DEVELOPMENT OF A MODEL FOR EVAPOTRANSPIRATION

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT

By

SUYANTO

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE -247 667 (INDIA)
December, 2002

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled "**DEVELOPMENT OF A MODEL FOR EVAPOTRANSPIRATION**", in partial fulfillment of the requirements for the award of the degree of **Master of Technology in Water Resources Development (Civil)**, submitted in the Water Resources Development Training Centre, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out from 16th July 2002 to 30th November 2002 under the supervision of **Dr. U. C. Chaube**, Professor, WRDTC, Indian Institute of Technology Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Date : December 02, 2002
Place : Roorkee

(SUYANTO)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(Dr. U. C. CHAUBE)
Professor
WRDTC
Indian Institute of Technology Roorkee
Roorkee-247 667

ACKNOWLEDGEMENT

I would like to express my sincere thanks and deep sense of gratitude to **Dr. U.C Chaube** , Professor , Water Resources Development Training Centre (WRDTC) , Indian Institute of Technology , Roorkee for valuable and unlimited guidance throughout the preparation of this dissertation.

I also would like to extend my sincere thanks to Professor **Devadutta Das**, Head WRDTC, Indian Institute of Technology of Roorkee, and other staff for all facilities, cooperation and their kindness.

I also express my gratitude to my colleagues for their help and information toward the improvement of this dissertation.

I have no words to adequately express my most sincere gratitude to my Wife ***Sunarnik,*** my children ***Wildan Habibinata Shabri*** and ***Walid Mudafi Robani,*** and all other family members for their constant encouragement and assistance extended to me during the entire study period at Roorkee.

(SUYANTO)

CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER .2 STUDY AREA AND DATA

CHAPTER .3 DEVELOPMENT OF GENERAL EVAPOTRANSPIRATION MODEL

CHAPTER.4 APPLICATION STUDY OF GENERAL EVAPOTRANSPIRATION MODEL

CHAPTER .5 SIMPLIFIED MODEL FOR EVAPOTRANSPIRATION

CHAPTER .6 SUMMARY AND CONCLUSION

LIST OF TABLES

List of Tables Continued

List of Tables Continued

LIST OF FIGURES

LIST OF NOTATIONS

a, b = Fraction of Extraterrestrial Radiatio at $n = 0$
$a+b$ = Fraction of Extraterrestrial Radiatio at clear days
ea = Saturation Vapour Pressure in mbar or kPa
ed = Actual Vapour Pressure in kPa
c = Adjustment Factor
D = Deficit of Saturation Vapour Pressure in kPa
Dav = Average Deficit of Saturation Vapour Pressure in kPa
$f(u)$ = Wind - Related Function
J = Julian day number
$U2$ = Wind Speed at 2 m height above ground in meter
$Uday$ = Day Time Wind Speed in m/sec
$Unight$ = Night Time Wind Speed in m/sec
$Uday/Unight$ = Ratio of Day Time and Night Time
n/N = Sunshine Hours
Ra = Extra Terrestrial Radiation in mm / day
Rs = Solar Radiation in mm/day
Rns = Net Extra Terrestrial Short wave Radiation in mm/day
Rnl = Net Extra Terrestrial Long wave Radiation in mm/day
Rn = Net Radiation in equavalent Evaporation in mm/day
Tk = Mean temperature in Degree Kelvin
$f(T)$ = Temperature Function
$f(n/N)$ = Sunshine Function
$f(ed)$ = Actual Vapour Pressure Function
RH = Relative Humidity in %
$RHmax$ = Maximum of Relative Humidity in %
$Rhmean$ = Average of Relative Humidity in %
T = Temperature in 0C
P = Atmospheric Pressure in kpa
ETo = Reference Crop Evapotranspiration in mm/day
Eo = Evaporation in mm/day
n = Bright Sunshine Hours per day, h
N = Total day length, h
n/N = Ratio of mean daily actual to maximum possible sunshine hours
w = Weighing Factor
ws = Sunshine Hour Angle in Radians
wa = Weighing Factor constant
Z = Elevation (altitude) above mean Sea Level in meters
α = The reflection Coeficient
σ = Stefan Boltzmann constant
λ = Latent Heat of Vaporization of water
γ = The Psychometric Constant in kPa $^0C^{-1}$
γ^* = The Psychometric Constant in kPa $^0C^{-1}$
ϕ = Latitude of site
δ = Declination in Degree Centrigrade
Δ = Gradient of Saturated Vapor Pressure in kPa 0 C-1

ABSTRACT

Several methods, empirical as well as physical processes based have been proposed in literature for estimation of meteorological parameters and for estimation of evapotranspiration. Choice of using a particular method in most cases is dictated by availability and accuracy of input data.

Objective of this dissertation work is to develop models based on empirical correlations between climatic parameters (dependent variable) and other parameters (independent variable), which are generally known or can be easily measured. Thus, reference to various tables in FAO procedure (Doorenbos and Pruitt 1977) could be avoided and the procedure becomes simplified.

First, a general model is proposed by compiling as well as developing regression equations. Table 3.4 shows that reference to eleven tables (as per FAO Procedure) has been avoided by using a general model. Only one table has to be referred, in the proposed general model.

Keeping in view the limited range of climatic variation in Indonesia and particularly in Aceh Province, simple linear equations have been developed and a simplified model has been proposed. The model and input data are summarized in Table 5.8 (chapter 5). The simplified model has been applied to estimate ETo and Eo at Jambo Aye Project.

Accuracy of the general model and the simplified model in estimation of extraterrestrial radiation (Ra), evaporation (Eo) and Potential evapotranspiration (ETo) in terms of percent of variation, coefficient of determination (R^2), bias (B) and variance (V) have been compared.

Extraterrestrial radiation (Ra) is estimated accurately in the general model as well as the simplified model. It is therefore not necessary to use complex mathematical expression given in the general model to estimate Ra.

Simplified model consisting of linear regression equations can be used for estimation of potential evapotranspiration in the limited range of variation for meteorological parameters as happens in Indonesia. Accuracy parameters of the simplified model are found to be better than those of the general model.

Simplified model has been developed specifically for limited range of variation in meteorological parameters in Indonesia. It is not applicable for other regions. General model is applicable for other regions also but accuracy has been compromised in consideration of general application.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Estimation of open water evaporation and potential evapotranspiration (PET) are required for the following studies and therefore is an important component of irrigation planning.

1. Assessment of rainfall deficit (Potential evapotranspiration minus effective rainfall) being an indicator of irrigation requirement to meet crop water demand.
2. Assessment of moisture availability index (MAI) being an indicator of possible of rainfed crop cultivation. MAI is defined as the ratio of 80% probability rainfall to monthly potential evapotranspiration (PET)
3. Assessment of crop growth period and agro climatic condition for crop growth
4. Assessment of average seasonal run off in ungaged catchments using climatic water balances techniques.

   Annual run off = a (gross water surplus - Soil Moisture rechange)

   Annual gross water surplus is defined as the sum of positive monthly differences between rainfall and potential evapotranspiration
5. Assessment of evaporation loss from lakes and reservoir

Reliable estimate of evaporation and potential evapotranspiration is necessary as error in estimation of these values may cause serious errors in planning and hydrologic design of irrigation project.

Several methods are employed in the determination and estimation of evapotranspiration.. Direct measurements of evapotranspiration can be done by lysimeter but such experiments need extensive care, longer time, high cost and sufficient data, which is normally not practicable. Moreover, exact simulation of prototype field conditions in lysimeter is practicaly not possible and hence the results obtained may not be very accurate. Several methods for estimating the evapotranspiration on the basis of correlation with climatic data have been developed, as listed below:

1. Jensen Method
2. Thornthwaite Method
3. Blaney-Criddle Method
    - Original
    - Modified (FAO)
4. Radiation Method
5. Pan-Evaporation Method
6. Chistiansen Method
7. Penman Method
    - Original
    - Modified (FAO)

All these empirical equations estimate the potential evapotranspiration, by utilizing one or more climate measurement.

All these equations have been developed from observations in temperature climates. Hence these equations need through study, before being used in tropical region such as Indonesia, India, which have different climate than that of temperature region.

Choice of using method for evapotranspiration computation in most of the cases is limited with the data availability. Table 1.1 shows the data requirements for each method.

1.2. CLIMATE OF INDONESIA

Indonesia lies just north and south of the equator. The latitude range between 10^0 N to 10^0 S and maximum altitude at the irrigation field is around 2000 m above mean sea level.

The climate is tropical with medium to high rainfall. It may be range from 1000 to 5000 mm a year. The variation of mean daily temperature between the warmest and the coldest months is only between about 20^0C to 30^0 C.

Temperature decreases with increasing altitude at about the rate of 1^0 C per 200 m. Otherwise temperature becomes somewhat high in the city areas.

The mean daily actual sunshine hours vary from about 30 % to 80 % of the maximum possible sunshine hours. Wind velocity varies with the maximum wind speed about 500 km/day. The wind velocity becomes somewhat less in the inland areas. The relation of day and night wind velocity varies from 1 to 3 and daytime wind may be maximum about 6 m/sec.

Table 1.1: Data Requirement for Various Methods

Method	Mean Temp	Max. & Min. Temp	Humi dity	Wind	Sun-shine	Radia-tion	Eva-pora-tion	Envi-ronment
1. Penman								
a. Original	*	-	*	*	*	(*)	-	-
b. Modified	*	-	*	*	*	(*)	-	0
2. Blaney Criddle								
a. Original	*	-	-	-	-	-	-	-
b. Modified	*	-	0	0	0	-	-	0
3. Radiation	*	-	0	0	*	(*)	-	0
4. Jensen.	*	-	-	-		-	-	
5. Pan-Evaporation	-	-	0	0		-	*	*
6. Thornwaite	*	-	-	-		-	-	-
7. Cristiansen	*	-	*	*		*	-	-

Note: * = Measured data (observed)

0 = Estimated data (assessed)

(*) = If available but not essential

1.3. OBJECTIVE AND SCOPE OF STUDY

Food and agriculture organization (Unites Nationals) has brought a publication entitled " Guidelines for Predicating Crop Water Requirements" Irrigation and Drainage paper – 24 (1977), authored by J. Doorenbos, and W.O. Pruitt. Several Procedures are discussed in this report for estimation of evapotranspiration. It is also recommended that modified Penman method should be used whenever possible for estimate of potential evapotranspiration.

However, in this method various tables have to be referred to obtain the values of climatical parameters some of which depend on location, latitude, altitude and some of which are interdependent.

Objective of this dissertation study is to develop models based on empirical correlations between climatic parameters (dependent variable) and other parameters (independent variable), which are generally known or can be easily measured. Thus reference to various tables can be avoided and the procedure becomes simplified. However, empirical relations may cause error if correlation is not very good. The proposed models can be useful in computerization of the estimation procedure and in sensitivity analysis of the potential evapotranspiration. In Indonesia, climatic variable such as radiation, temperature and wind speed occur in specific limited range. Therefore, it is proposed to further simplify the procedure for estimation of evapotranspiration.

Scope of the study is limited to geographic region of Indonesia for which latitude range is 10^0 N to 10^0 S. Further validity of correlation equations is checked for the location of Jambo Aye in Aceh Province in Indonesia where a multipurpose project is being planned.

CHAPTER 2

STUDY AREA AND DATA

2.1. ACEH PROVINCE

The special District of Aceh is a province of Indonesia and lies at the northern end of Sumatera between latitude 3^0 and 6^0 N (Figure 2.1. The total land area of 55,852 km^2 includes the island of Pulau Weh in the north and Simeulue and the Kepulauan Banyak group in the south – west coast.

Aceh province is mountainous, centring on the Bukit Barisan range, which runs the entire length of sumatera. The highest peaks are in the region of 3000 to 3400 m above sea level. Younger mountains formed from folded tertiary sediments make up the foothills of the north and east coasts. Three volcanoes of known recent activity exist. The recent laves and transported material from these volcanoes are of an acidic nature and are consequently of low facility.

Coastal plains are generally narrow (< 4 km) on the north and east but widening locally at the mouths of certain rivers, most notaly Kr. Baro and Kr.Pase, Kr.Keureutan. Tidal swamps occur at the mouths of the main rivers of the East Coast. On the West Coast, the coastal plain is generally much wider (up to 20 km) with active a gradation of sediments from both coastal and riverine sources. This deposition has led to the formation of peat beach swamps in most of the larger areas of coastal plain. However, stretches of the West Coast such as the Aceh Besar/Aceh Barat, border and the area around Tapak Tuan in Aceh Selatan have no coastal plain.

The climate is tropical with high humidity (80 – 90 %) and little variation in mean daily temperature (25^0 - 27^0C) throughout the seasons. Rainfall is generally high but subject to sharp regional variations due to the interaction of the prevailing monsoons and the central mountains. The West Coast is the wettest with typically mountains. Annual rainfall decreases towards the north coast where it reduces in some areas to as little as 1200 m.

2.2. PRINCIPAL RIVER SYSTEMS

The principal rivers of Aceh province are shown in Figur.2.1. All rivers, except the Lawe Alas in the central rift valley, follow a normal course to the sea on either side of the central mountains.

Most rivers are characterized by steep boulder stream in upper catchments with dense primary forest cover, flattening into braided channels, then meandering in their lower reaches as they emerge from the foothills into the coastal plain. The profile and section of the river between the 25 meters contour and its mouth is of considerable significance in determining irrigation supply potential, flood risk and erosion protection requirements. This varies considerably between rivers such as the Kr.Samalanga (average slope 1 in 240) and the incised Simpang kiri (average slope 1 in 5000).

2.3 THE STUDY AREA

The study area for the present study is the Water Resources Development Area number 12 (WRDA – 12) where in the Jambo Aye basin and the Jambo Aye irrigation project lies

2.4AGRICULTURE

The north and east coastal plains and foothills contain a portion of WRDA 12. The mountains and valley of the central Barisan range contain the upper portion of the WRDA – 12.

The northeast coastal plains contain the most productive and highly developed sawah areas of Aceh. Intensive cropping is limited by the annual rainfall which averages between 1500 to 2000 mm, and the base river flows that drain the central high lands to northeast. The growing season coincides with a single peak during which only 50 % of the annual total rainfall may be expected. This is barely sufficient for single rice crop. Irrigation is thus essential for a single or double rice crop.

On Jambo Aye river in Aceh Utara major irrigation schemes are being developed. However, these are not fully operational at the present time and it is estimated that overall only 20 % of the sawah area is currently double cropped with rice.

2.5 CENTRA BARISAN RANGE

The upper portion of the WRDA – 12 lies in the mountains and valleys of the Central Barisan range. The central up lands can be further devided into two sub-region; The Tangse / Gumpang region and the Takengon / Blang Kejeren region, using the criteria of the 600 m countur. Rice lands in the Tnge / Gumpang region are below the altitude limitation for double cropping and inded two crops of rice are some times grown in the Tangse scheme areas. The region in still typified as an upland area and the climate is modified by the hills encircling the Kr.Teunom headwaters. The Takengon / Blang Kejeren region is largely well above the 600 m contour (Taengon 1250 m) and cropping is presently constrained by varietal suitability to only one local variety rice crop each year.

Both sub-regions have well developed coffee crops, particularly the Takengon area where an strengthening project has been developing the C. arabica industry for export purposes. Vegetables too are well suited, as a second crop in these areas and with the expanding urban population of the coastal plains, the full potential of this industry has not yet been developed. With average rainfall at around 2000 mm there is still a marked dry season from late May to the end of August that necessitates good irrigation supplies for any intended intensive agriculture.

2.6 IRRIGATION PLANNING IN ACEH

Irrigation accounts for majority of water resources schemes in Aceh. More than 250 irrigation schemes are proposed to be taken by government.

Detailed data for these schemes are not available. Preliminary design of these schemes can be done through empirical studies only, for which simple models for estimation of evapotranspiration can be useful.

2.7 HYDROMETEOROLOGICAL DATA

Monthly rainfall data is available for four rain gauge stations in WRDA – 12

- Bireuen	1912 to 1983
- Isaq / kotadah	1936 to 1979
- Julu Rayu	1953 to 1983
- Lhokseumawe	1894 to 1983.

Representative meteorological station for the WRD-12 irrigation development area is Lhokseumawe for which data is given in Table 2.1

Table 2.1 Mean Monthly Climatic Data at Lhokseumawe Meteorological Station .

Climatic Variable						
Month	Air Temp (^{0}C)	Relative maximum Humidity (%)	Relative minimum Humidity (%)	Wind speed 2 m above ground	Ratio sunshine	Sunshine Duration (%)
Jan	24.9	85	82	177	0.45	67
Feb	25.2	85	81	177	0.42	63
Mar	26.4	85	80	160	0.44	66
Apr	26.4	85	82	125	0.37	57
May	26.6	85	82	104	0.35	54
Jun	26.3	85	80	101	0.38	59
Jul	26.2	85	81	108	0.38	58
Aug	25.8	85	73	121	0.36	55
Sept	25.7	85	82	118	0.30	47
Oct	25.5	90	84	104	0.31	47
Nov	25.5	90	85	114	0.34	51
Dec	25.3	90	86	135	0.24	36

CHAPTER 3

DEVELOPMENT OF GENERAL EVAPOTRANSPIRATION MODEL

3.1. INTRODUCTION

Hydrologists, in search for true to life description of a physical process create complex models, which require high level of input data and specification of an extensive set of parameters. In developing countries, input data in the form of frequently sampled hydro meteorological variables is generally not available. Similarly extensive set of soil and vegetation parameters is neither available from experiments nor is it readily available in the literature. Therefore, such research-oriented models could not become " tools of the trade" for hydrologic practitioners. A large number of empirical techniques and physically based models for estimation of evaporation and evapotranspiration are available in literature. Instead of evaluating all such techniques and models, emphases are to select a few preferred methods (empirical relations). Two standard evaporation rates i.e. potential evapotranspiration (ETo) and evaporation rates are needed in water resource planning.

The modified Penman method is generally recommended for the estimation of potential evapotranspiration (ETo). Food and Agriculture Organization (Unites Nations) has brought out a publication entitled "Guidelines for Predicating Crop Water Requirements"- Irrigation and Drainage paper – 24 (1977), authored by J. Doorenbos, and W.O. Pruitt. Several Procedures are discussed in this report for estimation of evapotranspiration. It is also recommended that modified Penman method should be used whenever possible for estimation of potential evapotranspiration. However, in this method various tables have to be referred to obtain the values of climatical parameters, some of which depend on location, latitude, altitude and some of which are interdependent.

In this chapter, an effort has been made to minimize use of tables by compiling as well as developing empirical correlation equations between:

various variables for a specific region. It will thus be useful in computerization of the method and in sensitivity analysis of the ETo estimate with respect to climate variables.

3.2. MODIFIED PENMAN METHOD

Potential evapotranspiration is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water.

Penman Method has been modified by Doorenbos and Pruitt (1977).. The equation is:

$$ET_o = c\,[\,w \times R_n + (1 - w) \times f(u) \times (e_a - e_d)\,]$$

Where,

ET_o = Reference crop evapotranspiration (mm / day)

c = Adjustment factor to compensate for the effect of day and height
weather conditions which depend upon ratio U_{day} / U_{night}, U_{day}, Rh_{max} and solar Radiation (Rs)

w = Weighing factor which depends upon temperature and altitude (dimensionless)

R_n = Net radiation as equivalent evapotranspiration depth in mm / day. It is
the difference between net shortwave radiation (Rns) and net long wave Radiation (Rn1).

f(u) = Wind related function, which depends upon 24 hr wind run (km / day) at 2 m height

$(e_a – e_d)$ = Difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in unit of Milli bar or Pascal's

Details of the method and examples and reference tables are given in Doorenboss & Pruitt (1977) and also in text book on hydrology.

3.3. DEVELOPMENT OF MODEL

In the following paragraphs some preferred empirical relations have been compiled / developed for estimation of open water evaporation and reference crop evapotranspiration. Effort has been made to minimize use of reference to tables and to provide insight into interdependency among various climate variables.

Step – 1: Saturation Vapour Pressure (e_a) :

Instead of using table 5 given in Doorebos and Pruitt (1977) the empirical formula as suggested by Raud Kivi (1979) gives similar results

$$e_a = 0.6108 \exp [(17.27 \times T) / (237.3 + T)]$$

Where,

e_a is in kilo Pascals ($Pa = N / m^2$) and T is in degrees Celsius .

Step-2 : Actual Vapour Pressure (e_d) and ($e_a - e_d$):

Actual vapour pressure (e_d) can be found out using the mean humidity (Rh_{mean} in %) by equation :

$$e_d = e_a \times (Rh_{mean} / 100) \text{ in unit of } e_a$$

Actual vapour pressure (**e_d**) can also be calculated if dew point temperature (**T_d**) is given instead of relative humidity. The temperature at which air would just become saturated at a given specific humidity is its dew point temperature T_d (in degree centigrade), so

$$e_a = 0.6108 \exp [(17.27 \times T_d) / (237.3 + T_d)]$$

where **e_d** is in kilo pascals and T_d is dew point temperature in $^{\circ}$Celsius.

Maidment (1993) states that computing vapour pressure deficit ($e_a - e_d$) at the measured maximum and minimum temperatures separately, and then taking the average of these deficit values provides a better estimate of the true daily average deficit rather than averaging temperatures (or relative humidities) first and then computing the deficit

$$(e_a)_{av} = (e_a \text{ at } T_{max} + e_a \text{ at } T_{min}) / 2$$

and vapour pressure deficit ($\overline{D}$)

$$\overline{D} = (e_a) \times (1 - RH) / 100 \text{ or}$$

$$\overline{D} = (e_a)_{av} - e_a \text{ at } T_d$$

Step. 3. Wind Function f (u)

The wind velocity in the boundary layer near earth's surface (up to about 50 m) is well described by the logarithmic profile law (Priestley 1959).

$$Uh / U^* = (1 / k) \times Ln (h / ho) \text{, or}$$

$$U^* = (k \times Uh) / Ln (h / ho)$$

Where the shear velocity is :

$$U^* = \sqrt{\frac{\tau o}{P}}$$

τo is the boundary shear stress and **p** is the fluid density , **K** is of the Von Karman's constant (≈ 0.4) and ho is roughness height of the surface.

Table 3.1 : Correlation between Roughness Height and Surface Type

Surface	Roughness height (h_o) cm
Ice, mud flats	0.001
Water	0,01 – 0,06
Grass (up to 10 cm)	0,1 – 2,0
Grass (10 cm to 50 cm)	2,0 – 5,0
Vegetation (1 m to 2 m)	20
Trees (10 m – 15 m)	40 – 70

Given wind velocity at height h, wind velocity at 2 m height can be found by

$$U2 = Uh\left[\frac{Ln - Ln.ho + Ln_2 - Lnh}{Ln.h - Ln.h}\right]$$

Wind function as given in Maidment (1993) is adopted for open water evaporation

$$f(u) = 6.43x (1 - 0.536x\, U_2) / \lambda$$

and for reference crop evapotranspiration

$f(u) = 900 \times U_2 / (T + 275)$

U2 is wind speed in m / sec at 2 m height.

Where λ is the latent heat of vaporization of water

Step. 4. Determination of weighting factor (w)

Instead of using table – 8 given in Doorebos and Pruitt (1977), the following equations have been used (Maidment 1993)

$W = \Delta / (\Delta + \gamma)$

$\Delta = (4098 \times e_a) / (237.3 + T)^2$, kpa / ^{0}C where e_a in kpa

γ = is psychometric constant

$\gamma = (Cp \times P) / (0.622 \times Lv)$

Cp is specific heat of moist air = 1.013 kJ per kg per degree centigrade. Lv is latent heat of vaporization. It varies slightly with temperature, Lv = 2.501 – 0.002361 T in kilo Joules / kg. Where T is temperature in °C, A joule is an SI unit representing the amount of energy required to exert a force of 1 Newton through distance 1 meter. P is average air pressure. It varies with elevation (altitude) above mean sea level. Z is in meters.

$$P = 101.3 [(293 - 0.0065 \times Z / 293)]^{5.256}$$

where:

Z = Elevation (altitude) above mean sea level in meters

T = Mean temperature in degree centigrade

P = Average air pressure in kpa

$\gamma = (0.0016286 \times P) / (2.501 - 0.002361 \times T)$ in kpa / ^{0}C

Therefore weighting (w) can be estimated using mean temperature (or T_{max} and T_{min}) and elevation (Z) only, weight w for reference crop evaporation is modified as

$we = \Delta / (\Delta + \gamma^*)$ and $wa = \gamma / (\Delta + \gamma^*)$

$\gamma^* = \gamma (1 + 0.33 \times U_2)$

Note that $we + wa \neq 1$

Whereas for open water evaporation

$we = \Delta / (\Delta + \gamma)$ and $wa = \gamma / (\Delta + \gamma)$

and $we + wa = 1$

Step. 5. Extraterrestrial radiation (R_a) .

Generally Equation for Extraterrestrial Radiation and Maximum Possible Day Light Hours:

Extraterrestrial radiation can be estimated using following equations

$$Ra\ (mm / day) = 15.392 \times dr\ (ws \,.\, \sin Ø \,.\, \sin L + \cos Ø \,.\, \cos L \,.\, \sin ws)$$

where dr is relative distance between earth and the sun given by :

$$dr = 1 + 0.033 \cos ((2\pi \times J) / 365 - 1.405)$$

Where :

J : Julian day number

Ø : Latitude of site (positive for Northern hemisphere , and negative for Southern Hemisphere)

δ : Solar declination (in radiation) given by

$\delta = 0.4093 \sin ((2\pi \times J / 365) - 1.405)$

ws is the sunset hour angle (radians) given by

$ws = \arccos (- \tan Ø \,.\, \tan L)$

Maximum Possible day light hours can be estimated by

$N = 24 \times ws /$

Therefore Ra and N at a location and on a particular day can be calculated from data on Ø & J only. Average Ra and N for month.: $Ra = f_1 (Ø , J)$ and average N (hrs / day) for a month $N = f_2 (Ø , J)$. In order to get average Ra (mm / day) and average N (hrs / day) for a month,, following table can be used table.

Table3.2. Recommended Average Day for each month (from Klein 1977) and values of n by Month.

Month	n for ith Day of Month	For the Average Day of the Month		
		Date	N, Day of year	δ, Declination
January	i	17	17	-20.9
February	31 + i	16	47	-13.0
March	59 + i	16	75	-2.4
April	90 + i	15	105	9.4
May	120+i	15	135	18.8
June	151+i	11	162	23.1
July	181+i	17	198	21.2
August	212+i	16	228	13.5
September	243+i	15	258	2.2
October	273+i	15	288	-9.6
November	304+i	14	318	-18.9
December	334+i	10	334	-23.0

Source : Klein , S.A (1977) "Calculation of Monthly average Isolation on Tilled Surfaces" in Journal of Solar Energy, Vol. 19, page 325 (1977) USA.

The above procedure provides estimate of N and Ra which is good to about 0.1 hour and 0.1 mm/day, respectively (Maidment,1993).

Step. 6 : Net Radiation (Rn)

Net radiation is the difference between all incoming and out going radiation.

$R_n = R_{ns} - R_{n1}$

Where :

R_{ns} = net shortwave solar radiation in mm / day

R_{n1} = net long wave solar radiation in mm / day . Earth surface is on average warmer, than atmosphere so there is net loss of energy as thermal energy from ground.

$$R_{ns} = (1 - \alpha)\, R_s$$

$$Rs = \left[a + b.\frac{n}{N}\right] Ra$$

$$Rn1 = f(T) \times f(ed) \times f(n/N)$$

$$f(T) = \sigma (T_k)^4$$

Net emissivity ($f(e_d)$)

$$f(e_d) = ae + be\,\sqrt{ed}$$

for average conditions :

ae = 0.34 and be = -0.14

$$\therefore\ f(ed) = 0.34 - 0.14\,\sqrt{ed}$$

$$f(n/N) = 0.10 + 0.90.\, n/N$$

where :

Rs = Total incoming short wave radiation (mm/day)

Ra = Extra terrestrial radiation received at the top of the atmosphere which depends upon the latitude and month (see step 5).

α = Reflectiveness (or albedo) of surface, for most crops K is taken as 0.25.For open water 0.08, for bare soil 0.1 (wet) to 0.35 (dry),for tall farm crop 0.18.

a,b = Constants depending upon local conditions ,for practical purposes,

a = 0.29 cos ϕ where Ø is latitude. For average climate, a = 0.25 and b = 0.50

ae,be = for average condition ae = 0.34 and be = -0.14,for arid area ae = 1.35,be = - 0.35 and for humid area ae = 1.0,be = 0.0

T_k = Mean temperature in degree Kelvin = 273 + T^{o} C

σ = Stephen – Bolzmann constant (4.903×10^{-9} MJ m^{-2} K^{-4} day^{-1})

n/N = Ratio of mean daily actual to maximum possible sunshine hours given in Table – 11 of Doorenbos and Pruitt (1977). Generally for practical purpose in Indonesia, value of N can be taken as 12 hours (in case of observed data is not available).

$Rn = (0.25 + 0.5\, n/N) \times Ra - 4.903 \times 10^{-9} (273 + T^{0}) \times (0.34 - 0.14\sqrt{ed}) \times (0.1 + 0.9 \times n/N)$ latitude (Ø),mean temperature and actual sunshine hours or cloud hour only.

Step. 7 : Adjustment Factor (C)

C is the adjustment factor to compensate for the day and night weather conditions. The values of adjustment factor (c) for different conditions of maximum relative humidity (RH_{max}), solar radiation (R_s), day time wind (U_{day}) and ratio of day and night and velocity (U_{day} / U_{night}) are presented in Table 3.5.(table 16 – FAO-24) .

Table 3.3 : Adjustment Factor (c) in presented Equation (Table 16- FAO-24)

Rs mm/day	RHmax 60 %		RHmax 90 %		RHmax 85 %	
Uday m/s	Uday / Unight = 1.0					
	6	9	6	9	6	9
0	0.98	1.05	1.06	1.10	-	-
3	0.86	0.94	0.92	1.01	-	-
1.5	0.92	0.995	0.99	1.055	0.955	1.025

3.4 INPUT DATA AND COMPUTATION ALGORITHM

In this study for empirical determination of evapotranspiration and evaporation, the following data are necessary :

3.4.1. Basic necessary Data

Elevation (Z), Latitude(Ø), month or day,mean temperature (T),mean Relative humidity (RH) or Dew point Temp (T_d), average sunshine hours perday for the period, wind speed and height at which it is measured (Uh), type of evaporating surface (crop, open water).

3.4.2. Desirable Data

In addition to above mentioned basic data if following data is available, the estimate can be made more accurate. Mean Max temperature T_{max} and Mean. Minimum temperature for the period (T_{min}) ; climatic classification such as arid area or humid area, experimentally determined correlation coefficients as, bs, ae, be. Table 3.4 shows how reference to various tables can be avoid by use of empirical / physical based equations.

Table 3.4. Input Data, for Equation in place of Tables

No	Input Data.	Reference to equation / table where data is used	
		As per General Model	As per tables In FAO-24
1.	Latitude	R_a = f (latitude, month)	Tables 10 – 11
2.	Altitude	w = f (T_{mean}, altitude)	Tables 8 – 9
3.	Month	R_a = f(latitude,month) N = (latitude,month)	Tables 10 – 11 Tables 11
4.	Mean Temp(T_{mean})	e_a = f (T_{mean}) w = f (T_{mean},altitude) R_{n1} = f (T_{mean},n/N,ed)	Tables 5,8, 9, 13
5.	Mean rel.hum (RH_{mean})	e_d = f (RH $_{mean}$, e_a)	$e_d = e_a$ x RH_{max}
6.	Wind speed (U_{mean})	$U_2 = C_{fw}$ U_{mean} . f(u)	Tables – 7
7.	U_{day} / U_{night} , U_{day} , Rh_{max}		
8	Height of wind measurement (h)	C_{fw} = f (h)	Table – Page 16
9.	Ratio actual & max. possible sunshine hours(n/N)	R_s = f(n/N,Rs) R_{n1} = f (T_{mean} , n/N, e_d)	Tables – Page17 Table – 12

Summary form of computational steps and input data at each step are given below.

3.5. SUMMARY MODEL AND COMPUTATIONAL STEPS

ETo = we x Rn + wa x f(u) x $\overline{D}$

Step 1. Saturation Vapour Pressure (ea)

Input data: T_{mean} in ^0C

e_a = 0.6108 exp [(17.27 x T) / (237.3 + T), or

Input data: T_{max}, and T_{min}

$(e_a)_{av}$ = $((e_a)$ at Tmax + (e_a) at Tmin) / 2 , in kpa

Input data : RH, and T_d

$\overline{D} = (e_a) \times (1 - RH / 100)$, or

$\overline{D} = (e_a)_{av} - (e_a)$ at T_d

Step 2. Estimate we and wa

Input data : Altitude (Z) , and Wind speed (U)

$\Delta = (4098 \times e_a) / (237.3 + T)^2$

$P = 101.3\,((293 - 0.0065 \times Z) / 293)^{5.526}$

$\lambda = 2.501 - 0.002361 \times T$

$\gamma = (0.0016286 \times P) / 9$

$$we = \frac{\Delta}{(\Delta + \gamma)} \text{ for open water surface}$$

wa = 1 - we

$$we = \frac{\Delta}{(\Delta + \gamma^*)} \text{ for reference crop evapotranspiration}$$

$$wa = \frac{\gamma}{(\Delta + \gamma^*)}$$

$\gamma^* = \gamma\,(1 + 0.33 \times U_2)$

Step 3 Estimate of Extraterrestrial radiation (Ra)

Input data :

Latitude Ø, Ø is Positive ve for Northern hemisphere and Ø is negative ve for Southern hemisphere, month

For a given month get J and L from table 3.2

ws = arc cos (-tan Ø . tan δ) in Radians

$dr = 1 + 0.033 \cos (2\pi \times J /365)$

$Ra = 15.392 \times dr (ws \times \sin \varnothing . \sin L + \cos \varnothing . \cos L . \sin ws)$ in mm/day

$N = (24 \times ws) / \pi$

Step 4. Net Radiation (Rn)

Input data :

Bright sunshine hours (n)

$Rn = (0.25 + 0.50.n / N) \times Ra - NTk^4 (0.34 - 0.14 \sqrt{ed}) (0.1 + 0.9.n/N)$

$N = 0.510 \times 10^{-9}$ in mm/day k^4

$Tk = 273 + T$

Step 5. Estimation of Wind function f(u)

Input data :

Wind speed (U)

$f1(u) = 6.43 ((1 + 0.536 \times U) / 9)$ for open water surface

$f2(u) = (900.U) / (T + 275)$ for reference crop evapotranspiration

Step 6. Estimation of ETo and Eo

For reference crop evapotranspiration

$$ETo = we \times Rn + wa \times f2(u) \times \overline{D}$$

For open water surface

$$Eo = w \times Rn + (1 - w) \times f1(u) \times D$$

Table 3.5. Summary Model and Computation Steps

Step	Input Data	Formula
I. Estimate e_a or $(e_a)_{av}$ and $\overline{D}$	T or(T_{max},T_{min}) RH or T_d	$e_a = 0.6108 \exp((17.27 \times T) / (273.3 + T))$,(kpa) $(e_a)_{av} = ((e_a) \text{ at } T_{max} + (e_a) \text{ at } T_{min}) / 2$, (kpa) $\overline{D} = (e_a)_{av} \times (1 - RH / 100)$ (kpa) $D = (e_a)_{av} - (e_a) \text{ at } T_d$ (kpa)
II. Estimate we and wa	Z and U m/sec	$\Delta = (4098 \times ea) / (237.3 + T)^2$ (kpa/^{0}C) $P = 101.3 ((293 - 0.0065 \times Z) / 293)^{5.256}$ (kpa) $\lambda = 2.501 - 0.002361 \times T$ $\delta = (0.0016286 \times P) / 9$ **for open water surface** $we = \Delta / (\Delta + \gamma)$ $wa = 1 - w$ **reference crop evapotranspiration** $we = \Delta / (\Delta + \gamma^*)$ $wa = \delta / (\Delta + \gamma^*)$ $\delta^* = \delta (1 + 0.33 \times U2)$
III.Estimate Ra	Ø, month Ø is + ve for Northern hemisphire and - ve for. Southern hemisphire	for a given month get J and L form table 3.2. ws = arcos (-tanØ.tanL), (radiation) dr = 1 + 0.033cos ((2™x J) / 365) Ra = 15.392.dr (ws SinØ.SinL + CosØ CosL.Sinws) (mm/day)
IV.Estimate N		$N = (24 \times ws) / \pi$
V.Estimate Rn	actual sunshine hour n	$Rn = (0.25 + 0.5 \times n/N)\, Ra - NTk^4 (0.34 - 0.14\sqrt{ed})(0.1 + 0.9 \times n/N)$ $N = 0.510 \times 10^{-9}$ mm/day.k^4
VI.Estimate f(u)	U2	for open water surface $f1(u) = 6.43 (1 + 0.536 \times U2) / \lambda$ for reference crop $f2(u) = (900 \times U2) / (T + 275)$
VII.Estimate ETo and Eo		For reference crop evapotranspiration $ETo = we\, Rn + wa\, f2(u) \times \overline{D}$ For open water surface $Eo = w \times Rn + (1 - w) \times f1(u) \times D$

3.6 ACCURACY OF MODEL

In the present study main objective is to propose a model for estimation of evapotranspiration and evaporation on monthly basis so as to avoid reference to various tables in FAO procedure. Estimated evapotranspiration and evaporation by FAO procedure are considered as reference values to find accuracy of the Proposed model.

Percentage error of estimated value respect to reference value by FAO-24 tables is :

$$= \frac{\text{Estimated Value by FAO procedure - Estimation Value by proposed Mode}}{\text{Estimated by FAO procedure}} \text{x}100\%$$

$$\text{Percentage error for Evapotranspiration (ETo)} = \frac{ETo_r - ETo_f}{ETo_r} \text{x}100\%$$

$$\text{Percentage error for Evaporation (Eo)} = \frac{Eo_r - Eo_f}{Eo_r} \text{x}100\%$$

Where :

ETr = Estimated values by FAO procedure of evapotranspiration and evaporation

ETm = Model estimation values of evapotranspiration by the proposed model Maidment (1993) has proposed the following parameters for model accuracy.

Estimation errors can be either systematic (recurring), or random due to case-specific conditions, such as errors in the meteorological estimation on which the ETo estimation is based. Estimation accuracy is best assessed by retrospective comparison of estimation actually made or that might have been made, and the values observed during the forecast period. Let Q_f (i) be the model estimated value and Q_o (i) be the FAO procedure based estimated value (taken as reference) of evapotranspiration or evaporation. Define M_f and M_o as the means of the model estimation and reference values, as follows :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Qf(i)$$

$$M_o = \frac{1}{n}\sum_{i=1}^{n} Qo(i)$$

Where n is the total number of values, (here n = 12 corresponding to months).

Bias : $B = M_f - M_o$

Mean squared error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n} \left[Q_f(i) - Q_o(i)\right]$$

Root mean square error : $RMSE = (MSE)^{0.5}$

Variance : $V = MSE - B^2$

Relative bias : $RB = B / M_o$

Mean absolute error : (MAE):

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_o(i)\right]$$

Relative mean absolute error (RMAE) :

$$RMAE = \frac{MAE}{M_O}$$

Model efficiency (E) :

$$E = 1 - \frac{MSE}{V}$$

R squared (R^2) :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_o(i)\, Q_f(i) - M_o M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_o^2 - M_o^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f\right)}\right]$$

Bias and relative bias are measures of systematic error in the estimation; that is over a period of many years, they measure the degree to which the estimation is consistently above or below the actual value. Variance is a measure of the variability, or scatter, of a number of estimation about the true value, and is therefore a measure of the random error. Mean square error, root mean square error, mean absolute error, relative mean absolute error, and model efficiency are all measures that incorporate both systematic and random errors. A perfect estimation exists only if both the bias and the variance are zero, which occurs only when all estimated values are identical to the observations. R^2 is the square of the correlation coefficient between the reference and estimated values. Although R^2 is a widely used measure of model accuracy, care must be taken if appreciable bias is present, since R^2 evaluates the accuracy of an estimation with respect to random error only. The highest value of R^2 , 1.0, can be achieved for cases where there is a constant bias in estimation; that is, the estimated value is equal to the reference value plus or minus a constant. For this reason, instead of using R^2, model accuracy is better assessed by using the bias and the variance, or the bias and the mean absolute error. MAE or RMAE is preferred to MSE because, when compared to squared error measures, absolute error measures are less dominated by a small number of large errors, and are thus a more reliable indicator of typical error magnitudes.

CHAPTER 4

APPLICATION STUDY OF GENERAL EVAPOTRANSPIRATION MODEL

The meteorological data for the Jambo Aye Irrigation Project in Aceh Province of Indonesia are summarized in Table .4.1.

Table 4.1 : Summary of Climate Data Jambo Aye Irrigation Project

Latitude : 5 ° N

Altitude : 500 m

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
T_{mean} (°C)	24.9	25.2	26.4	26.4	26.6	26.3	26.2	25.8	25.7	25.5	25.5	25.3	25.8
RH_{mean} (%	82	81	80	82	82	80	81	73	82	84	85	86	73.17
Ratio Sunshine Hours (n/N)	0.45	0.42	0.44	0.37	0.35	0.38	0.38	0.36	0.30	0.31	0.34	0.24	0.36
U2	177	177	160	125	104	101	108	121	118	104	114	135	128.7
RH_{max} (%)	85	85	85	85	85	85	85	85	85	90	90	90	86.25
Sunshine duration (0.80–1600 h)	67	63	66	57	54	59	58	55	47	47	51	36	53.00

Note : U_{day} = 1.5 m/sec

U_{day}/U_{night} = 1

80% < RH < 90 %

4.1. CALCULATION OF ETo USING GENERAL MODEL

Given data :

- Altitude = 500 m
- Latitude = 5° N (0.0873 radian)
- Declination (δ) = -20.9 (from table 3.2 in chapter 3)

- Month = January (equivalen day J = 17 from table 3.2)
- Mean temperature T_{mean} = 24.9°C
- Mean Relative humidity RH_{mean} = 82 %
- Max. Relative Humidity RH_{max} = 85 %
- Mean wind speed (U_{mean}) at 2 m height of wind measurement = 177 km / day
- Day time wind speed U_{day} = 1.5 m / sec
- Ratio U_{day} / U_{night} = 1.0
- Ratio of actual to max, possible sunshine hours (n/N) = 0.45

Climate data for other months are given in table 4.1

Solution : Procedure calculation as the following steps :

Step. 1 : Saturation Vapour pressure (e_a)

e_a = 0.6108 exp (17.27 T / 237.3 + T)

= 0.6108 exp (17.27 x 24.9 / 237.3 + 24.9)

= 3.149 kpa

$\overline{D}$ = $(e_a)_{av}$ x (1 – (RH / 100)

= 3.149 x 1 – (82 / 100)

= 0.567 kpa

Step. 2 : Actual Vapour Pressure (e_d)

e_d = e_a x RH $_{mean}$ / 100

= 3.159 x 82 / 100

= 2.582 kpa

Step. 3 : Wind Funtion f (u)

Here observed wind speed at 2 m height in km / day (i.e. h = 2 m)

u_2 = uh (Ln_2-Ln ho / Ln_2 – Ln ho)

= 177 (Ln_2-Ln 0.20 / Ln_2 –Ln 0.20)

= 177 km / day

$= 177 \times 1000 / (24 \times 60 \times 60)$

$= 2.049 \text{ m / sec}$

for reference crop evapotranspiration

$f(u) = (900 \times U_2) / (T + 275)$

$= (900 \times 2.049) / (24.9 + 275)$

$= 6.149$

for open water surface

$f(u) = 6.43 ((1 + 0.536 \times U_2) / 9)$

$= 6.43 \times ((1 + 0.536 \times 2.0486) / 2.442)$

$= 5.524$

Step. 4 : Weighting Factor (w)

$P = 101.3 ((293 - 0.0065 \times Z) / 2)^{5.256}$

$= 101.3 ((293 - 0.0065 \times 500) / 293)^{5.256}$

$= 95.532 \text{ kpa}$

$\lambda = 2.501 - 0.00236 \times T$

$= 2.501 - 0.00236 \times 24.9$

$= 2.442 \text{ m J kg}^{-1}$

$\gamma = (0.001628 \times P) / 9$

$= (0.001628 \times 95.532) / 2.442$

$= 0.064 \text{ kpa } {}^0C^{-1}$

$\gamma^* = \gamma (1 + 0.33 \times U_2)$

$= 0.064 (1+ (0.33 \times 2.049)$

$= 0.1078$

$\Delta = (4098 \times e_a) / (237.3 + T)^2$

$= (4098 \times 3.149) / (237.3 + 24.9)^2$

$= 0.188 \text{ kpa } {}^0C^{-1}$

for water surface

$we = \Delta / (\Delta + \gamma)$

$= 0.188 / (0.188 + 0.0637)$

$= 0.747$

$wa = (1 - we)$
$= (1 - 0.747)$
$= 0.253$

for reference crop
$we = \Delta / (\Delta + \gamma^*)$
$= 0.188 / (0.188 + 0.1068)$
$= 0.637$
$wa = \gamma / (\Delta + \gamma^*)$
$= 0.0637 / (0.188 + 0.1068)$
$= 0.216$

Step. 5 : Extra Terrestrial Radiation (Ra)

$ws = \text{arc cos} (- \tan Ø . \tan L)$
$= \text{arc cos} (- \tan 5^0 \times \tan -20.9^0)$
$= 1.537$ radian , or $88.09\ {}^0C$.
$dr = 1 + 0.033 \cos (2\pi \times J / 365)$
$= 1.032$

Latitude : 5 ° N on January , use linear Regression equation :
$Ra = 15.392\ dr (ws \times \sin Ø \times \sin L + \cos Ø \times \cos L \times \sin ws)$
$= 15.392 \times 1.032 (1.537 \times \sin 5^0 \times \sin -20.9^0 + \cos 5^0 \times \cos - 20.9^0 \times \sin 88.09)$
$= 14.02$ mm/day

Step. 6 : Net Radiation (Rn)

$Rs = (0.25 + 0.50 . n / N) \times Ra$
$= (0.25 + 0.50 . 0.45) \times 14.02$
$= 6.655$ mm/day
$Rns = (1 - K) \times Rs$
$= (1 - 0.25) \times 6.655$
$= 4.991$ mm/day
$Tk = 273 + T\ {}^0C$

$= 273 + 24.9$

$= 297.9\ {}^{0}K$

$f(T) = \sigma\, (Tk)^4$

$= 2.0075 \times 10^{-9} \times (\ 297.9\ )^4$

$= 15.810$

$f(n/N = 0.1 + 0.9 \times 0.45$

$= 0.505$

$f(e_d) = 0.34 - 0.14\sqrt{ed}$

$= 0.34 - 0.14\sqrt{2.582}$

$= 0.115$

$Rn1 = \sigma\, Tk^4\ (\ a3 - a4\sqrt{ed}\ )\ (\ a5 + a6\ n/N\ )$

$= f\,(\ T\ ) \times f\,(\ n/N\ ) \times f\,(\ ed\ )$

$= 15.810 \times 0.505 \times 0.115$

$= 0.918$ mm / day

$Rn = Rns - Rn1$

$= 4.991 - 0.918$

$= 4.073$ mm / day

Step 7 . ETo Computation

For reference crop evapotranspiration

$ETo = we.Rn + wa.\ f2(u)\ \overline{D}$

$= 0.747 \times 4.073 + (\ 0.253 \times 6.148 \times 0.567\ )$

$= 3.924$ mm / day

$Eo = we \times Rn + (\ 1 - wa\ ) \times f(u) \times D$

$= 0.747 \times 4.073 + (\ 1 - 0.253\ ) \times 5.524 \times 0.567$

$= 5.378$ mm/day

Similar procedure can be used for other months and calculation are shown in table 4.2.

4.2. CALCULATION OF ETo USING FAO-24 TABLES

Based upon the above given data, the procedures calculations as the following steps :

Step1. Determination of Saturation Vapour pressure (e_a)

T_{mean} = 24.9 °C,

Use Table 1 (Table 5 – FAO), we get is

e_a = 31.51 m bar

Step 2. Actual Vapour Pressure (ed)

e_d = ea x Rh_{mean} / 100, where Rh_{mean} = 82 %

= 31.51 x 82 / 100

= 25.838 m bar

so , (ea – ed) = 31.51 - 25.838 = 5.672 m bar

Step. 3 : Wind Function f (u) :

U_{mean} = U_2 = 177 km / day

Use table 2 (Table – 7 FAO), f (u) = 0.750

Step. 4 : Weighting Factor (w) :

$$\left.\begin{array}{l} T_{mean} = 24.9\ ^{\circ}C \\ \text{Altitude} = 500\ m \end{array}\right\} \text{Use table A-3 in Appendix A, } w = 0.749$$

Step. 5 : Net Radiation (Rn)

a) Extraterrestrial radiation (Ra)

$$\left.\begin{array}{l} \text{Latitude} = 5\ ^{\circ}C \\ \text{Month} = \text{January} \end{array}\right\} \text{Use table A-4 in Appendix A , Ra = 14.10 mm/day}$$

b) Solar radiation (Rs)

Rs = (0.29 + 0.52 n/N) Ra , where n/N = 0.45 , Ra = 14.10 mm/day

= (0.25 + 0.50 x 0.45) 14.10

= 6.698 mm / day

c) Net short wave radiation (Rns)

n/N = 0.45 , use Table A-5 in Appendix A

Rns = (1 - 0.25) Rs

= (1 – 0.25) 6.698

= 5.030 mm/day

d) Net long wave radiation (Rn1)

T_{mean} = 24.9 ^oC, use Table A-6 in Appendix A , f (T) = 15.625

ed = 25.838 m bar, use Table A-7 in Appendix A, f (u) = 0.12

n/N = 0.45, use table A- 8 in Appendix A, f(n/N) = 0.510

Rn1 = f(T) x f(ed) x f(n/N)

= 15.625 x 0.12 x 0.510

= 0.956 mm/day

Rn = Rns - Rn1

= 5.030 – 0.956

= 4.070 mm / day

Step. 6 : Adjustment factor (c)

U_{day}/U_{night} = 1

Uday = 1.5 m / sec , use Table 4.15 (Table – 16 FAO), C = 0.994

RHmax = 85 % (Interpolation same as Chapter 4.2.1,Step-7)

Rs = 6.707 mm/day

C = 0.994 from Table A-9 in Appendix A

Step.7 : Determination Of ETo

ETo = C (w x. Rn + (1 – w) x f(u) x (ea – ed))

= 0.994 (0.749 x 4.070 + (1 - 0.749) x (0.750) x (5.672)

= 4.088 mm / day

Eo = C (w x. Rn + (1 – w) x f(u) x (ea – ed))

= 0.994 (0.749 x 5.205 + (1 - 0.749) x (0.750) x (5.672)

= 4.933 mm / day

Similarly procedure has been used for calculations in other months as shown in Table 4.3. Meteorological variates as per General Model and as per FAO tables are summarized in Table 4.4 for January.

4.3. COMPARISON OF THE RESULTS

4.3.1 Percent Error in Estimation:

The results from modified Penman Method as per FAO tables were compared with those obtained from use of general model and it could be seen that evapotranspiration by using general model is similar to ETo obtained as per tables in FAO-24.

Extraterrestrial radiation (Ra) is the most important input variable. The comparison of Ra is shown in table 4.5. Percentage error with respect to FAO procedure ranges from 0.21% in September to 1.592% in December.

The comparison of the monthly ETo values are given in Table 4.6 Percentage error with respect to FAO procedure ranges from 0.310 % in December month to 8.791% in June month. Comparison of monthly Evaporation (Eo) values is shown in table 4.7. Percentage error in estimated Eo with respect to FAO procedure ranges from – 9.286% in August month to 5.672% in October month. It is important to note that percentage errors are less than 10% (small) in all months.

4.3.2 Model Accuracy

Maidment (1993) has given various parameters to test accuracy of a proposed model. These have been briefly explained in Chapter 3 section 3.6. Taking estimations as per FAO Procedure (Tables) to be reference values, the accuracy Parameters have been evaluated and are discussed below

4.3.2.1 Accuracy in estimation of extraterrestrial radiation :

Computation of various parameters is shown in table 4.8. Coefficient of determination R^2 is 0.9926. Bias (B) is only – 0.1226 and variance is 0.0029. Therefore estimation of extraterrestrial radiation can be considered to be accurate.

4.3.2.2 Accuracy in estimation of evapotranspiration (ETo) :

Computation of various parameters is shown in Table 4.9. Coefficient of determination R^2 is 0.9476. Bias (B) is – 0.2382% in month of June, which can be considered as acceptable being less then 10% (Maidtment 1993).

4.3.2.3 Accuracy in estimation of evaporation (Eo):

Computation of various parameters is shown in Table 4.10. Coefficient of determination is 0.8606. Bias (B) is 0.0392 and variance is 0.0565. Highest relative error is – 9.286% still within tolerable limit. Accuracy in estimation of evaporation is not as good as in estimation of evapotranspiration by the proposed general model.

It is necessary to Test the accuracy of the model under a variety of different climatic conditions before it can be recommended as an only general model. In the present study emphasis is on a general model applicable to Indonesia (10^0 N to 10^0 S latitude range).

Table 4.2 Estimation Evapotranspiration (ETo) by General Model
Place : Jambo Aye Project
Latitude : 5 ^{0} N
Altitude : 500 m

Month	ea m bar	ed m bar	D m bar	Dav m bar	we	wa	we_{rc}	wa_{rc}	Ra mm/day	Rs mm/day	Rns mm/day	Rnl mm/day	Rn mm/day	f1(u)	f2(u)	ETo mm/day	Eo mm/day
January	3.149	2.582	0.567	0.567	0.747	0.253	0.637	0.216	14.010	6.655	4.991	0.918	4.073	5.524	6.148	3.924	5.378
February	3.206	2.597	0.609	0.609	0.749	0.251	0.641	0.214	14.799	6.808	5.106	0.868	4.238	5.525	6.142	4.113	5.698
March	3.442	2.753	0.688	0.688	0.761	0.239	0.664	0.209	15.371	7.224	5.418	0.862	4.556	5.254	5.530	4.377	6.217
April	3.442	2.822	0.620	0.620	0.761	0.239	0.683	0.215	15.354	6.679	5.009	0.732	4.277	4.681	4.320	3.894	5.460
May	3.483	2.856	0.627	0.627	0.763	0.237	0.697	0.217	14.858	6.315	4.736	0.694	4.042	4.339	3.592	3.617	5.156
June	3.422	2.737	0.684	0.684	0.760	0.240	0.695	0.220	14.478	6.370	4.778	0.772	4.006	4.288	3.492	3.618	5.273
July	3.401	2.755	0.646	0.646	0.759	0.241	0.690	0.219	14.586	6.418	4.814	0.765	4.048	4.402	3.735	3.654	5.231
August	3.322	2.425	0.897	0.897	0.755	0.245	0.678	0.220	15.045	6.469	4.852	0.828	4.024	4.613	4.190	3.959	6.164
September	3.302	2.708	0.594	0.594	0.754	0.246	0.679	0.221	15.267	6.107	4.580	0.648	3.932	4.564	4.088	3.563	5.012
October	3.263	2.741	0.522	0.522	0.752	0.248	0.685	0.225	14.887	6.029	4.522	0.654	3.868	4.334	3.605	3.377	4.613
November	3.263	2.774	0.490	0.490	0.752	0.248	0.679	0.224	14.146	5.941	4.456	0.691	3.765	4.497	3.952	3.311	4.489
December	3.225	2.773	0.451	0.451	0.750	0.250	0.665	0.221	13.679	5.061	3.796	0.537	3.259	4.840	4.683	2.973	4.086

Table 4.3 Estimation Evapotranspiration (ETo) by Modified Penman using FAO-24 Tables

Place : Jambu Aye Project

Latitude : 5 ^{0}N

Altitude : 500 m

Month	ea m bar	ed m bar	D m bar	Dav m bar	we	Ra mm/day	Rs mm/day	Rns mm/day	Rnl mm/day	Rn mm/day	f(u)	ETo mm/day	Eo mm/day
January	31.510	25.838	5.672	5.672	0.749	14.100	6.698	5.076	0.956	4.120	0.748	4.125	4.933
February	32.080	25.985	6.095	6.095	0.752	14.900	7.575	5.185	0.904	4.281	0.748	4.408	5.767
March	34.500	27.600	6.900	6.900	0.764	15.450	8.015	5.500	0.895	4.605	0.540	4.499	5.964
April	34.440	28.241	6.199	6.199	0.764	15.450	7.453	5.068	0.748	4.320	0.540	4.134	5.515
May	3.483	2.856	0.627	0.627	0.763	14.858	6.315	4.736	0.694	4.042	4.339	3.617	5.256
June	3.422	2.737	0.684	0.684	0.760	14.478	6.370	4.778	0.772	4.006	4.288	3.618	5.264
July	3.401	2.755	0.646	0.646	0.759	14.586	6.418	4.814	0.765	4.048	4.402	3.654	5.256
August	3.322	2.425	0.897	0.897	0.755	15.045	6.469	4.852	0.828	4.024	4.613	3.959	5.640
September	3.302	2.708	0.594	0.594	0.754	15.267	6.107	4.580	0.648	3.932	4.564	3.563	5.021
October	3.263	2.741	0.522	0.522	0.752	14.887	6.029	4.522	0.654	3.868	4.334	3.377	4.890
November	3.263	2.774	0.490	0.490	0.752	14.146	5.941	4.456	0.691	3.765	4.497	3.311	4.741
December	3.225	2.773	0.451	0.451	0.750	13.679	5.061	3.796	0.537	3.259	4.840	2.973	4.058

Table 4.4 : Comparison of Meteorological Variates for January Month as per FAO tables and General Model

Item	As per Tables in FAO-24		As per General Model	
	Values	unit	Values	unit
ea	31.510	mb	3.149	kpa
ed	25.838	mb	2.582	kpa
(ea - ed)	5.672	mb	0.567	kpa
U2	177.000	km/day	2.049	m/sec
f1(u)	0.748		5.524	
f2(u)	-		6.148	
we (for open water surface)	-		0.747	
wa (for open water surface)	-		0.253	
we (for reference crop)	0.749		0.637	
wa (for reference crop)	-		0.216	
Ra	14.100	mm/day	14.010	mm/day
Rs	6.698	mm/day	6.655	mm/day
Rns	5.076	mm/day	4.991	mm/day
Rnl	0.956	mm/day	0.918	mm/day
Rn	4.120	mm/day	4.073	mm/day
c	0.994		1.000	
ETo	4.125	mm/day	3.924	mm/day
Eo	4.933	mm/day	5.378	mm/day

Table 4.5 : Comparison of (Ra) by FAO Tables and General Model

No No	Month	Calculation Extraterrastrial Radiation (Ra) in mm/day		
		As per FAO Tables	As per General Model	Relative error (%)
1	January	14.100	14.010	0.639
2	February	14.900	14 799	0.678
3	March	15.450	15.371	0.514
4	April	15.450	15.354	0.624
5	May	15.000	14.858	0.948
6	June	14.550	14.478	0.495
7	July	14.750	14.586	1.109
8	August	15.150	15.045	0.695
9	September	15.300	15.267	0.216
10	October	15.050	14.887	1.081
11	November	14.350	14.146	1.424
12	December	13.900	13.679	1.592

Table 4.6 : Comparison of ETo by FAO-24 tables and General Model

No	Month	Calculation Evapotranspiration (ETo) in mm/day		
		As per FAO-24 tables	As per General Model	Relative Error (%)
1	January	4.125	3.924	4.875
2	February	4.408	4.113	6.683
3	March	4.499	4.377	2.721
4	April	4.134	3.894	5.802
5	May	3.940	3.617	8.207
6	June	3.966	3.618	8.791
7	July	3.970	3.654	7.964
8	August	4.311	3.959	8.173
9	September	3.748	3.563	4.942
10	October	3.633	3.377	7.059
11	November	3.520	3.311	5.922
12	December	2.983	2.973	0.310

Table 4.7 : Comparison of Eo by As per FAO-24 tables and General Model

No	Month	Calculation Evaporation (Eo) in mm/day		
		As per FAO-24 tables	As per General Model	Relative Error (%)
1	January	4.933	5.378	-9.029
2	February	5.767	5.698	1.191
3	March	5.964	6.217	-4.243
4	April	5.515	5.460	1.007
5	May	5.256	5.156	1.898
6	June	5.264	5.273	-0.176
7	July	5.256	5.231	0.471
8	August	5.640	6.164	-9.286
9	September	5.021	5.012	0.195
10	October	4.890	4.613	5.672
11	November	4.741	4.489	5.333
12	December	4.058	4.086	-0.670

TABLE 4.8 ACCURACY IN ESTIMATION OF EXTRATERESTRIAL RADIATION BY GENERAL MODEL

No	Month	Values of Ra in mm/day		$(Q_f - Q_r)$	$(Q_f - Q_r)^2$	$Q_f \times Q_r$	$Q_r^2 - M_r^2$	$Q_f^2 - M_f^2$	Relative Error (%)
		As per FAO Tables (Q_r)	As per General Model (Q_f)						
1	January	14.100	14.010	-0.090	0.008	197.540	-21.094	-20.004	0.639
2	February	14.900	14.799	-0.101	0.010	220.505	2.106	2.728	0.678
3	March	15.450	15.371	-0.079	0.006	237.476	18.798	19.973	0.514
4	April	15.450	15.354	-0.096	0.009	237.212	18.798	19.449	0.624
5	May	15.000	14.858	-0.142	0.020	222.867	5.096	4.472	0.948
6	June	14.550	14.478	-0.072	0.005	210.654	-8.202	-6.673	0.495
7	July	14.750	14.586	-0.164	0.027	215.149	-2.342	-3.520	1.109
8	August	15.150	15.045	-0.105	0.011	227.928	9.618	10.061	0.695
9	September	15.300	15.267	-0.033	0.001	233.585	14.186	16.798	0.216
10	October	15.050	14.887	-0.163	0.026	224.054	6.598	5.349	1.081
11	November	14.350	14.146	-0.204	0.042	202.99[illegible]	-13.982	-16.183	1.424
12	December	13.900	13.679	-0.221	0.049	190.135	-26.694	-29.174	1.592
	TOTAL	177.950	176.479	-1.471	0.215	2620.096	2.887	3.275	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 14.8292

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 14.7066

Bias :

$$B = M_f - M_r$$

= -0.1226

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_r(i)\right]^2$$

= 0.0180

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.1340

Variance :

$$V = MSE - B^2$$

= 0.0029

Relative Bias :

$$RB = \frac{B}{M_r}$$

= -0.0083

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum \left|Q_f(i) - Q_r(i)\right|$$

= 0.1226

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

0.0083

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.9926

TABLE 4.9 ACCURACY IN ESTIMATION OF EVAPOTRANSPIRATION (ETo) BY GENERAL MODEL

No	Month	Values of ETo in mm/day As per FAO Tables (Q_r)	 As per General Model (Q_f)	(Q_f - Q_r)	$(Q_f - Q_r)^2$	$Q_f Q_r$	Q_r^2-M_r^2	Q_f^2-M_f^2	Relative Erro (%)
1	January	4.125	3.924	-0.201	0.040	16.184	1.518	1.717	4.875
2	February	4.408	4.113	-0.295	0.087	18.130	3.932	3.241	6.683
3	March	4.499	4.377	-0.122	0.015	19.694	4.749	5.481	2.721
4	April	4.134	3.894	-0.240	0.058	16.098	1.594	1.486	5.802
5	May	3.940	3.617	-0.323	0.105	14.250	0.028	-0.597	8.207
6	June	3.966	3.618	-0.349	0.122	14.350	0.237	-0.589	8.791
7	July	3.970	3.654	-0.316	0.100	14.508	0.268	-0.325	7.964
8	August	4.311	3.959	-0.352	0.124	17.070	3.093	1.997	8.173
9	September	3.748	3.563	-0.185	0.034	13.353	-1.449	-0.984	4.942
10	October	3.633	3.377	-0.256	0.066	12.267	-2.297	-2.276	7.059
11	November	3.520	3.311	-0.208	0.043	11.655	-3.107	-2.712	5.922
12	December	2.983	2.973	-0.009	0.000	8.869	-6.599	-4.836	0.310
	TOTAL	47.2374	44.3795	-2.8579	0.7936	176.4259	1.9672	1.6021	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 3.9365

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 3.6983

Bias :

$$B = M_f - M_r$$

= -0.2382

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n} \left[Q_f(i) - Q_r(i)\right]^2$$

= 0.0661

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.2572

Variance :

$$V = MSE - B^2$$

= 0.0094

Relative Bias :

$$RB = \frac{B}{M_r}$$

= -0.0605

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum \left|Q_f(i) - Q_r(i)\right|$$

= 0.2382

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

= 0.0605

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.9476

TABLE 4.10 ACCURACY IN ESTIMATION OF EVAPORATION (Eo) BY GENERAL MODEL

No	Month	Values of Eo in mm/day As per FAO Tables (Q_r)	Values of Eo in mm/day As per General Model (Q_f)	$(Q_f - Q_r)$	$(Q_f - Q_r)^2$	$Q_f\,Q_r$	Q_r^2-M_r^2	Q_f^2-M_f^2	Relative Error (%)
1	January	4.933	5.378	0.445	0.198	26.530	-2.626	1.558	-9.029
2	February	5.767	5.698	-0.069	0.005	32.863	6.300	5.105	1.191
3	March	5.964	6.217	0.253	0.064	37.082	8.613	11.288	-4.243
4	April	5.515	5.460	-0.056	0.003	30.113	3.460	2.443	1.007
5	May	5.256	5.156	-0.100	0.010	27.098	0.663	-0.783	1.898
6	June	5.264	5.273	0.009	0.000	27.761	0.753	0.442	-0.176
7	July	5.256	5.231	-0.025	0.001	27.495	0.666	-0.002	0.471
8	August	5.640	6.164	0.524	0.274	34.762	4.849	10.622	-9.286
9	September	5.021	5.012	-0.010	0.000	25.165	-1.745	-2.252	0.195
10	October	4.890	4.613	-0.277	0.077	22.558	-3.045	-6.089	5.672
11	November	4.741	4.489	-0.253	0.064	21.282	-4.478	-7.220	5.333
12	December	4.058	4.086	0.027	0.001	16.580	-10.489	-10.676	-0.670
	TOTAL	62.3067	62.7766	0.4699	0.6968	329.2892	2.9212	4.4361	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 5.1922

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 5.2314

Bias :

$$B = M_f - M_r$$

= 0.0392

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_r(i)\right]^2$$

= 0.0581

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.2410

Variance :

$$V = MSE - B^2$$

= 0.0565

Relative Bias :

$$RB = \frac{B}{M_r}$$

= 0.0075

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum \left|Q_f(i) - Q_r(i)\right|$$

= 0.0392

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

= 0.0075

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.8606

TABLE 4.11 ACCURACY IN ESTIMATION EXTRATERESTRIAL RADIATION BY SIMPLIFIED MODEL

No	Month	Values of Ra in mm/day As per FAO Tables (Q_r)	Values of Ra in mm/day As per Simplified Model (Q_f)	($Q_f - Q_r$)	($Q_f - Q_r$)^2	$Q_f\ Q_r$	Q_r^2-M_r^2	Q_f^2-M_f^2	Relative Error (%)
1	January	14.100	14.117	0.017	0.000	199.050	-21.094	-20.533	-0.121
2	February	14.900	14.883	-0.017	0.000	221.761	2.106	1.690	0.112
3	March	15.450	15.467	0.017	0.000	238.957	18.798	19.390	-0.107
4	April	15.450	15.467	0.017	0.000	238.961	18.798	19.396	-0.108
5	May	15.000	14.967	-0.034	0.001	224.498	5.096	4.173	0.223
6	June	14.550	14.584	0.033	0.001	212.190	-8.202	-7.144	-0.230
7	July	14.750	14.717	-0.034	0.001	217.068	-2.342	-3.247	0.227
8	August	15.150	15.151	0.000	0.000	229.530	9.618	9.715	-0.003
9	September	15.300	15.300	0.000	0.000	234.090	14.186	14.267	0.000
10	October	15.050	15.050	-0.001	0.000	226.495	6.598	6.665	0.003
11	November	14.350	14.350	0.000	0.000	205.923	-13.982	-13.900	0.000
12	December	13.900	13.867	-0.033	0.001	192.751	-26.694	-27.529	0.237
	TOTAL	177.9500	177.9170	-0.0330	0.0056	2641.2735	2.8873	2.9434	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 14.8292

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 14.8264

Bias :

$$B = M_f - M_r$$

= -0.0028

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_r(i)\right]^2$$

= 0.0005

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.0216

Variance :

$$V = MSE - B^2$$

= 0.0005

Relative Bias :

$$RB = \frac{B}{M_r}$$

= -0.0002

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum\left|Q_f(i) - Q_r(i)\right|$$

= 0.0028

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

= 0.0002

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.9982

CHAPTER 5

SIMPLIFIED MODEL FOR EVAPOTRANSPIRATION

5.1 INTRODUCTION

A general model for estimation of open water evaporation and evapotranspiration was discussed in previous chapter as an alternative to the modified Penman Method given by Doorenbos and Pruitt (1977). Radiation, temperature and wind speed are the important climate variables influencing evaporation and evapotranspiration rates. In Indonesia, climate variables occur in specific limited range. Therefore an attempt has been made to further simplify the procedure by developing appropriate regression equations.

5.2 RANGE OF CLIMATE VARIATION

5.2.1 Climatic Variation Over Entire Country

Indonesia lies just north and south of the equator. The latitude range is between 10^0S to 10^0N and maximum altitude of the irrigated agriculture is around 2000 m above mean sea level.

The climate is tropical with medium to high rainfall. It may range from 1000 to 5000 mm in a year. The mean daily temperature in the warmest and the coldest months is only about 30^0C to 20^0C of the daytime. Temperature decreases with increasing altitude at about the rate of 1^0C per 200 m. Also temperature becomes somewhat high in the city areas.

The mean daily actual sunshine hours vary from about 30 % to 80 % of the maximum possible sunshine hours. Wind velocity varies up to the maximum wind speed of about 500 km/day. The wind velocity becomes somewhat less in the inland areas. The ratio of day and night time wind velocity varies from 1 to 3 and day time wind may be maximum about 6 m/sec.

5.2.2. Climatic Variation Over Aceh Province

Meteorological data for five stations in Aceh Province shows geographic variation and monthly variation as discussed below.

Rainfall: Table 5.1, give mean monthly values of rainfall. Takengon being located at 1250 m altitude compared to other from rainfall stations in coastal region receives higher rainfall. Fig. 5.1, shows graphical comparison of monthly rainfalls. Monthly rainfall in coastal region ranges from 50 mm to 100 mm in June and 200 to 364 mm in December.

Temperature: Table 5.2, gives mean monthly temperature. Fig. 5.2, shows comparison of temperature and variation from month to month. Temperature is an important climate variable. Variation in mean monthly temperature is in a limited range between 25 ^{0}C to less than 28 ^{0}C in the coastal region. Temperature varies between 20.5 ^{0}C to 19 ^{0}C. Therefore in the present study a range of 20 ^{0}C to 30 ^{0}C has been considered.

Relative Humidity: Relative Humidity varies in the range of 70 to 90 % at all the five stations and over all months except in May and July at Lhokseumawe, which does not appear to be realistic. Table 5.3, and Fig. 5.3, shows the variation in relative humidity.

Wind Run: Table 5.4, and Figure. 5.4, show the variation in mean monthly values of wind run. The range of variation is 50 to 250 km/day in Aceh Province

5.3 PROPOSED SIMPLIFIED MODEL

The Penman Method equation as modified by Doorenbos and Pruitt (1977) is

$$ETo = c\,[\,w \times Rn + (1 - w)\,.\,f(u)\,.\,(ea - ed)\,]$$

5.3.1 Adjustment Factor (c)

It is dimensionless. It is required to compensate for effect of day and night weather conditions characterized by ratio of day and night wind speed (U_{day} / U_{night}), day time wind speed at 2 m height (U2) in m / second, maximum relative humidity RH_{max} (%) and solar radiation Rs measured in equivalent water depth of evaporation per day (mm/day) . If is proposed to develop:

$$c = fn(U) \quad \text{for } U \leq 6 \text{ m / sec}$$

for specific values of RH_{max} , (U_{day}/U_{night}) and R_s which are found to vary in limited range .

5.3.2 Weighting Factor (w)

It is dimensionless. Basically it depends on rate of variation of saturation vapour pressure with temperature, atmospheric pressure and latent heat of vaporization. Study of interrelation among the variables in previous chapter shows that w can be related with altitude (Z) in meter and mean air temperature (T_{mean}) in ^{0}C. Since variation in T_{mean} is 20 ^{0}C to 30^0 C in Indonesia, w has been related with Z for different values of T_{mean}.

5.3.3 Extraterrestrial Radiation (Ra)

Ra in mm/day depends on latitude (Ø) and calendar day. Since in the present study, monthly. ETo and Eo are being analyzed. Ra is related to Latitude in degrees for different months.

5.3.4 Net Long wave Radiation (R_{nl})

R_{nl} (mm/day) depends on T_{mean}, ratio of actual to max possible sunshine hours averaged for the month (n/N) and actual vapour pressure (e_d) in milli bar unit ed is a function of RH and T_{mean}. Since RH and T_{mean} vary in limited range in Indonesia and particularly in Aceh Province, e_d also varies in limited range. Therefore R_{nl} has been related to n/N for specific combination of mean and e_d.

Since ed is already computed, and T_{mean} is input data, it is easy to estimate R_{nl} form relation between R_{nl} and (T_{mean}, e_d).

Graphical linear regression analysis for above mentioned terms c, w, R_a, R_{ne}, have been carried out using data from tables in FAO publication (Doorenbos & Pruitt 1977). Linear equations are found to be best fits.

5.4 RELATION BETWEEN WEIGHING FACTOR (w) AND TEMPERATURE

$$w = \frac{(dea/dT)}{(dea/dT)+\gamma} = \frac{\Delta}{\Delta+\gamma} = \frac{1}{1+\frac{\gamma}{\Delta}}$$

$$\Delta = \frac{(40.454ea)}{(237.3+T)^2}$$

$$\gamma = \frac{0.386.P}{L}$$

$$P = 1013 - 0.1055.Z$$

$$L = 595 - 0.51\ T$$

$$\therefore \gamma = \frac{0.386*[1013-0.1055.Z]}{595-0.51.T} = \frac{391.018-0.0407.Z}{595-0.51T}$$

where :

Z : Elevation in meter

P : atmospheric pressure in mbar

L : Latent heat vaporization calorie / gram

γ : Phychrometer constant in unit of Δ

Therefore w is a function of altitude (Z) and mean temperature T. It is a complicated function of T. For different values of T as a parameter, relation between w and Z was attempted. It is found that relationship is linear. In Indonesia, mean temperature varies from 20^0C to 30^0C and altitude range is 0 to 2000 m. In this range following linear relations have been developed as shows in Table 5.5. Figure 5.5 shows that for most accurate estimation of w for given altitude two different linear relationships can be used in the range of 0 to 1000 m altitude and 1000 m to 2000 m altitude.

Tables 5.5 Relation of Temperature between Weighing Factor

Temperature in ^{0}C	Weighing Factor in %
T = 20	w = 0.002410.Z + 68.270
T = 21	w = 0.002350.Z + 69.420
T = 22	w = 0.002900.Z + 70.540
T = 23	w = 0.002250.Z + 70.610
T = 24	w = 0.002190.Z + 72.650
T = 25	w = 0.002130.Z + 73.670
T = 26	w = 0.002080.Z + 74.640
T = 27	w = 0.002020.Z + 75.595
T = 28	w = 0.001965.Z + 76.515
T = 29	w = 0.001905.Z + 77.405
T = 30	w = 0.00185.Z + 78.260

5.5 RELATION BETWEEN EXTRATERRESTRIAL RADIATION AND LATITUDE

Entire Indonesia lies between 10^0 N latitude and 10^0 S latitude. Extraterrestrial radiation Ra in mm/day depends on latitude and months. Regression analysis shows that linear equations can be fitted between Ra and latitude (Ø in degrees) for different months and separately for Northern hemisphere (Northern latitudes) and for Southern hemisphere (Southern latitudes). Figures 5.6. to 5.8. show linear variation of Ra with northern latitude in different months. Figures 5.9. to 5.11. show variation of Ra with southern latitude in different months. The expression is:

$$Ra = A + B . \emptyset$$

Ø is latitude in degrees.

Best fit coefficient are shown in Table 5.6.

Table 5.6 Best-Fit Coefficients for Linear Relation between Ra and Latitude

Month	Northern hemisphere		Southern hemisphere	
	A	B	A	B
January	15.0238	-0.18143	14.9905	0.1386
February	15.5333	-0.13000	15.5143	0.0771
March	15.6809	-0.0429	15.7143	-0.0229
April	15.2667	0.0400	15.3238	-0.1114
May	14.4095	0.1114	14.4143	-0.1629
June	13.8905	0.1386	13.9095	-0.1886
July	14.0952	0.1243	14.0762	-0.1686
August	14.7857	0.0729	14.7905	-0.1314
September	15.3000	0.0000	15.3000	-0.0500
October	15.4143	-0.0726	15.4000	0.0500
November	15.1000	-0.1500	15.0857	0.1128
December	14.8129	-0.1890	14.8190	0.1428

For maximum Possible Sunshine Hours following relationship as given in Chapter 4 is recommended

$$N = \frac{24}{\pi}.ws \text{ in hours}$$

Where ws is the sunset hour angle (radians)

5.6 RELATION BETWEEN NETLONGWAVE RADIATION AND SUNSHINE HOUR

$$Rnl = 2.0 \times 10^{-9} \times (Tk)^4 \times (0.1 + 0.9.n/N) \times (0.34 - 0.14\sqrt{ed})$$

$$= f(T) \times f(n/N) \times f(ed)$$

Since ed is a function of T & RH and for a given latitude (Ø), N depends on month only; Rnl can be expressed as a fn of T, RH, n, Ø and average day (δ) of month as given in table 4.2 of chapter 4.

Alternately Rnl can be expressed as fn. of Rh, T and n/N. Since variation in T is only in the range of 20^0C to 30^0C and Rn varies in the range 60 to 90 %, these can be used as a parameter and relation between Rnl and n/N can be attempted. Temperature and relative humidity affect actual vapour pressure. Since actual vapour pressure computation is required to find vapour pressure deficit therefore here Rnl is made a fn of T, n/N, and ed in this study

$$Rnl = A + B.n/N$$

Best fit coefficients are shown in table 5.7

Table 5.7 Linear Regression between (n/N) and Rnl. Expressed ; Rnl = A + B (n/N)

ed / T	20 m bar		22 mbar		24 mbar		26 mbar		28mbar		30 mbar	
	A	B	A	B	A	B	A	B	A	B	A	B
20	0.2110	1.9000	0.1975	17732	0.1828	1.6509	0.1710	1.5330	0.577	1.4224	0.1459	1.3148
22	0.2166	1.9528	0.2030	1.8225	0.1879	1.6968	0.1757	1.5756	0.1621	1.4620	0.1500	1.3514
24	0.2225	2.0057	0.2085	1.8719	0.1929	1.7427	0.1805	1.6182	0.1665	1.5015	0.1540	1.3860
26	0.2285	2.0598	0.2141	1.9224	0.1982	1.7898	0.1854	1.6619	0.1710	1.5421	0.1582	1.4254
28	0.2348	2.1165	0.2200	1.9753	0.2036	1.8390	0.1905	1.7077	0.1757	1.5845	0.1626	1.4647
30	0.241	2.1733	0.2259	2.0283	0.2091	1.8883	0.1956	1.7534	0.1669	1.5039	0.1669	1.5039

5.7 ESTIMATION OF ADJUSTMENT FACTOR (C)

Adjustment factor c depends on Rs, RH_{max}, U_{day} and ratio U_{day}/U_{night}. Value of c increases with increases in value of Rs, RH_{max}, and ratio U_{day}/U_{night} but decreases with increases in U_{day}.

In Aceh Province Rh varies from 80 % to 90 %. Radiation Rs varies between 5 to 8 mm/day ratio U_{day} / U_{night} is nearly one. Max wind speed is 275 km / day (~ 3 m / sec).

Keeping in view the above-mentioned information following linear relationships can be adopted for Aceh Province. It is assumed that Rhmax is in range 60% to 90%, $U_{day}/U_{night} = 1$, and Uday varies for 0 to 6 m/sec.

Different linear relations exist between C and U_{day} for U_{day} range from 0 to 6 m/sec and from 6 to 9 m/sec as seen in figures 5.12 and figure 5.13. For accurate estimation of C these different relations can be used depending on value of U_{day}.

for Rs = 3 mm/day

$c = 1.02 - 0.0567\ U_{day}$, RHmax = 90%

$c = 0.9567 - 0.05674\ U_{day}$ RHmax = 60%

for Rs = 6 mm / day

$c = 1.06 - 0.0467\ U_{day}$ RHmax = 90%

$c = 0.98 - 0.04\ U_{day}$ RHmax = 60%

for Rs = 9 mm / day

$c = 1.100 - 0.030\ U_{day}$ RHmax = 90%

$c = 1.0483 - 0.035\ U_{day}$ RHmax = 60%

for Rs = 12 mm / day

$c = 1.098 - 0.0157\ U_{day}$ RHmax = 90%

$c = 1.05 - 0.02\ U_{day}$ RHmax = 60%

5.8 SIMPLIFIED MODEL

Table 5.8. Computation Steps of ETo and Eo

Step	Input	Equation
I	Elevation (Z) in meter	w = A + B.Z
II	Latitude (Ø) in degrees & month	Ra = A + B.Ø, get A, B from table 4.2 $N = \frac{24}{\pi} * ws$
III	Actual Sunshine hours n	Rs = [0.25 cos Ø + 0.5 x n/N] x Ra
IV	Reflection coefficient (K) = 0.25 for most crop and = 0.08 for water	Rns = (1 – K). Rs
V	T mean (^{0}C) and RH %	
VI	T_{mean} and Computed ed	ea = 6.11 exp [17.27 T / 237.3+T] ed = ea x RH / 100 Rnl = A + B.n/N, get A, B from table 5.3 for specific T, ed Rn = Rns – Rnl
VII	Wind speed U2 (m/sec)	f(u) = a (b + c.U2)
VIII	For $U_{day}/U_{night} = 1$ $U_{day} < 6$ m/sec Computed Rs <12 mm/day Rhmax 60 to 90%	Adjusment factor C = A + B.U
IX	Computed ETo & Eo	ETo = c [w.Rn + (1 – w).f_1(u).(ea – ed)] Eo = c [w.Rn + (1 – w).f_2(u).(ea – ed)]

5.9 APPLICATION STUDY OF SIMPLIFIED MODEL

Jambo Aye Irrigation Project

Given data:

Latitude (Ø) = 5 ^{0}N
Elevation (Z) = 500 meter
Month = January
Tmean = 24.9 ^{0}C
Rhmean = 82 %
Rhmax = 85 %
U_{day} = 1.5 m/sec
U_{day}/U_{night} = 1
n/N = 0.45

Step 1. For Z = 500 m, T = 24.9 ^{0}C

We need interpolation value of w between 24 ^{0}C and 25^{0}C so that, we get as follow:

at T = 24 ^{0}C
w (%) = 0.00213 x Z + 72.72
= 0.00213 x 500 + 72.72
= 73.78 %

at T = 25 ^{0}C
w (%) = 0.00213 x Z + 73.73
= 0.00213 x 500 + 73.73
= 74.765 %

at T = 24.9 ^{0}C
w (%) = (((24.9 – 24) / (25 – 24)) x (74.765 - 73.765)) + 73.78
= 74.667 %

and (1 – w) = 0.2533

Step 2. For Ø = 5 ^{0}N & January month

Ra = -0.1814 Ø + 15.024
= 14.117 mm/day

since n/N is given so N is not computed

Step 3. For Ø = 5 ^{0}N, n/N = 0.45 and computed Ra =14.117

Rs = (0.25 cos Ø + 0.50 .n/N). Ra

= 6.6921 mm/day

Step 4 . For rice crop = 0.25

Rns = (1 – α) x Rs

= 5.0191 mm/day

For surface water α = 0.08

Rns = (1 – α) x Rs

= 6.160 mm/day

Step 5 . For Tmean = 24.9^{0}C and Rhmean = 82 %

ea = 6.11 exp ((17.27 x T) / (237.3 + T)

= 31.5 m bar, and

ed = ea x RH / 100

= 25.83 m bar, and

(ea – ed) = 31.50 – 25.83

= 5.67 m bar

Step 6. For Tmean = 24.9^{0}C and Computed ed = 25.83 m bar and n/N = 0.45

Rnl = A + B.n/N

To determine value of Rnl we have to interpolation between t = 24 ^{0}C and 26 ^{0}C

Rnl (T = 24, ed = 26) = 0.1805 + 1.6182.n/N

= 0.9087 mm/day

Rnl (T = 26, ed = 26) = 0.1854 + 1.6619.n/N

= 0.9333 mm/day

so the value of

Rnl = 0.9087 + ((24.9 – 24) / (26 – 24)) x (0.9333 - 0.9087)

= 0.9197 mm/day

Rn = Rns – Rnl

= 4.0994 mm/day

Step 7 For U2 = 177 km/day or 2.0486 m/sec

f(u) = a7(a8 + a9 x U2)

= 0.27 (1 + 0.01 x 117)

= 0.7479

Step 8 Adjustment Factor (c)

Here RHmax = 85 %; Rs = 6.6921 mm/day; U_{day}/U_{night} = 1 and U_{day} = 1.5 m/sec

For Rhmax = 90%, C = 1.0692-0.0428 x U_{day}

= 1.005

For Rhmax = 60%, C = 0.9958-0.0388 x U_{day}

= 0.9375

So, Adjustment factor (C) for Rhmax = 85% is

C = 0.9375 + (25/30 x (1.005 – 0.9375))

= 0.9938

Step 9 . ETo computation

ETo = c [w x Rn + (1 – w). f_1(u).(ea-ed)]

= 0.9938 x [(0.74667 x 4.0994) + (0.2533 x 0.7479 x 5.67)]

= 4.1094 mm/day

Eo = c [w x Rn + (1 – w) .f_2(u). (ea-ed)]

= 0.9938 x [(0.74667 x 5.237) + (0.2533 x 0.7479 x 5.67)]

= 4.9535 mm/day

Similar computations were made for other months and estimated reference crop potential evapotranspiration using the simplified model is shown in table 5.9. Potential evapotranspiration and evaporation using Modified Penman method and FAO Tables as given in Doorenbos and Pruitt (1977) have already been estimated in chapter 4 for Jambo Aye Project. Meteorological variates for January month as per simplified model and as per FAO tables are summary rise in table 5.10

5.10 COMPARISON OF SIMPLIFIED MODEL WITH GENERALL MODEL AND FAO PROCEDURE

5.10.1 Extraterrestrial Radiation (Ra)

As already discussed in chapter 4, Ra is the most important input variable. Accuracy in estimation of Ra with reference to estimated Ra by FAO Procedure is analyzed by computation of several accuracy parameters as shown in table 5.11

Percentage error range from 0.000% in November to 0.227% in July Compared to Ra estimation by general model (Table 4.8 in chapter 4), the error is greatly reduced. Similarly coefficient of determination R^2 is higher, bias (B) and variance V are less.

	Simplified Model (Table 5.11)	General Model (Table 4.8)
% error in Ra	0.000 to 0.227	0.216% to 1.592%
Bias (B) in Ra	- 0.0028	- 0.1226
Variance in Ra	0.0005	0.0029
Coeff. of determination in Ra	0.9982	0.9926

It is therefore recommended that linear regression between Ra and Latitude for different months can be used instead of complicated nonlinear sinusoidal relation in General Model.

Table 5.12 shows accuracy of terms of various parameters. General model is applicable for complete range of Latitude.

5.10.2 Accuracy in Estimation of ETo

Table 5.13 shows computation of accuracy parameters of simplified model with reference to the FAO Procedure. Table 5.14 shows comparison of simplified model with reference to general model. Accuracy parameters of simplified model and general model with reference to FAO procedure are compared below:

	Simplified Model (Table 5.13)	General Model (Table 4.9)
% error in ETo	- 3.651 to 2.013	0.310% to 8.791%
Bias (B) in Eto	- 0.0098	- 0.2382
Variance in ETo	0.0041	0.0094
Coeff of determination in ETo	0.9771	0.9476

It is clear that simplified model performs better than the general model. Performance of simplified model with reference to general model (Table 5.14) is also satisfactory as.

5.9.3 Accuracy in estimation of Evaporation (Eo)

Table 5.15 shows computation of accuracy parameters of simplified model with reference to FAO Procedure. Table 5.16 shows comparison of simplified model with reference to general model. The accuracy parameters of simplified model and general model with reference to FAO Procedure are compared below:

	Simplified Model (Table 5.13)	General Model (Table 4.9)
% error in Eo	- 0.419% to 11.274%	- 9.286% to 5.672%
Bias (B) in Eo	- 0.4643	0.0392
Variance in Eo	0.0233	0.0565
Coeff of determination in Eo	0.9045	0.8606

Performance of simplified model and general model are satisfactory. Simplified model seems to be more accurate then the general model. Simplified model is able to provide better accuracy as it has been develop specifically for limited range of variation in meteorological parameters; a typical characteristic for Indonesia region. It is not applicable for other regions. Generalized model is applicable for all possible ranges of meteorological parameters. Accuracy has therefore been compromised in consideration of general application.

Table 5.1 Mean Monthly Rainfall (mm) in Aceh Province

Location	Rainfall (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Biang Bintang	284	103	90	73	152	89	111	152	192	235	257	364
Lhokseumawe	229	144	146	137	83	41	47	49	69	122	233	256
Takengon	207	241	306	326	245	162	242	164	334	403	364	290
Pulo lele	172	103	141	109	125	76	69	70	115	173	216	211
Maulaboh	200	58	75	99	124	87	73	91	110	163	190	261

Figure 5.1 Mean monthly Rainfall of in Aceh Province, Indonesia

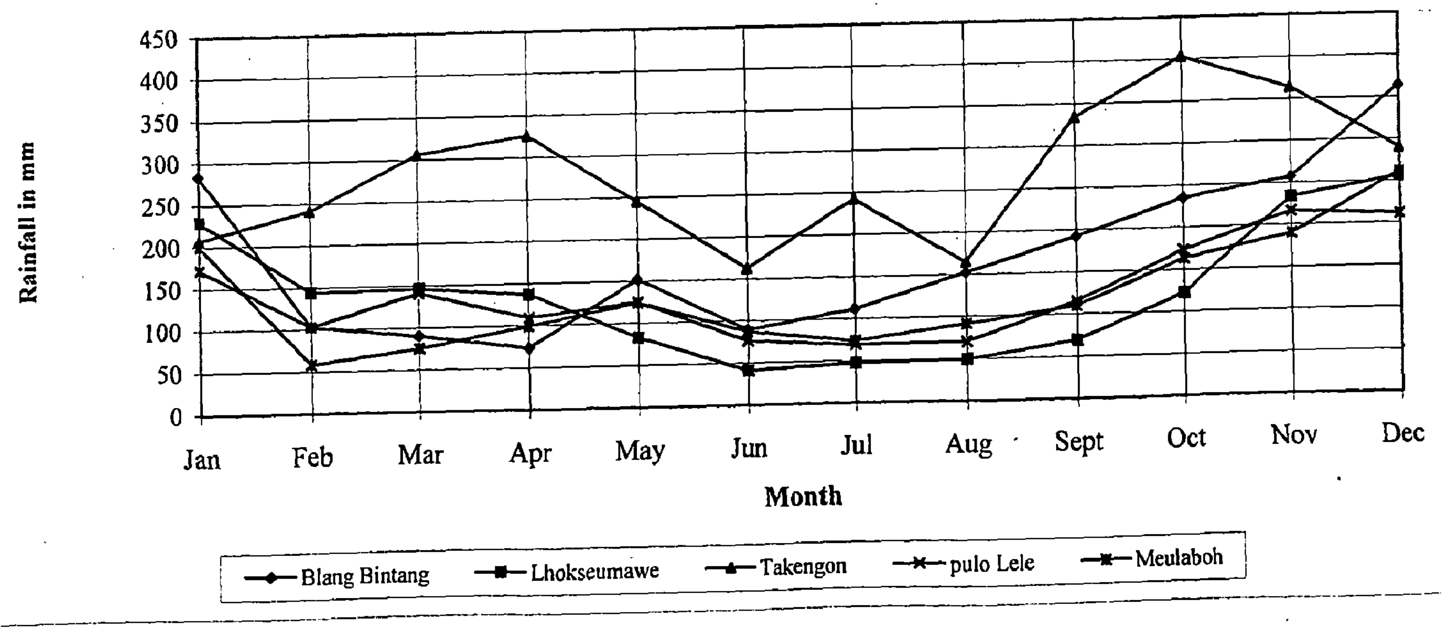


Table 5.2 Mean Monthly Air Temperature (0 C) in Aceh Province

Location	Temperature (^{0} C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Biang Bintang	25.6	25.8	26.3	26.6	26.8	27.4	26.9	27.3	26.44	26	25.8	25.4
Lhokseumawe	24.9	25.2	26.4	26.4	26.6	26.3	26.2	25.8	25.7	25.5	25.5	25.3
Takengon	19.5	19.5	20	20.1	20.3	19.5	19.2	19.2	19.4	19.6	20.1	19.5
Pulo lele	25.7	26	25.9	25.7	25.9	25.9	25.2	25.7	25.3	25.8	25.7	25.8
Maulaboh	25.8	26.1	25.9	26	25.8	25.8	25.4	25.4	25.2	25.3	25.6	25.2

Figure 5.2 : Mean monthly Air Temperature of in Aceh Province, Indonesia

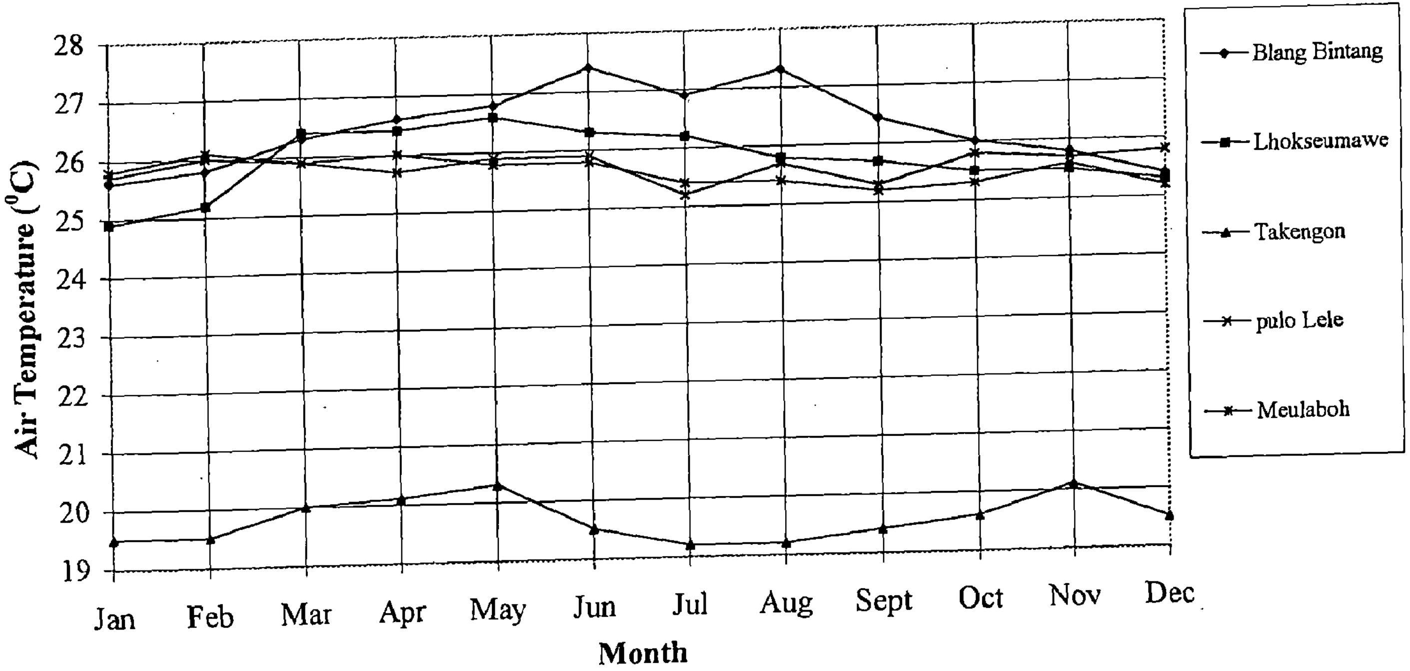


Table 5.3 Mean Monthly Relative Humidity (%) in Aceh Province

Location Station	Mean Relative Humidity (%)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Biang Bintang	80	82	81	82	80	73	73	70	76	82	83	84
Lhokseumawe	82	81	80	82	32	80	31	73	82	84	85	86
Takengon	76	79	78	81	84	79	77	75	80	86	78	78
Pulo lele	88	88	88	89	89	87	88	88	88	89	89	88
Maulaboh	84	84	84	85	86	82	83	84	85	85	86	85

Figure 5.3 : Mean monthly Air Relative Humidity in Aceh Province,Indonesia

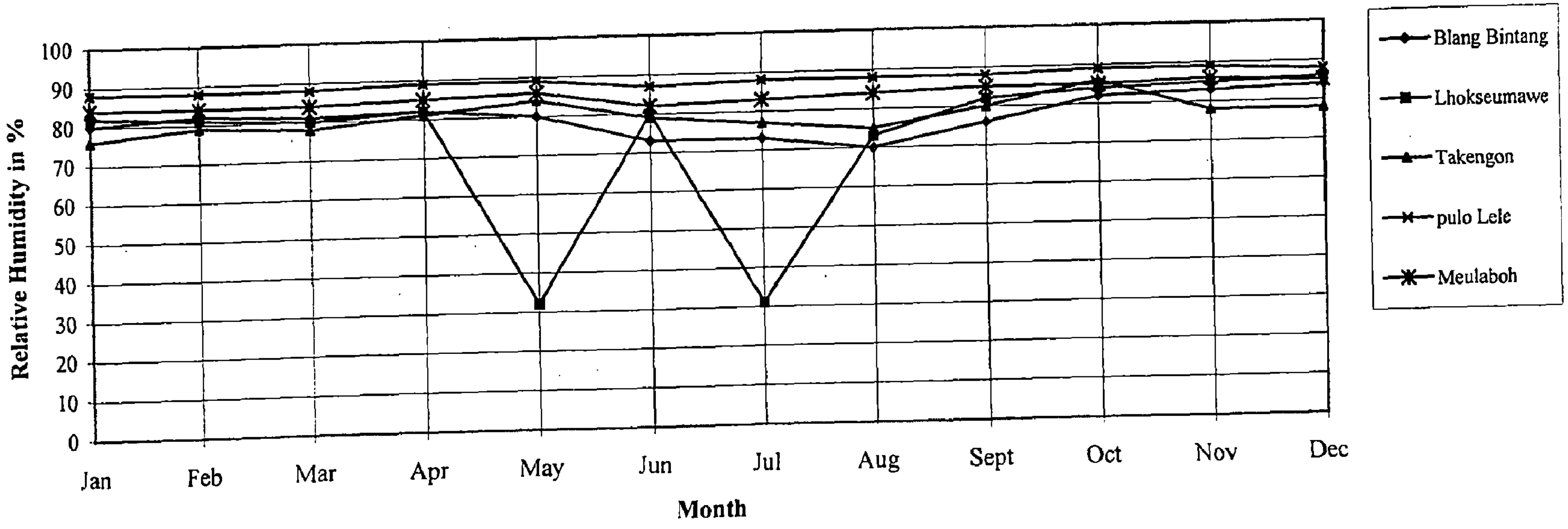


Table 5.4. Mean Monthly Wind Run at 2 m above Ground

Location	Mean Monthly Wind Run (km / day)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Biang Bintang	240	240	240	210	210	240	240	275	240	210	210	240
Lhokseumawe	177	177	160	125	104	101	108	121	118	104	114	135
Takengon	98	82	78	76	73	80	80	79	71	60	66	69
Pulo lele	240	240	240	210	210	240	240	275	240	210	210	240
Maulaboh	161	161	161	161	145	129	129	129	161	161	161	161

Figure 5.4 : Mean monthly Wind Run at 2 m above ground

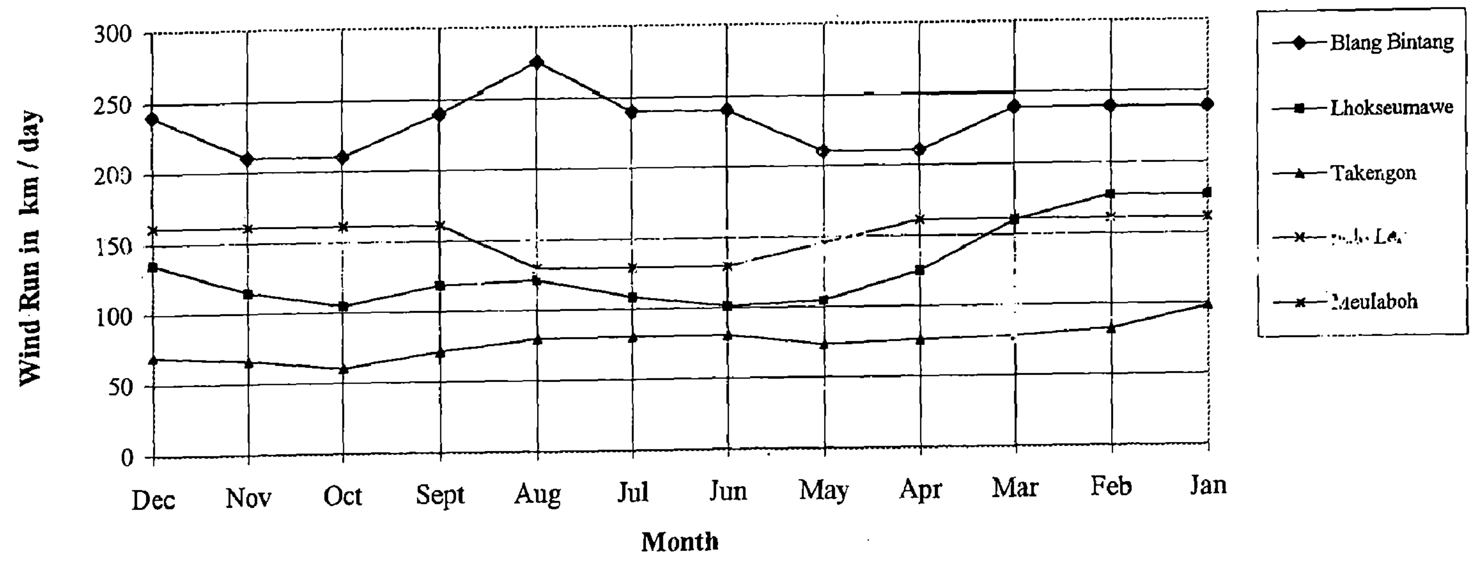


Table 5.9 Estimation Evapotranspiration (ETo) by Simplified Model

Place : Jambo Aye Project

Latitude : 5 ^{0} N

Altitude : 500 m

No	Month	T_{mean} °C	Rh_{mean} %	Rh_{max} %	U_{day} m/sec	$\frac{U_{day}}{U_{night}}$	n/N	U_2 km/day	W	1-W	Ra mm/day	Rs mm/day	Rns mm/day	ea m bar	ed m bar	Rnl mm/day	Rn mm/day	f(u)	C	Eto mm/day	Eo mm/day
1	January	24.9	82	85	1.5	1	0.45	177	0.747	0.253	14.117	6.692	5.019	31.500	25.830	0.920	4.099	0.748	0.994	4.109	4.954
2	February	25.2	81	85	1.5	1	0.42	177	0.750	0.250	14.883	6.832	5.124	32.068	25.975	0.874	4.250	0.748	0.941	4.313	5.181
3	March	26.4	80	85	1.5	1	0.44	160	0.761	0.239	15.467	7.255	5.441	34.429	27.543	0.869	4.572	0.702	1.006	4.664	5.514
4	April	26.4	82	85	1.5	1	0.37	125	0.761	0.239	15.467	6.713	5.035	34.429	28.232	0.739	4.296	0.608	0.938	4.145	5.008
5	May	26.6	82	85	1.5	1	0.35	104	0.763	0.237	14.967	6.347	4.760	34.837	28.566	0.700	4.059	0.551	0.986	3.861	4.672
6	June	26.3	80	85	1.5	1	0.38	101	0.760	0.240	14.584	6.403	4.802	34.226	27.381	0.778	4.024	0.543	0.930	3.900	4.716
7	July	26.2	81	85	1.5	1	0.38	108	0.759	0.241	14.717	6.461	4.846	34.025	27.560	0.772	4.074	0.562	0.989	3.922	4.746
8	August	25.8	73	85	1.5	1	0.36	121	0.755	0.245	15.151	6.500	4.875	33.230	24.258	0.832	4.043	0.597	0.989	4.318	5.144
9	September	25.7	82	85	1.5	1	0.30	118	0.754	0.246	15.300	6.105	4.579	33.034	27.088	0.653	3.926	0.589	0.981	3.747	4.515
10	October	25.5	84	90	1.5	1	0.31	104	0.757	0.243	15.050	6.081	4.561	32.644	27.421	0.659	3.902	0.551	0.992	3.617	4.389
11	Nopember	25.5	85	90	1.5	1	0.34	114	0.752	0.248	14.350	6.013	4.510	32.644	27.748	0.697	3.813	0.578	0.990	3.535	4.296
12	December	25.3	86	90	1.5	1	0.24	135	0.750	0.250	13.867	5.118	3.838	32.259	27.743	0.541	3.297	0.635	0.937	2.989	3.601

Table 5.10 : Comparison results on January Month As per FAO tables and Simplified Model

Item	As per Tables in FAO-24		As per Simplified Model	
	Values	unit	Values	unit
ea	31.510	m bar	31.500	m bar
ed	25.838	m bar	25.830	m bar
(ea - ed)	5.672	m bar	5.670	m bar
U2	177.000	km/day	177.000	km/day
f1(u)	0.748		0.748	
f2(u)	-		-	
we (for open water surface)	-		-	
wa (for open water surface)	-		-	
we (for reference crop)	0.749		0.747	
wa (for reference crop)	-		-	
Ra	14.100	mm/day	14.117	mm/day
Rs	6.698	mm/day	6.692	mm/day
Rns	5.076	mm/day	5.019	mm/day
Rnl	0.956	mm/day	0.920	mm/day
Rn	4.120	mm/day	4.099	mm/day
c	0.994		0.994	
ETo	4.125	mm/day	4.109	mm/day
Eo	4.933	mm/day	4.954	mm/day

Table 5.11 .: Comparison of (Ra) by General Model and Simplified Model

No	Month	alculation Extraterrastrial Radiation (Ra) in mm/da		
		As per General Model	As per Simplified Model	Relative error (%)
1	January	14.010	14.117	-0.764
2	February	14.799	14.883	-0.570
3	March	15.371	15.467	-0.624
4	April	15.354	15.467	-0.737
5	May	14.858	14.967	-0.731
6	June	14.478	14.584	-0.729
7	July	14.586	14.717	-0.892
8	August	15.045	15.151	-0.703
9	September	15.267	15.300	-0.216
10	October	14.887	15.050	-1.090
11	November	14.146	14.350	-1.444
12	December	13.679	13.867	-1.376

Table 5.12 : Comparison of (Ra) by FAO Tables and Simplified Model

No	Month	Calculation Extraterrastrial Radiation (Ra) in mm/day		
		As per FAO Tables	As per Simplified Model	Relative error (%)
1	January	14.100	14.117	-0.121
2	February	14.900	14.883	0.112
3	March	15.450	15.467	-0.107
4	April	15.450	15.467	-0.108
5	May	15.000	14.967	0.223
6	June	14.550	14.584	-0.230
7	July	14.750	14.717	0.227
8	August	15.150	15.151	-0.003
9	September	15.300	15.300	0.000
10	October	15.050	15.050	0.003
11	November	14.350	14.350	0.000
12	December	13.900	13.867	0.237

Table 5.13 : Comparison ETo by General Model and Simplified Model

No	Month	Calculation Evapotranspiration (ETo) in mm/day		
		As per General Model (mm/day)	Simplified Model (mm/day)	Relative Error (%)
1	January	3.924	4.109	-4.734
2	February	4.113	4.313	-4.859
3	March	4.377	4.664	-6.550
4	April	3.894	4.145	-6.445
5	May	3.617	3.861	-6.747
6	Juny	3.618	3.900	-7.791
7	July	3.654	3.922	-7.340
8	August	3.959	4.318	-9.065
9	September	3.563	3.747	-5.181
10	October	3.377	3.617	-7.132
11	November	3.311	3.535	-6.740
12	December	2.973	2.989	-0.516

Table 5.14 : Comparison of Eo by FAO Tables and Simplified Model

No	Month	As per FAO-24 tables (mm/day)	Simplified Model Eo (mm/day)	Relative Error (%)
1	January	4.933	4.954	-0.419
2	February	5.767	5.181	10.167
3	March	5.964	5.514	7.545
4	April	5.515	5.008	9.196
5	May	5.256	4.672	11.107
6	Juny	5.264	4.716	10.412
7	July	5.256	4.746	9.694
8	August	5.640	5.144	8.797
9	September	5.021	4.515	10.085
10	October	4.890	4.389	10.259
11	November	4.741	4.296	9.391
12	December	4.058	3.601	11.279

Table 5.15 : Comparison Eo by General Model and Simplified Model

No	Month	As per General Model (mm/day)	Simplified Model (mm/day)	Relative Error (%)
1	January	5.378	4.954	7.897
2	February	5.698	5.181	9.084
3	March	6.217	5.514	11.308
4	April	5.460	5.008	8.273
5	May	5.156	4.672	9.387
6	Juny	5.273	4.716	10.569
7	July	5.231	4.746	9.267
8	August	6.164	5.144	16.547
9	September	5.012	4.515	9.909
10	October	4.613	4.389	4.863
11	November	4.489	4.296	4.287
12	December	4.086	3.601	11.870

Table 5.16 : Comparison of ETo by FAO Tables and Simplified Model

No	Month	As per FAO-24 tables (mm/day)	Simplified Model ETo (mm/day)	Relative Error (%)
1	January	4.125	4.109	0.372
2	February	4.408	4.313	2.149
3	March	4.499	4.664	-3.651
4	April	4.134	4.145	-0.268
5	May	3.940	3.861	2.013
6	Juny	3.966	3.900	1.685
7	July	3.970	3.922	1.209
8	August	4.311	4.318	-0.152
9	September	3.748	3.747	0.017
10	October	3.633	3.617	0.430
11	November	3.520	3.535	-0.419
12	December	2.983	2.989	-0.205

TABLE 5.17 ACCURACY IN ESTIMATION EXTRATERESTRIAL RADIATION BY SIMPLIFIED MODEL

No	Month	Values of Ra in mm/day		$(Q_f - Q_r)$	$(Q_f - Q_r)^2$	$Q_f\,Q_r$	$Q_r^2-M_r^2$	$Q_f^2-M_f^2$	Relative Error (%)
		As per FAO Tables (Q_r)	As per Simplified Model (Q_f)						
1	January	14.100	14.117	0.017	0.000	199.050	-21.094	-20.533	-0.121
2	February	14.900	14.883	-0.017	0.000	221.761	2.106	1.690	0.112
3	March	15.450	15.467	0.017	0.000	238.957	18.798	19.390	-0.107
4	April	15.450	15.467	0.017	0.000	238.961	18.798	19.396	-0.108
5	May	15.000	14.967	-0.034	0.001	224.498	5.096	4.173	0.223
6	June	14.550	14.584	0.033	0.001	212.190	-8.202	-7.144	-0.230
7	July	14.750	14.717	-0.034	0.001	217.068	-2.342	-3.247	0.227
8	August	15.150	15.151	0.000	0.000	229.530	9.618	9.715	-0.003
9	September	15.300	15.300	0.000	0.000	234.090	14.186	14.267	0.000
10	October	15.050	15.050	-0.001	0.000	226.495	6.598	6.665	0.003
11	November	14.350	14.350	0.000	0.000	205.923	-13.982	-13.900	0.000
12	December	13.900	13.867	-0.033	0.001	192.751	-26.694	-27.529	0.237
	TOTAL	177.950	177.917	-0.033	0.006	2641.273	2.887	2.943	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 14.8292

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 14.8264

Bias :

$$B = M_f - M_r$$

= -0.0028

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_r(i)\right]^2$$

= 0.0005

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.0216

Variance :

$$V = MSE - B^2$$

= 0.0005

Relative Bias :

$$RB = \frac{B}{M_r}$$

= -0.0002

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum\left|Q_f(i) - Q_r(i)\right|$$

= 0.0028

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

= 0.0002

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.9982

TABLE 5.18 COMPARISON OF EXTRATERESTRIAL RADIATION BY GENERAL MODEL AND SIMPLIFIED MODEL

No	Month	Values of Ra in mm/day		$(Q_f - Q_r)$	$(Q_f - Q_r)^2$	$Q_f\,Q_r$	$Q_r^2\text{-}M_r^2$	$Q_f^2\text{-}M_f^2$	Relative Error (%)
		As per General Model (Q_r)	As per Simplified Model (Q_f)						
1	January	14.010	14.117	0.107	0.011	197.778	-20.004	-20.533	-0.764
2	February	14.799	14.883	0.084	0.007	220.258	2.728	1.690	-0.570
3	March	15.371	15.467	0.096	0.009	237.730	19.973	19.390	-0.624
4	April	15.354	15.467	0.113	0.013	237.469	19.449	19.396	-0.737
5	May	14.858	14.967	0.109	0.012	222.370	4.472	4.173	-0.731
6	June	14.478	14.584	0.106	0.011	211.139	-6.673	-7.144	-0.729
7	July	14.586	14.717	0.130	0.017	214.661	-3.520	-3.247	-0.892
8	August	15.045	15.151	0.106	0.011	227.935	10.061	9.715	-0.703
9	September	15.267	15.300	0.033	0.001	233.585	16.798	14.267	-0.216
10	October	14.887	15.050	0.162	0.026	224.046	5.349	6.665	-1.090
11	November	14.146	14.350	0.204	0.042	202.990	-16.183	-13.900	-1.444
12	December	13.679	13.867	0.188	0.035	189.684	-29.174	-27.529	-1.376
	TOTAL	176.4787	177.9170	1.4383	0.1962	2619.6445	3.2750	2.9434	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 14.7066

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 14.8264

Bias :

$$B = M_f - M_r$$

= 0.1199

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_r(i)\right]^2$$

= 0.0164

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.1279

Variance :

$$V = MSE - B^2$$

= 0.0020

Relative Bias :

$$RB = \frac{B}{M_r}$$

= 0.0081

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum\left|Q_f(i) - Q_r(i)\right|$$

= 0.1199

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

= 0.0081

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.9952

TABLE 5.19 ACCURACY IN ESTIMATION OF EVAPOTRANSPIRATION (ETo) BY SIMPLIFIED MODEL

No	Month	Values of ETo in mm/day		$(Q_f - Q_r)$	$(Q_f - Q_r)^2$	$Q_f\,Q_r$	Q_r^2-M_r^2	Q_f^2-M_f^2	Relative Error (%)
		As per FAO Tables (Q_r)	As per Simplified Model (Q_f)						
1	January	4.125	4.109	-0.015	0.000	16.950	1.518	1.468	0.372
2	February	4.408	4.313	-0.095	0.009	19.010	3.932	3.183	2.149
3	March	4.499	4.664	0.164	0.027	20.984	4.749	6.332	-3.651
4	April	4.134	4.145	0.011	0.000	17.135	1.594	1.762	-0.268
5	May	3.940	3.861	-0.079	0.006	15.211	0.028	-0.513	2.013
6	June	3.966	3.900	-0.067	0.004	15.467	0.237	-0.212	1.685
7	July	3.970	3.922	-0.048	0.002	15.573	0.268	-0.034	1.209
8	August	4.311	4.318	0.007	0.000	18.617	3.093	3.227	-0.152
9	September	3.748	3.747	-0.001	0.000	14.045	-1.449	-1.376	0.017
10	October	3.633	3.617	-0.016	0.000	13.142	-2.297	-2.333	0.430
11	November	3.520	3.535	0.015	0.000	12.441	-3.107	-2.926	-0.419
12	December	2.983	2.989	0.006	0.000	8.914	-6.599	-6.486	-0.205
	TOTAL	47.2374	47.1197	-0.1177	0.0499	187.4901	1.9672	2.0931	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 3.9365

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 3.9266

Bias :

$$B = M_f - M_r$$

= -0.0098

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_r(i)\right]^2$$

= 0.0042

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.0645

Variance :

$$V = MSE - B^2$$

= 0.0041

Relative Bias :

$$RB = \frac{B}{M_r}$$

= -0.0025

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum\left|Q_f(i) - Q_r(i)\right|$$

= 0.0098

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

= 0.0025

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.9771

TABLE 5.20 COMPARISON OF EVAPOTRANSPIRATION (ETo) BY GENERAL MODEL AND SIMPLIFIED MODEL

No	Month	Values of ETo in mm/day		$(Q_f - Q_r)$	$(Q_f - Q_r)^2$	$Q_f Q_r$	$Q_r^2 - M_r^2$	$Q_f^2 - M_f^2$	Relative Error (%)
		As per General Model (Q_r)	As per Simplified Model (Q_f)						
1	January	3.924	4.109	0.186	0.034	16.124	1.717	1.468	-4.734
2	February	4.113	4.313	0.200	0.040	17.740	3.241	3.183	-4.859
3	March	4.377	4.664	0.287	0.082	20.413	5.481	6.332	-6.550
4	April	3.894	4.145	0.251	0.063	16.141	1.486	1.762	-6.445
5	May	3.617	3.861	0.244	0.060	13.963	-0.597	-0.513	-6.747
6	June	3.618	3.900	0.282	0.079	14.108	-0.589	-0.212	-7.791
7	July	3.654	3.922	0.268	0.072	14.333	-0.325	-0.034	-7.340
8	August	3.959	4.318	0.359	0.129	17.096	1.997	3.227	-9.065
9	September	3.563	3.747	0.185	0.034	13.351	-0.984	-1.376	-5.181
10	October	3.377	3.617	0.241	0.058	12.214	-2.276	-2.333	-7.132
11	November	3.311	3.535	0.223	0.050	11.704	-2.712	-2.926	-6.740
12	December	2.973	2.989	0.015	0.000	8.887	-4.836	-6.486	-0.516
	TOTAL	44.3795	47.1197	2.7402	0.7015	176.0722	1.6021	2.0931	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 3.6983

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 3.9266

Bias :

$$B = M_f - M_r$$

= 0.2283

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_r(i)\right]^2$$

= 0.0585

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.2418

Variance :

$$V = MSE - B^2$$

= 0.0063

Relative Bias :

$$RB = \frac{B}{M_r}$$

= 0.0617

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum\left|Q_f(i) - Q_r(i)\right|$$

= 0.2283

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

= 0.0617

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.9767

TABLE 5.21 ACCURACY IN ESTIMATION OF EVAPORATION (Eo) BY SIMPLIFIED MODEL

No	Month	Values of Eo in mm/day		$(Q_f - Q_r)$	$(Q_f - Q_r)^2$	$Q_f\,Q_r$	$Q_r^2 - M_r^2$	$Q_f^2 - M_f^2$	Relative Error (%)
		As per FAO Tables (Q_r)	As per Simplified Model (Q_f)						
1	January	4.933	4.954	0.021	0.000	24.435	-2.626	2.184	-0.419
2	February	5.767	5.181	-0.586	0.344	29.878	6.300	4.487	10.167
3	March	5.964	5.514	-0.450	0.202	32.889	8.613	8.054	7.545
4	April	5.515	5.008	-0.507	0.257	27.622	3.460	2.728	9.196
5	May	5.256	4.672	-0.584	0.341	24.554	0.663	-0.526	11.107
6	June	5.264	4.716	-0.548	0.300	24.826	0.753	-0.112	10.412
7	July	5.256	4.746	-0.510	0.260	24.947	0.666	0.175	9.694
8	August	5.640	5.144	-0.496	0.246	29.010	4.849	4.104	8.797
9	September	5.021	4.515	-0.506	0.256	22.671	-1.745	-1.968	10.085
10	October	4.890	4.389	-0.502	0.252	21.461	-3.045	-3.094	10.259
11	November	4.741	4.296	-0.445	0.198	20.370	-4.478	-3.897	9.391
12	December	4.058	3.601	-0.458	0.210	14.612	-10.489	-9.389	11.279
	TOTAL	62.3067	56.7352	-5.5715	2.8668	297.2759	2.9212	2.7472	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 5.1922

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 4.7279

Bias :

$$B = M_f - M_r$$

= -0.4643

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_r(i)\right]^2$$

= 0.2389

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.4888

Variance :

$$V = MSE - B^2$$

= 0.0233

Relative Bias :

$$RB = \frac{B}{M_r}$$

= -0.0894

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum \left|Q_f(i) - Q_r(i)\right|$$

= 0.4643

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

= 0.0894

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.9045

TABLE 5.22 COMPARISON OF EVAPORATION (Eo) BY GENERAL MODEL AND SIMPLIFIED MODEL

No	Month	Values of Eo in mm/day As per General Model (Q_r)	Values of Eo in mm/day As per Simplified Model (Q_f)	(Q_f - Q_r)	$(Q_f - Q_r)^2$	$Q_f\,Q_r$	Q_r^2-M_r^2	Q_f^2-M_f^2	Relative Error (%)
1	January	5.378	4.954	-0.425	0.180	26.641	1.558	2.184	7.897
2	February	5.698	5.181	-0.518	0.268	29.522	5.105	4.487	9.084
3	March	6.217	5.514	-0.703	0.494	34.284	11.288	8.054	11.308
4	April	5.460	5.008	-0.452	0.204	27.344	2.443	2.728	8.273
5	May	5.156	4.672	-0.484	0.234	24.088	-0.783	-0.526	9.387
6	June	5.273	4.716	-0.557	0.311	24.870	0.442	-0.112	10.569
7	July	5.231	4.746	-0.485	0.235	24.830	-0.002	0.175	9.267
8	August	6.164	5.144	-1.020	1.040	31.704	10.622	4.104	16.547
9	September	5.012	4.515	-0.497	0.247	22.627	-2.252	-1.968	9.909
10	October	4.613	4.389	-0.224	0.050	20.244	-6.089	-3.094	4.863
11	November	4.489	4.296	-0.192	0.037	19.283	-7.220	-3.897	4.287
12	December	4.086	3.601	-0.485	0.235	14.710	-10.676	-9.389	11.870
	TOTAL	62.7766	56.7352	-6.0414	3.5358	300.1478	4.4361	2.7472	

n = 12

Mean of reference value :

$$M_r = \frac{1}{n}\sum_{i=1}^{n} Q_r(i)$$

= 5.2314

Mean of Estimanted value :

$$M_f = \frac{1}{n}\sum_{i=1}^{n} Q_f(i)$$

= 4.7279

Bias :

$$B = M_f - M_r$$

= -0.5034

Mean Squared Error :

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[Q_f(i) - Q_r(i)\right]^2$$

= 0.2946

Root Mean Squared Error :

$$RMSE = (MSE)^{0.5}$$

= 0.5428

Variance :

$$V = MSE - B^2$$

= 0.0412

Relative Bias :

$$RB = \frac{B}{M_r}$$

= -0.0962

Mean Absolute Error :

$$MAE = \frac{1}{n}\sum\left|Q_f(i) - Q_r(i)\right|$$

= 0.5034

Relative Mean Absolute Error :

$$RMAE = \frac{MAE}{M_r}$$

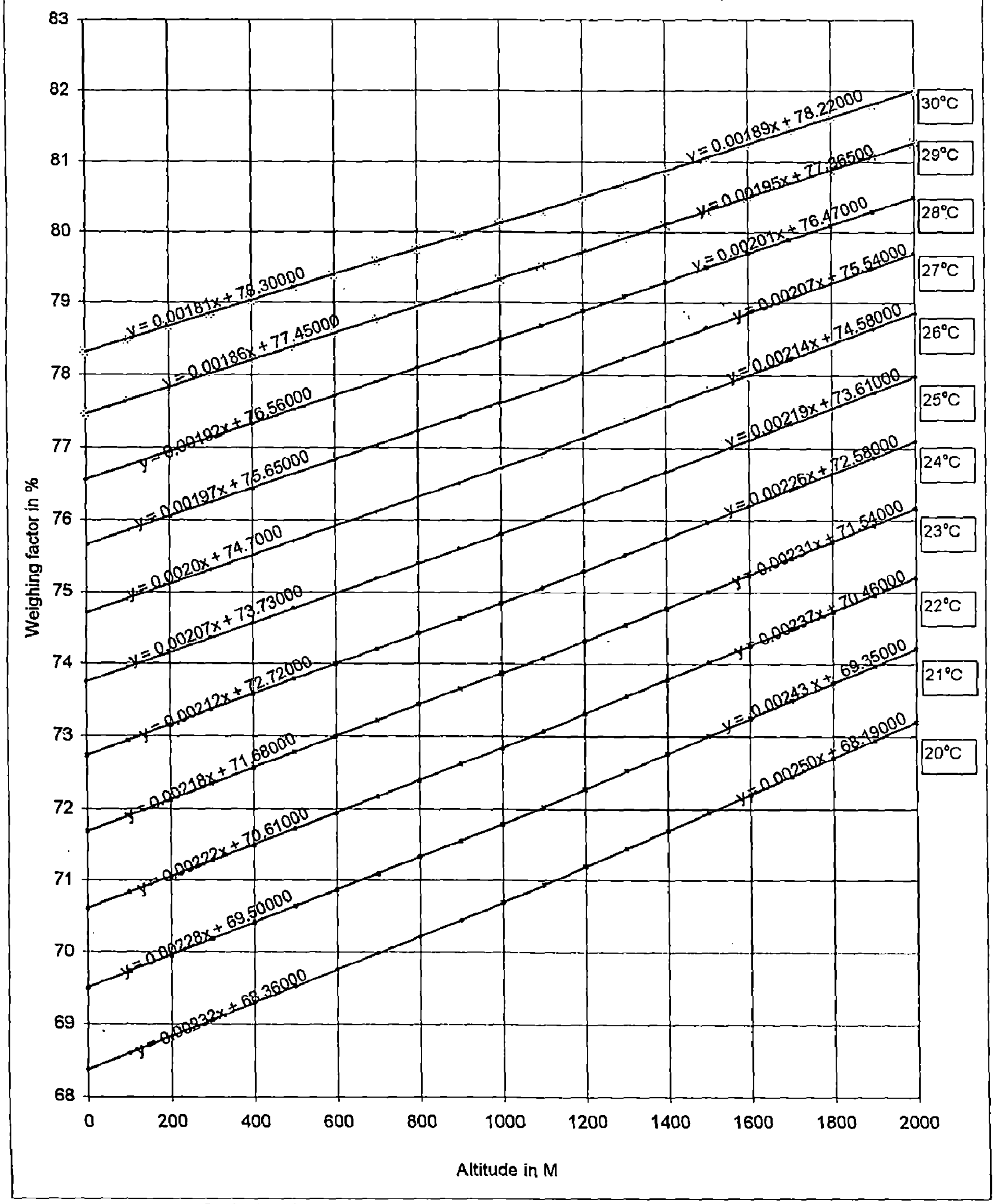
= 0.0962

R squared :

$$R^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} Q_r(i)Q_f(i) - M_r M_f}{\left(\frac{1}{n}\sum_{i=1}^{n} Q_r^2 - M_r^2\right)\left(\frac{1}{n}\sum_{i=1}^{n} Q_f^2 - M_f^2\right)}\right]^2$$

= 0.9179

Figure 5.5 Relationship between weigh factor (W) and Altitude at different temperature



For Alltitude lessthen 1000 m ← → For Alltitude more then 1000 m

Figure 5.6. Relationship Between Ra and Latitude For Dec to March (Northern Hemisphere)

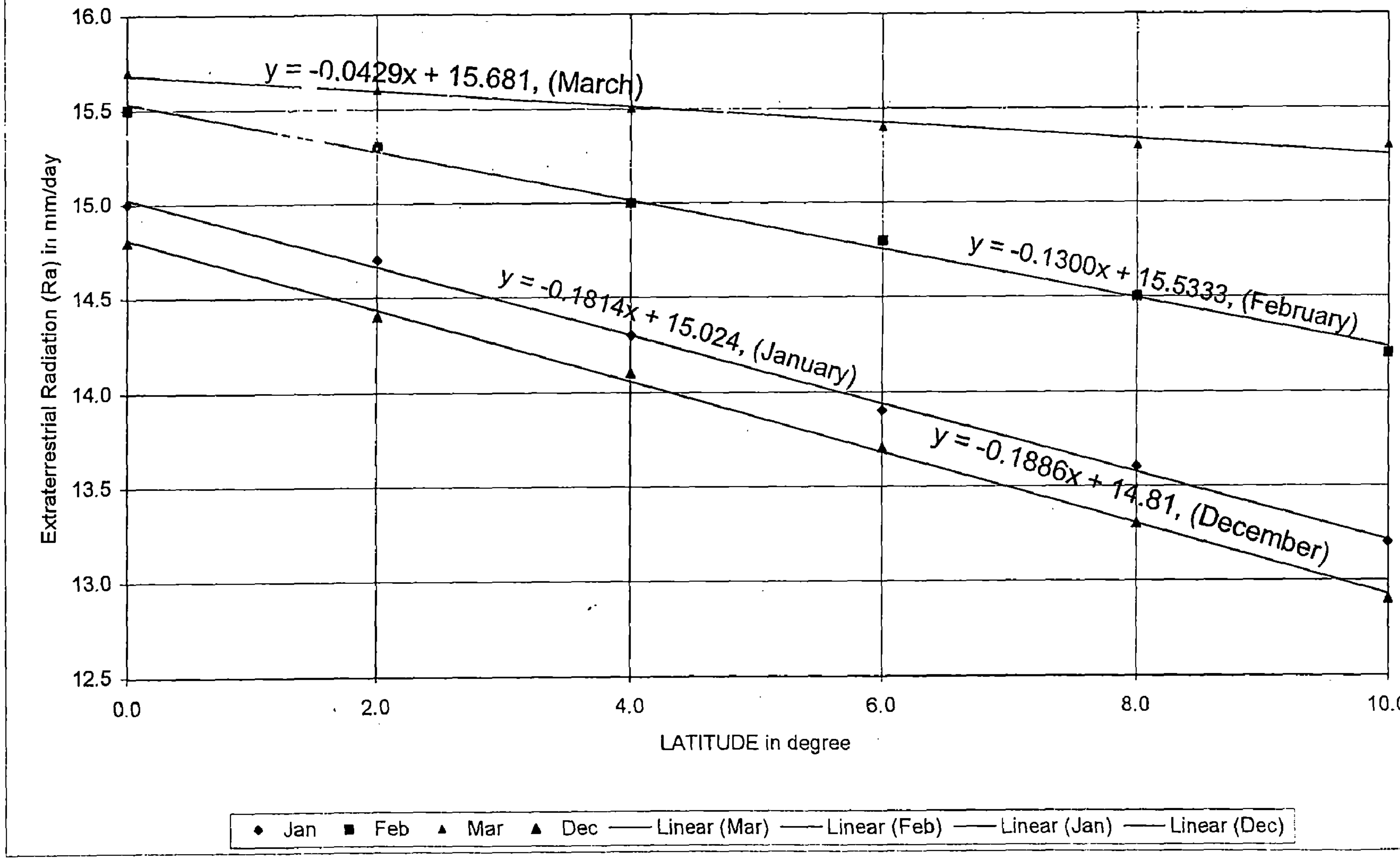


Figure 5.7 Relationship Between Ra and Latitude For Apr to July (Northern Hemisphere)

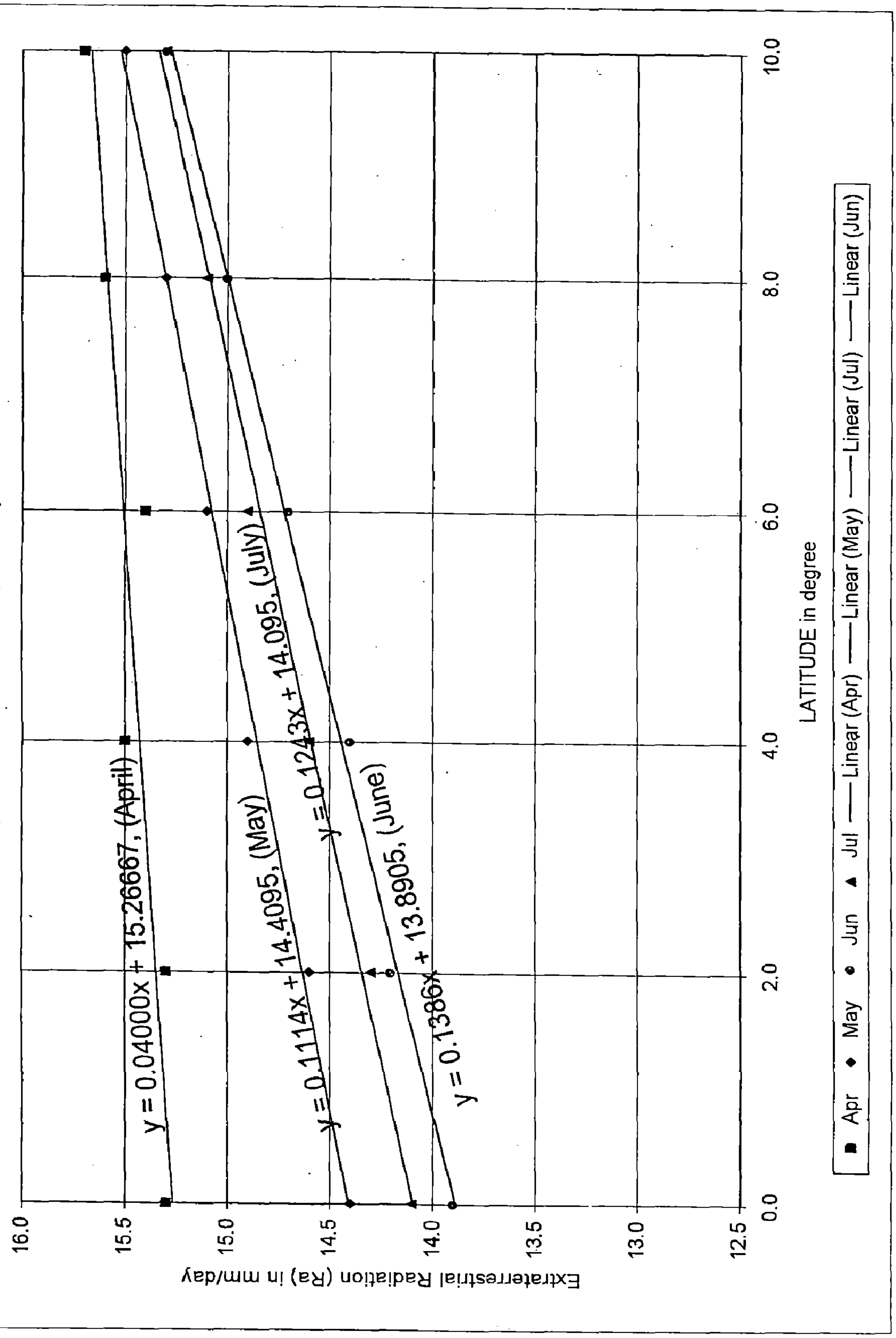
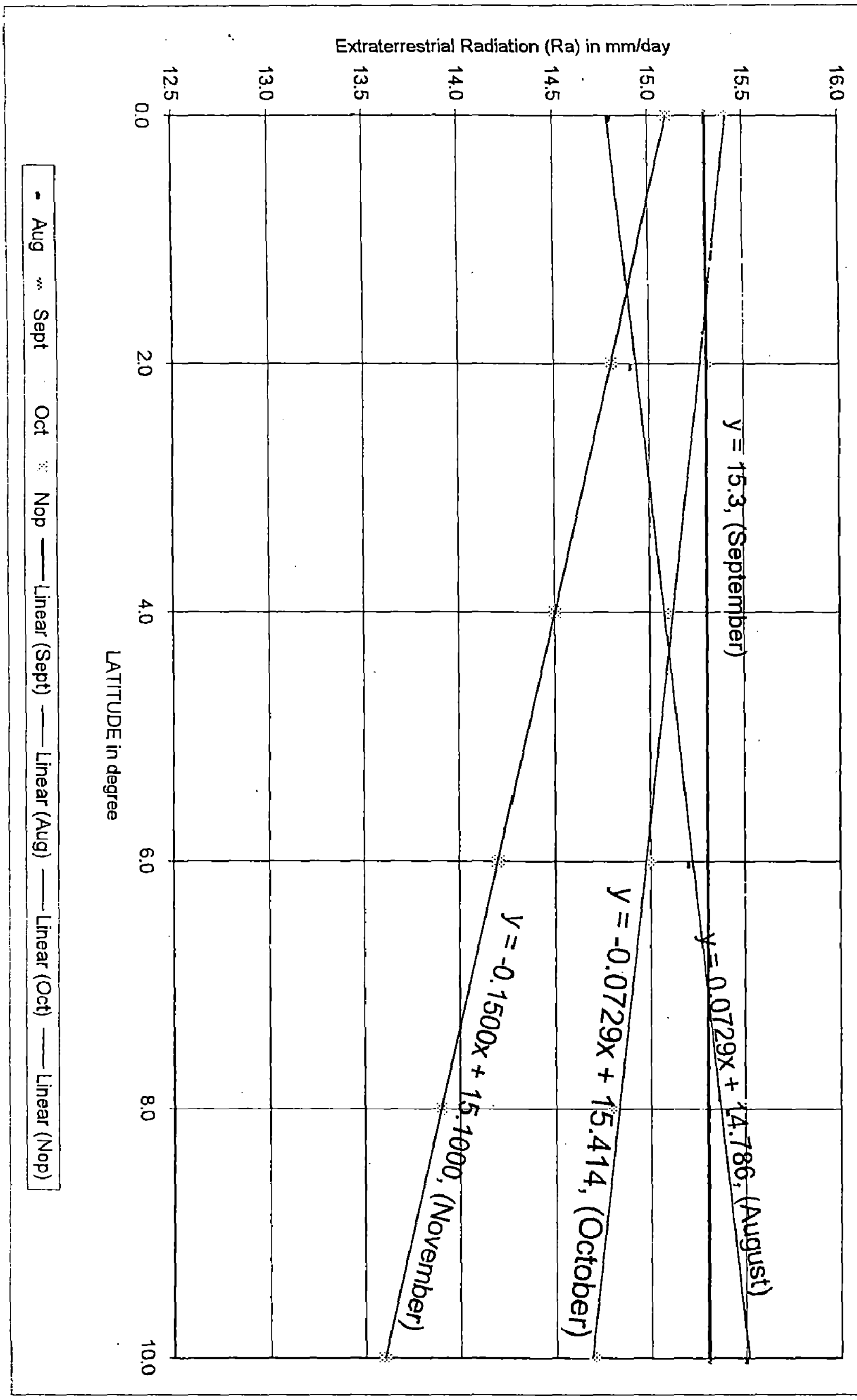


Figure 5.8. Relationship Between Ra and Latitude For August to Nop (Northern Hemisphere)



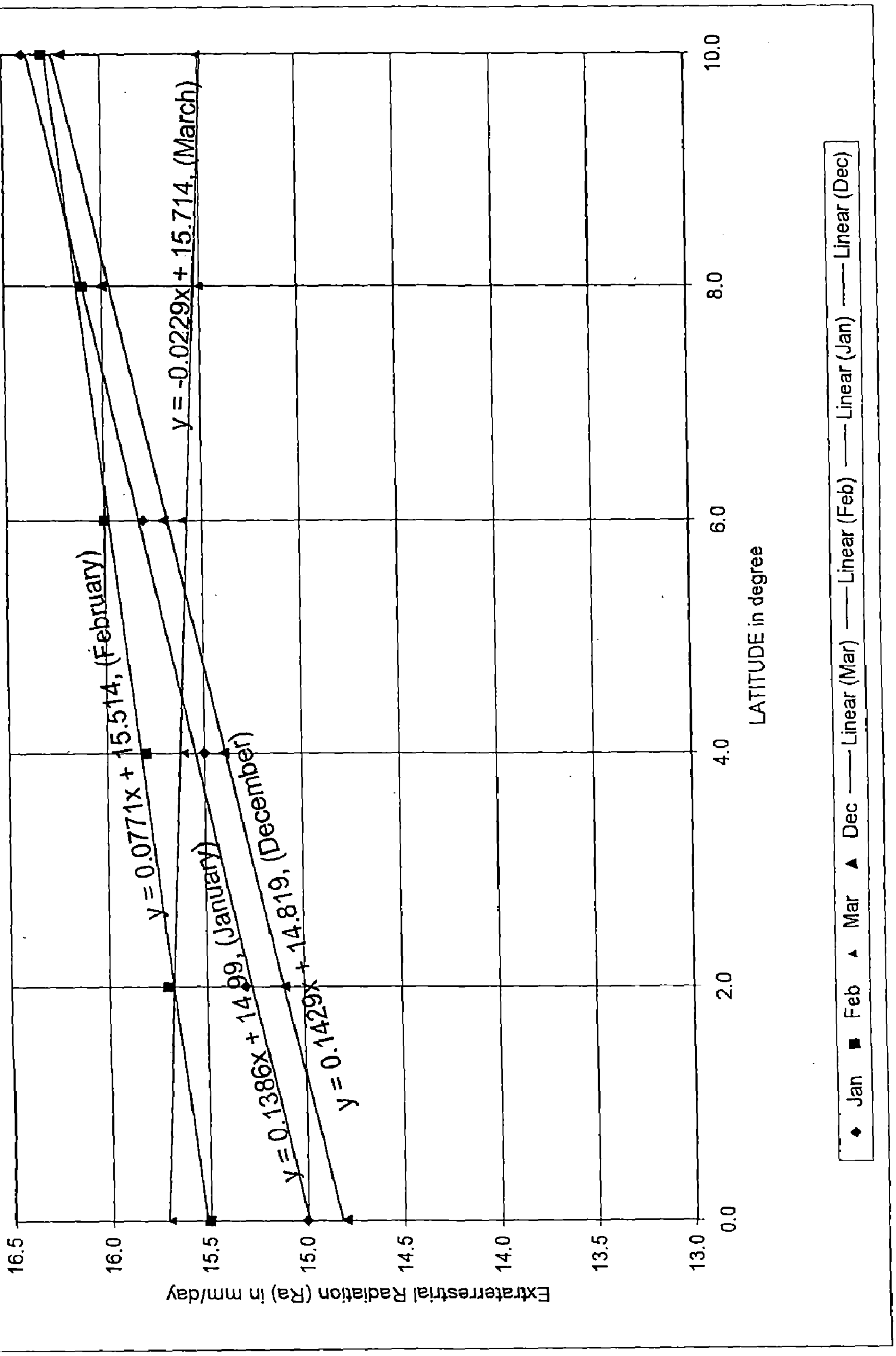


Figure 5.9 Relationship Between Ra and Latitude For Dec to March (Southern Hemisphere)

Figure 5.10. Relationship Between Ra and Latitude For April to July (Southern Hemisphere)

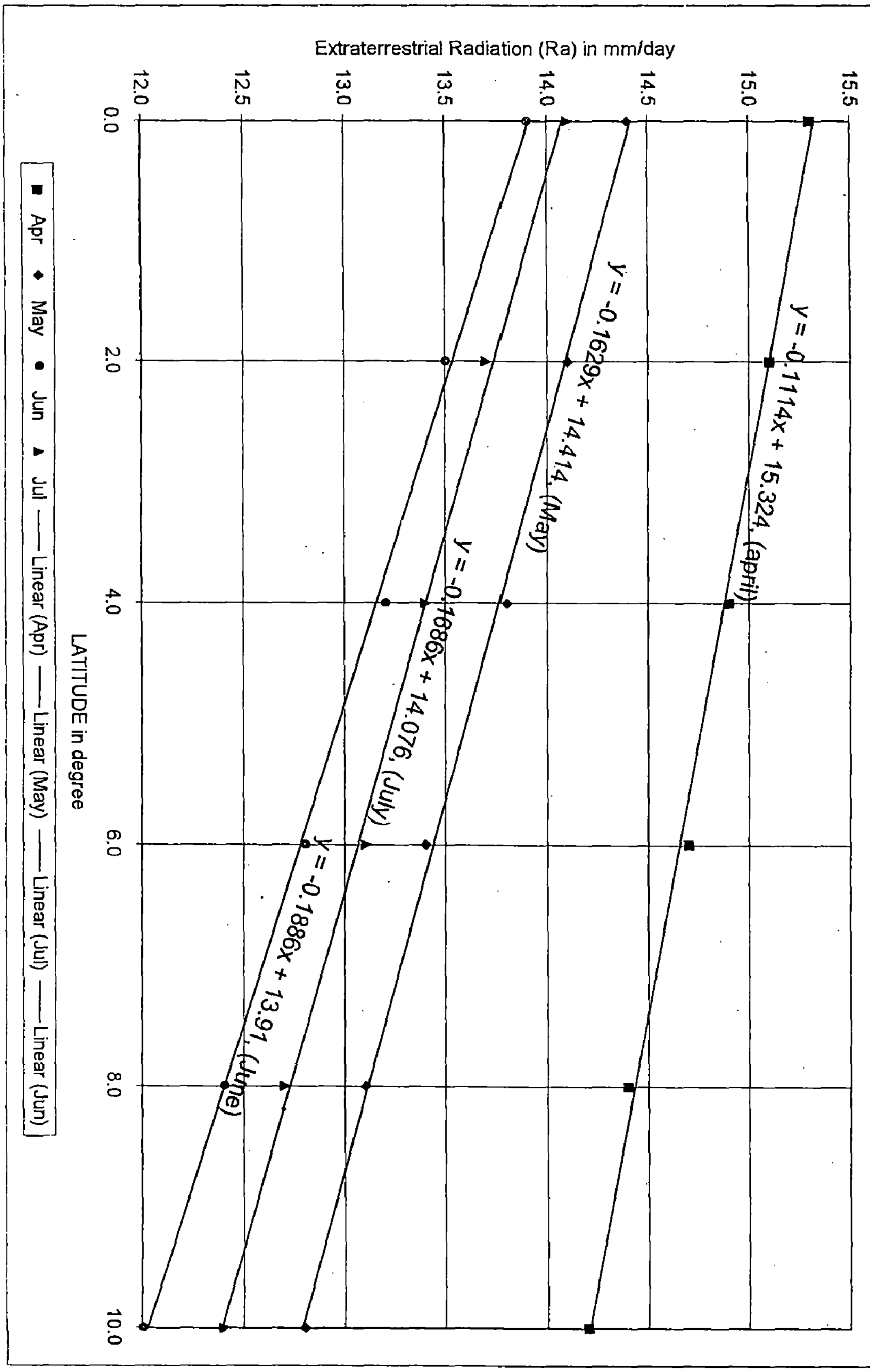


Figure 5.11 Relationship Between Ra and Latitude For August to Nov (Southern Hemisphere)

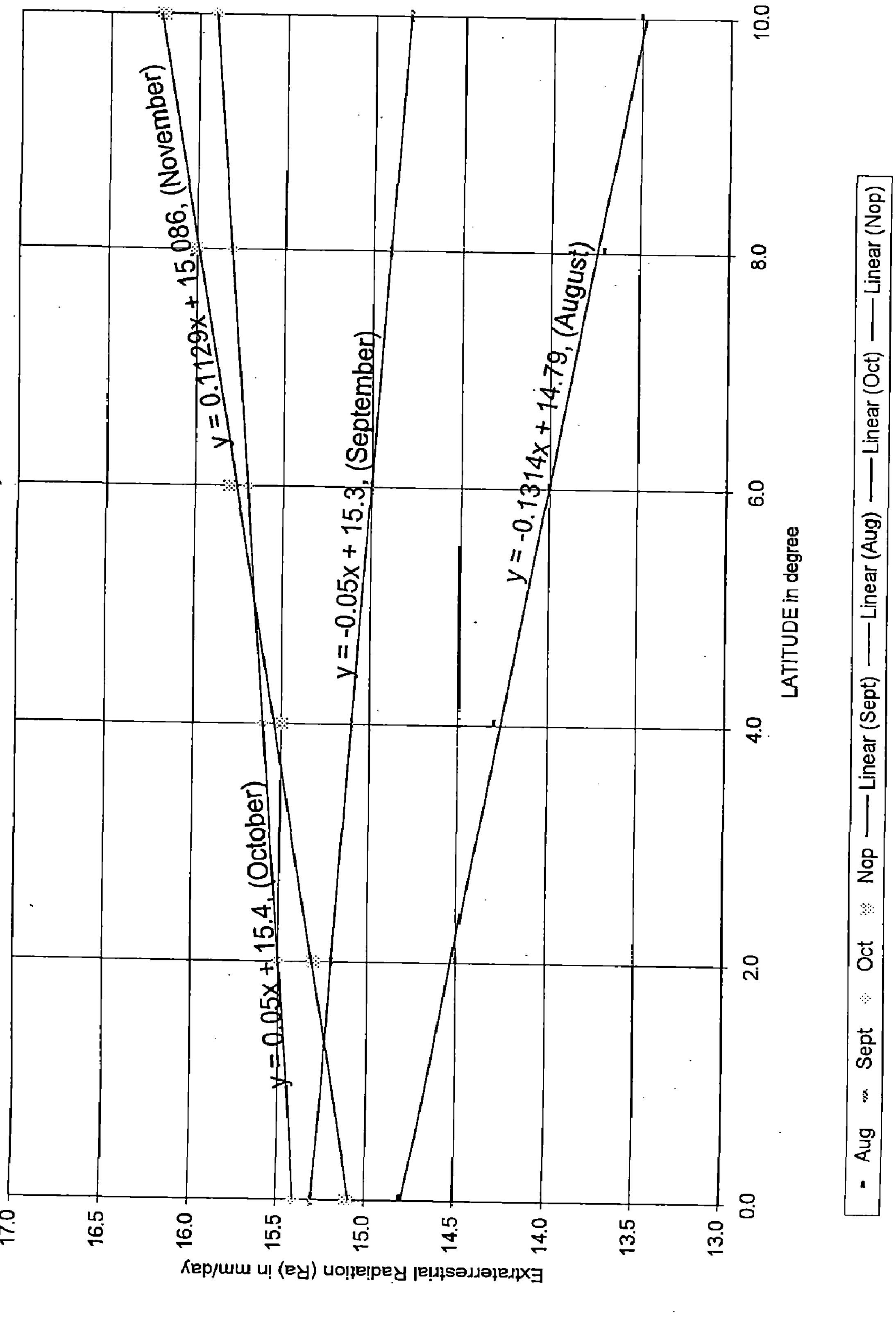
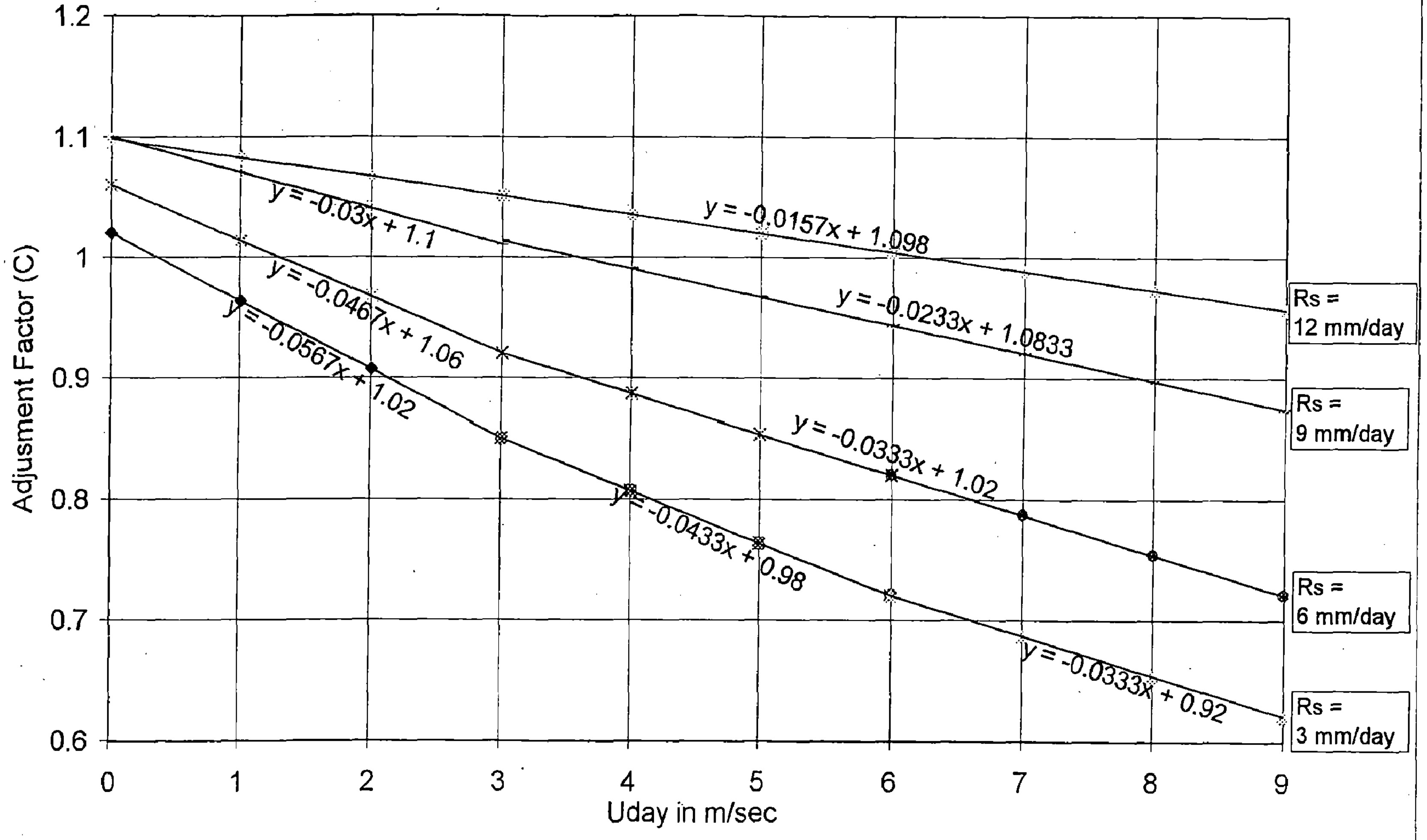


Fig. 5.12. Adjusment Factor (C) for Uday/Unight =1 and RHmax = 90%



CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 SUMMARY

Estimation of potential evapotranspiration and open water evaporation are required for several studies such as assessment of rainfall deficit, moisture availability index, assessment of crop growth period, assessment of seasonal water availability and most importantly in estimation of irrigation water requirement and evaporation losses. Therefore reliable estimate of evaporation and evapotranspiration are necessary. Error in estimation of these values may cause serious errors in planning and hydrologic design of water utilisation Projects.

Several methods, empirical as well as physical process based have been proposed in literature for estimation of meteorological parameters and for estimation of evapotranspiration Choice of using a particular method in most cases is dictated by availability and accuracy of input data.

Hydrologists in search for true to life description of evaporation or evapotranspiration process create complex models requiring high level of input data and specification of extensive set of parameters. Food and Agriculture Organization (United Nations) has brought out a publication (Doorenbos and Pruitt, 1977) in which several procedures are discussed for estimation of evapotranspiration and evaporation. It is also recommended that modified Penman method should be used whenever possible for estimation of potential evapotranspiration. However, in this method, various tables have to be referred to obtain the values of climatical parameters, some of which depend on location, latitude, altitude and some of which are interdependent.

Objective of this dissertation was to develop models based on empirical correlations between climatic parameters (dependent variable) and other parameters (independent variable), which are generally known or can be easily measured. Thus reference to various tables in FAO Procedure could be avoided and the procedure becomes simplified. However empirical relations may cause error if correlation is not very good. The proposed models can be useful in computerization of the estimation procedure and in sensitivity analysis of the potential evapotranspiration. In Indonesia, climatic variables such as radiation, temperature and wind speed occur in specific limited range. Therefore it was proposed to further simplify the procedure for estimation of evapotranspiration.

A large number of empirical techniques and physically based models for estimation of evaporation and evapotranspiration are available in literature. Instead of evaluating all such techniques and model, emphasis is to select a few preferred methods (empirical relations).

First, a general model is proposed by compiling as well as developing regression equations Table 3.4 shows that reference to eleven tables (as per FAO Procedure) has been avoided by using a general model. Only one table has to be referred, in the general model.

Summary form of the general model and input data are shows in table 3.5. The model consists of linear, nonlinear and sinusoidal mathematical expressions. Maidment (1993) has suggested that an error of 10% to 15% is usual in estimation of ETo and proposed several parameters for testing accuracy of a model. In addition to coefficient of determination (R^2) other parameters such as bias (B) and variance (V) are also necessary for checking accuracy of model.

The general model was applied to test its accuracy for estimation of evaporation and evapotranspiration at a location in Indonesia (Jambo Aye Project). Indonesia lies just north and south of the equator. The latitude range is between 10^0S to 10^0N and maximum altitude of the irrigated agriculture is around 2000 m above mean sea level.

The climate is tropical with medium to high rainfall. It may range from 1000 to 5000 mm in a year. The mean daily temperature in the warmest and the coldest months is only about 30^0C to 20^0C. Temperature decreases with increasing altitude at the rate of about 1^0C per 200 m. Also temperature becomes somewhat high in the city areas.

The mean daily actual sunshine hours vary from about 30 % to 80 % of the maximum possible sunshine hours. Wind velocity varies up to the maximum wind speed of about 500 km/day. The wind velocity becomes somewhat less in the inland areas. The ratio of day and night time wind velocity varies from 1 to 3 and day time wind may be maximum about 6 m / sec.

Keeping in new the limited range of climatic variation in Indonesia and particularly in Aceh Province, simple linear equations have been developed and a simplified model has been proposed. The model and input data are summarized in Table 5.8 (chapter 5). The simplified model was applied to estimate ETo and Eo at Jambo Aye Project.

Accuracy of general model and simplified model in estimation of extraterrestrial radiation (Ra) evaporation (Eo) and Potential evapotranspiration (ETo) in terms of percent of variation, coefficient of determination (R^2), bias (B) and variance (V) are compared in table 6.1, below:

Input data required in the general model and the simplified model are more or less same i.e.: month specification, latitude (ϕ), altitude (Z), mean monthly temperature (T), Relative humidity (RH), actual sunshine hour (n), Wind speed (u),

In addition, simplified model requires adjustment factor (c) for which RHmax has to be specified.

Table 6.1 Accuracy of Model with Reference FAO Tables

No	Item	Accuracy of Ra		Accuracy of Eo		Accuracy of ETo	
		General Model	Simplified Model	General Model	Simplified Model	General Model	Simplified Model
1	Percent of Variation (%)	0.216 to 1.590	0.00 to 0.227	-9.30 to 5.670	-0.42 to 11.300	0.310 to 8.700	-3.650 to 2.010
2	Coef. Of Determination (r^2)	0.9926	0.9982	0.8606	0.9045	0.9476	0.9771
3	Bias (B)	-0.1226	-0.0028	0.0392	-0.4643	-0.2382	-0.0098
4	Variance (V or S^2)	0.0029	0.0005	0.0565	0.0233	0.0094	0.0041

6.2 CONCLUSION:

i) Extraterrestrial radiation (Ra) is estimated accurately in the general model as well as simplified model. It is therefore not necessary to use complex mathematical expression given in the general model to estimate Ra.

ii) Simplified model consisting of linear regression equations can be used for estimation of potential evapotranspiration in the limited range of variation for meteorological parameters as happens in Indonesia . Accuracy parameters of the simplified model are better than those of general model as seen in table 6.1.

iii) Estimation of evaporation by general as well as simplified models is not so accurate as that of evapotranspiration.

iv) Coefficient of determination (R^2) is more in case of simplified model compared to general model but it also has higher bias in estimation of evaporation (Eo). Further, percent of variation in estimate with reference to estimate by FAO procedure is also highest (11.3%) for simplified model. Further study is needed to decide relative preference of one model over the other for estimation of evaporation.

v) Simplified model has been developed specifically for limited range of variation in meteorological parameters in Indonesia . It is not applicable for other regions. General model is applicable for other regions also but accuracy has been compromised in consideration of general application.

vi) It is necessary to compare the accuracy of proposed models with reference to field observations also and also for different locations.

REFERENCES

1. Aceh Design Unit, 1988. Provincial Water Resources Development Plan and Inventory of Water Resources Scheme, Department of Public Works, Indonesia
2. Doorenbos, J and WO Pruitt, 1977. Guidelines for Predicting Crop Water Requirement' Irrigation and Drainage Paper – 24, United Nations (FAO), Rome
3. Klein, S.A , 1977. Calculation of Monthly Average Insolation on Tilted Surfaces, Journal of Solar Energy, Vol 19, Page 325 (1976) USA.
4. Maidment R.D , 1993. Handbook of Hydrology, editor: David R, Maidment Mc Graw-Hill, United States of America.
5. Priestley, C. H. B., 1959. Turbulence Transfer in the Lower Atmosphere, University of Chicago as given in Maidment, 1993.
6. Raudkivi A. J., 1979. Hydrology, Pergamon Press Oxford (UK), 1979.
7. Rizal. S , 1995. Regional Graphic Procedure for Irrigation Project Planning – A Case Study of Indonesia M.E Dissertation WRDTC – Univ. of Roorkee, Roorkee India.
8. Sosrodarsono, Ir. S; Kensaku Takeda, 1980. Hydrology for Water Resources, Seventh Reprint by Gramedia, Indonesia.

APPENDIX – A: FAO TABLES

Table A- 1 Saturation Vapoure Pressure (e_a) mbar as Function of Air Temperature (T) ^{0}C (Table 5,FAO)

Temperature (T) ^{0}C	e_a mbar		Temperature (T) ^{0}C	e_a mbar
0	6.1		20	23.4
1	6.6		21	24.9
2	7.1		22	26.4
3	7.6		23	28.1
4	8.1		24	29.8
5	8.7		25	31.7
6	9.3		26	33.6
7	10.0		27	35.7
8	10.7		28	37.8
9	11.5		29	40.1
10	12.3		30	42.4
11	13.1		31	44.9
12	14.0		32	47.6
13	15.0		33	50.3
14	16.1		34	53.2
15	17.0		35	56.2
16	18.2		36	59.4
17	19.4		37	62.8
18	20.6		38	66.3
19	22.0		39	69.9

Also actual vapour (e_d) can be obtained from this table using available T dew point data
(Example: T dew point is 18 ^{0}C; ed is 20.6 mbar)

Table A-2 Value of Wind Function f (u) = 0.27 (1 + U2/100) for Wind Run at 2 m height in km/day (Table 7, FAO)

Wind Km/day	0	10	20	30	40	50	60	70	80	90
	-	0.30	0.32	0.35	0.38	0.41	0.43	0.46	0.49	0.51
100	0.54	0.57	0.59	0.62	0.65	0.67	0.70	0.73	0.76	0.78
200	0.81	0.84	0.86	0.89	0.92	0.94	0.97	1.00	1.03	1.05
300	1.08	1.11	1.13	1.16	1.19	1.21	1.24	1.27	1.30	1.32
400	1.35	1.38	1.40	1.43	1.46	1.49	1.51	1.54	1.57	1.59
500	1.62	1.65	1.67	1.70	1.73	1.76	1.78	1.81	1.84	1.90
600	1.89	1.92	1.94	1.97	2.00	2.02	2.05	2.08	2.11	2.15
700	2.16	2.19	2.21	2.24	2.27	2.29	2.32	2.35	2.38	2.40
800	2.43	2.46	2.48	2.51	2.54	2.56	2.59	2.62	2.64	2.65
900	2.70									

Table A-3 Values of Weighting Factor (w) for the Effect of Radiation on ETo at Different Temperatures and altitudes (Table 9, FAO)

Temperature	W at Altitude m					
	0	500	1000	2000	3000	4000
2	0.43	0.44	0.46	0.49	0.52	0.54
4	0.46	0.48	0.49	0.52	0.55	0.58
6	0.49	0.51	0.52	0.55	0.58	0.61
8	0.52	0.54	0.55	0.58	0.61	0.64
10	0.55	0.57	0.58	0.61	0.64	0.66
12	0.58	0.60	0.61	0.64	0.66	0.69
14	0.61	0.62	0.64	0.66	0.69	0.71
16	0.64	0.65	0.66	0.69	0.71	0.73
18	0.66	0.67	0.69	0.71	0.73	0.75
20	0.69	0.70	0.71	0.73	0.75	0.77
22	0.71	0.72	0.73	0.75	0.77	0.79
24	0.73	0.74	0.75	0.77	0.79	0.81
26	0.75	0.76	0.77	0.79	0.81	0.82
28	0.77	0.78	0.79	0.81	0.82	0.84
30	0.78	0.79	0.80	0.82	0.84	0.85
32	0.80	0.81	0.82	0.84	0.85	0.86
34	0.82	0.82	0.83	0.85	0.86	0.87
36	0.83	0.84	0.85	0.86	0.87	0.89
38	0.84	0.85	0.86	0.87	0.88	0.90
40	0.85	0.86	0.87	0.88	0.89	0.90

Table A-4 Extraterrestrial Radiation (Ra) expressed in equivalent evapotranspiration in mm/day

No	Month	Northern Hemisphere		Southern Hemisphere	
		Latitude in ^{0}C		Latitude in ^{0}C	
		4	6	4	6
1	January	14.3	13.9	15.5	15.8
2	February	15.0	14.8	15.8	16.0
3	March	15.5	15.4	15.6	15.6
4	April	15.5	15.4	14.9	14.7
5	May	14.9	15.1	13.8	13.4
6	June	14.4	14.7	13.2	12.8
7	July	14.6	14.9	13.4	13.1
8	August	15.1	15.2	14.3	14.0
9	September	15.3	15.3	15.1	15.0
10	October	15.1	15.0	15.6	15.7
11	November	14.5	14.2	15.5	15.8
12	December	14.1	13.7	15.4	15.7

Table A-5 Conversion Factor for Extra-Terrestrial Radiation (Ra) to Net Solar Radiation (Rns) for a given Reflection K of 0.25 and Different Ratio of Actual to maximum Sunshine Hours (1 – K) (0.29 + 0.52 n/N) , (Table 12, FAO)

N / N	(1 – K) (0.25 + 0.50 n/N)
0.00	0.19
0.05	0.21
0.10	0.22
0.15	0.24
0.20	0.26
0.25	0.28
0.30	0.30
0.35	0.32
0.40	0.34
0.45	0.36
0.50	0.37
0.55	0.39
0.60	0.41
0.65	0.43
0.70	0.45
0.75	0.47
0.80	0.49
0.85	0.51
0.90	0.52
0.95	0.54
1.00	0.56

Table A-6 Effect of Temperature f (T) on Longwave Radiation (Rn1), (Table 13 , FAO)

Temperature (T) ^{0}C	f (T) = N Tk^4
0	11.0
2	11.4
4	11.7
6	12.0
8	12.4
10	12.7
12	13.1
14	13.5
16	13.8
18	14.2
20	14.6
22	15.0
24	15.4
26	15.9
28	16.3
30	16.7
32	17.2
34	17.7
36	18.1

Table A-7 Effect of Vapour Pressure f (ed) on longwave Radiation (Rn1) , (Table 14, FAO)

e_d mbar	F(ed) = 0.34 –0.044 $\sqrt{ed}$
6	0.23
8	0.22
10	0.20
12	0.19
14	0.18
16	0.16
18	0.15
20	0.14
22	0.13
24	0.12
26	0.12
28	0.11
30	0.10
32	0.09
34	0.08
36	0.08
38	0.07
40	0.066

TableA-8 Effect of The Ratio Actual and Maximum Bright Sunshine Hours f (n/N) on Longwave Radiation (Rn1), (Table 15, FAO).

n/N	f(n/N) = 0.1 + 0.9 n/N
0.00	0.10
0.05	0.15
0.10	0.19
0.15	0.24
0.20	0.28
0.25	0.33
0.30	0.37
0.35	0.42
0.40	0.46
0.45	0.51
0.50	0.55
0.55	0.60
0.60	0.64
0.65	0.69
0.70	0.73
0.75	0.78
0.80	0.82
0.85	0.87
0.90	0.91
0.95	0.96
1.00	1.00