peninsular Malaysia

3. To design simpler empirical models for the application in Peninsular Malaysia by Multiple Linear Regression (MLR) and optimized by using Particle Swarm Optimization (PSO).

## 1.4 Scope of Study

The scope of this study is focused on the development of optimal simpler empirical model that can be used under Malaysia climate by using historical data gathered from 17 meteorological stations around Peninsular Malaysia. Therefore, several scope and limitation were needed to justify clearly before commencing the analysis.

Stage 1: Perform pre-processing data by screening outliers in the data by using Boxplot method and Expected Maximization (EM) for data imputation.

Stage 2: Calculate the daily ET by using FAO-PM that later be taken as benchmark data as the actual ET data is not available for Malaysia region. Although the evaporation data is computed, the evaporation data may not be sufficient to be use in this study.

Stage 3: Identify the most prominent data affecting ET in Malaysia by performing data correlation and sensitivity analysis.

Stage 4: Development of simpler empirical model by using MLR and number of inputs based on Stage 3.

Stage 5: Optimized the empirical models obtained using PSO algorithm. This includes the development of PSO program using C language software.

Lastly, after obtaining the optimized empirical model, the performance of developed model and existing ET models were compared against the FAO-PM model to ensure the accuracy of the performance.

## 1.5 Significant of Study

A simpler reliable more site specific ET estimation model produced through this study will be beneficial for both academicians and consultancies. The issue in estimating ET for water balance management system can be properly overcome the water scarcity issue. This study not only gives contribution in fundamental literature review of ET study in Malaysia but also can be referred as part of supplementary study for future development of ET models, sustainable reservoir storage management and water balance system.

## 1.6 Structure of Thesis

This thesis comprises of five chapters. Chapter 1 (**Introduction**), Chapter 2 (**Literature Review**), Chapter 3 (**Research Methodology**), Chapter 4 (**Results and Discussion**), Chapter 5 (**Conclusion and Recommendation**).

Chapter 1 contains of 5 essential elements comprise of the overview of the study, statement problem, objectives of study, scope and significant of this study.

Chapter 2 presented the previous literature review. This is an important element in classifying the originality of the study that need to be conducted. Few aspect where stressed in this chapter includes comprehensive explanation of ET includes the application of ET estimation empirical models and the overview application of PSO contributing in enhancing ET estimation models.

Chapter 3 explained in details the methodology used to execute this study. This includes a brief explanation on the data exploration such as outlier detection and data imputation, algorithm used for both MLR and PSO. Sensitivity analysis methodology also described in this chapter.

Chapter 4 explained and interpreted all the results obtained from this study as according to the objectives sequence. Finally, Chapter 5 provides the summary includes the conclusion of this study. Recommendations for future development are also listed in this chapter.

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