

APPLICABILITY OF REFERENCE CROP EVAPOTRANSPIRATION
FROM MEASURED TEMPERATURE (HARGREAVES METHOD - 1982)
TO SRI-LANKA

පළමුව
ලකුමේගොදාගේ කීර්ති ප්‍රියාකරා සේනවිරත්න (ප.උ.ආ.)
ලකුමේගොදා

by

Lokumeeagodage Keerthi Priyankara Seneviratne B.Sc. Eng
Hons (S.L), C. Eng. , M.I.C.E. (Lond), M.I.E. (S.L)



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

52630

MAY, 1988.

UNIVERSITY COLLEGE

52630

A thesis submitted in partial fulfilment of
the requirements for the degree of Master
of Engineering.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Department of Civil Engineering

Faculty of Engineering

University of Moratuwa, Sri-Lanka.

This dissertation has not been previously
presented in whole or part, to any
University or Institution for a higher
degree.



University of Moratuwa, Sri Lanka.

Electronic Theses & Dissertations

L.K.P. Seneviratne

www.lib.mrt.ac.lk

May, 1988.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

ACKNOWLEDGEMENTS

I wish to express my deepest appreciation to my project supervisor Dr. H.C. Kariyawasam for the valuable guidance and help given to me to complete this study.

I also wish to express my sincere gratitude to Eng. D.M. Panapitiya, Assistant Director of Mahaweli Engineering and Construction Agency, for his help in the initial development of this research.

Grateful acknowledgement is due to Eng. J.A.P. Weerasinghe of Irrigation Department, for providing relevant data required for the study.

I am deeply obliged to Department of Meteorology and Department of Agriculture for providing relevant data and information.

Special expression of thanks to my friends who helped me in many ways.

I am very indebted to my wife and mother for their help, patience, sacrifice and encouragement throughout my study.



University of Moratuwa, Sri Lanka.

Electronic Theses & Dissertations

www.lib.mrt.ac.lk

Lokumeegodage Keerthi Priyankara Seneviratne

TABLE OF CONTENTS

Chapter		page
	ACKNOWLEDGEMENTS	V
	LIST OF TABLES	IX
	LIST OF FIGURES	XV
	LIST OF SYMBOLS AND ABBREVIATIONS.....	XVII
	ABSTRACT	XIX
1	INTRODUCTION	1
1.1	Objective	3
2	METHODS AVAILABLE FOR THE DETERMINATION OF REFERENCE CROP EVAPOTRANSPIRATION	
2.1	 Blaney Criddle method	4
2.2	Radiation method	8
2.3	Modified Penman method	15
2.4	Pan Evaporation method	28
2.5	Hargreaves method	32
3	COMPARISON OF HARGREAVES METHOD OF ESTIMATING REFERENCE CROP EVAPOTRANSPIR- ATION WITH OTHER COMPUTATIONAL METHODS AT DIFFERENT LOCATIONS.	
3.1	Damien, Haiti	34
3.2	Bangladesh	34
3.3	Aspendale, Australia	35
3.4	Lompoe, California	35
3.5	Seabrook, Newjersey	35
4	PROCEDURE	
4.1	ESTIMATION OF REFERENCE CROP EVAPOT- RANSPIRATION (ET ₀) FOR AGRICULTURAL RESEARCH STATION MAHAILLUPPALLANA	40

TABLE OF CONTENTS (CONTINUED)

Chapter		Page
4.1.1	ET0 from Modified Penman method	40
4.1.2	ET0 from Hargreaves method	40
4.1.3	ET0 from Pan evaporation method	41
4.2	ESTIMATION OF REFERENCE CROP EVAPOTRANSPIRATION (ET0) FOR WEATHER STATION BATTICALOA	41
4.2.1	ET0 from Modified Penman method	41
4.2.2	ET0 from Hargreaves method	41
4.2.3	ET0 from Pan evaporation method	42
4.3	ESTIMATION OF REFERENCE CROP EVAPOTRANSPIRATION (ET0) FOR AGRICULTURAL RESEARCH STATION PERADENIYA	42
4.3.1	ET0 from Hargreaves method	42
4.3.2	ET0 from Pan evaporation method	42
4.4	ESTIMATION OF REFERENCE CROP EVAPOTRANSPIRATION (ET0) FOR VARYING WIND SPEEDS ...	43
4.4.1	ET0 estimates for station Mahailluppallama	43
4.4.2	ET0 estimates for station Batticaloa	43
4.5	RATIO OF THE SQUARE ROOT OF THE DIFFERENCE BETWEEN MAXIMUM AND MINIMUM TEMPERATURES AND RELATIVE HUMIDITY	43
4.6	ESTIMATION OF CROP WATER REQUIREMENT FOR SOYA BEAN CULTIVATION COMMENCING ON JUNE AT MAHAILLUPPALLAN	68
5	RESULTS AND DISCUSSION	
5.1	COMPARISON OF REFERENCE CROP EVAPOTRANSPIRATION FROM DIFFERENT METHODS FOR MAHAILLUPPALLAMA	71
5.2	COMPARISON OF REFERENCE CROP EVAPOTRANSPIRATION FROM DIFFERENT METHODS FOR BATTICALOA	71

TABLE OF CONTENTS (CONTINUED)

Chapter		Page
5.3	COMPARISON OF REFERENCE CROP EVAPOT- RANSPIRATION FROM DIFFERENT METHODS FOR PERADENIYA	72
5.4	COMPARISON OF ETO VALUES OF MODIFIE- D PENMAN METHOD FOR DIFFERENT WIND SPEEDS WITH HARGREAVES METHOD	72
5.5	RELATION BETWEEN MAXIMUM AND MINIMUM TEMPERATURES, RELATIVE HUMIDITY AND WIND SPEED	73
5.6	COMPARISON OF ESTIMATED CROP WATER REQUIREMENTS WITH MEASURED LYSIMETER VALUES FOR SOYA BEANS	73
6	CONCLUSION	82
7	RECOMMENDATIONS FOR FURTHER STUDIES	83
	REFERENCES	84
	APPENDICES	
	Appendix - A Crop coefficients	86
	Appendix - B Measured crop water requirements for soya beans using lysimeters	98
	Appendix - C Wind speed and relative humidity data	100
	Appendix - D Pan evaporation data .	107
	Appendix - E Agro Meteorological data	112



LIST OF TABLES

Table	Page
2.2.1 Values of weighting factor W for the effect of radiation on ET_0 at different temperatures and altitudes.....	10
2.2.2. Extra-terrestrial radiation R_a expressed in equivalent evaporation for Northern hemisphere	11
2.2.3 Mean daily maximum duration of bright sun shine hours N for different months and latitudes	12
2.2.4 Ratio R_s/R_a for different cloudiness values and Ratio n/N for different cloudiness values	13
2.3.1 Saturated vapour pressure e_a in mbar as a function of mean air temperature	18
2.3.2 Vapour pressure e in mbar from dry and wet bulb temperature data (Aspirated psychrometer)	19
2.3.3 Vapour pressure e in mbar from dry and wet bulb temperature data (Non ventilated psychrometer)	20
2.3.4. Vapour pressure e from Dew point temperature	21
2.3.5 Factors for correcting wind speed at heights other than 2m	21
2.3.6 Values of weighting factor W for the effect of radiation on ET_0 at different temperatures and altitudes	22
2.3.7 Extra-terrestrial radiation R_a expressed in equivalent evaporation (Northern Hemisphere)	23
2.3.8 Mean daily maximum duration of bright sun shine hours N for different months and latitudes	24
2.3.9 Correction for temperature $f(t)$ on long wave radiation R_{nl}	25
2.3.10 Correction for vapour pressure $f(e)$ on long wave radiation R_{nl}	25

LIST OF TABLES (CONTINUED)

Table	Page
2.3.11 Correction for the ratio actual and maximum bright sun shine hours $f(n/N)$	26
2.4.1 Pan coefficient k_p for Colorado sunken pan for different ground cover and levels of mean relative humidity and 24 hours wind	29
2.4.2 Pan coefficient k_p for class - A pan for different ground cover and levels of mean relative humidity and 24 hours wind	30
2.4.3 Relation between evaporation from different sunken pans and from Colorado sunken pan for different climatic conditions and pan environments	31
2.5.1 Extra-terrestrial radiation R_a expressed in equivalent evaporation (Northern Hemisphere)	33
3.1.1 Monthly average ratios of lysimeters ET to ET_0 estimated by various methods and standard deviations of ratios for Damien, Haiti	36
3.2.1 Monthly average ratios of estimated values of ET_0 using Hargreaves and Penman method and standard deviation of ratios as percentage of mean ratio for different locations in Bangladesh	37
4.1.1.1 Reference crop evapotranspiration (ET_0) at Mahailuppallama using modified Penman method for year 1979	
-do- for year 1980	
-do- for year 1981	
-do- for year 1982	
-do- for year 1983	
-do- for year 1984	
-do- for year 1985	

LIST OF TABLES (CONTINUED)

Table	Page
And Monthly average values of reference crop evapotranspiration (ET ₀) at Mahailuppallama using Modified Penman method	44
4.1.2.1 Reference crop evapotranspiration (ET ₀) at Mahailuppallama using Hargreaves method for year 1979	
-do- for year 1980	
-do- for year 1981	
-do- for year 1982	
-do- for year 1983	
-do- for year 1984	
-do- for year 1985	
And Monthly average values of reference crop evapotranspiration (ET ₀) at Mahailuppallama using Hargreaves method..	45
4.1.3.1 Reference crop evapotranspiration (ET ₀) at Mahailuppallama using Pan evaporation method for year 1979	46
4.1.3.2 -do- for year 1980	47
4.1.3.3 -do- for year 1981	48
4.1.3.4 -do- for year 1982	49
4.1.3.5 -do- for year 1983	50
4.1.3.6 Monthly average values of reference crop evapotranspiration (ET ₀) at Mahailuppallama using pan evaporation method	51
4.2.1.1 Reference crop evapotranspiration (ET ₀) at Batticaloa using Modified Penman method for year 1979	
-do - for year 1980	



University of Moratuwa, Sri Lanka

Electronic Theses & Dissertations

www.moratuwa.ac.lk

LIST OF TABLES (CONTINUED)

Table	Page
-do - for year 1981	
-do - for year 1982	
-do- for year 1983	
-do- for year 1984	
-do- for year 1985	
And Monthly average values of reference crop evapotranspiration (ET ₀) at Batticaloa using Modified Penman method	52
4.2.2.1 Reference crop evapotranspiration (ET ₀) at Batticaloa using Hargreaves method for year 1979	
-do- for year 1980	
-do- for year 1981	
-do- for year 1982	
-do- for year 1983	
-do- for year 1984	
-do- for year 1985	
And Monthly average values of ET ₀ at Batticaloa using Hargreaves method	53
4.2.3.1 Reference crop evapotranspiration at Umnichehi using measured pan evaporation	54
4.3.1.1 Reference crop evapotranspiration at Peradeniya using Hargreaves method for year 1979	
-do- year 1980	
-do- year 1981	
-do- year 1982	
-do- year 1983	
-do- year 1984	



LIST OF TABLES (CONTINUED)

Table		Page
	-do- year 1985	
	And Monthly average values of ET ₀ at Peradeniya using Hargreaves method	55
4.3.2.1	Reference crop evapotranspiration (ET ₀) at Peradeniya using measured pan evaporation for year 1979	56
4.3.2.2	-do- year 1980	57
4.3.2.3	-do- year 1981	58
4.3.2.4	-do- year 1982	59
4.3.2.5	-do- year 1983	60
4.3.2.6	-do- year 1984	61
4.3.2.7	-do- year 1985	62
4.3.2.8	Monthly average values of ET ₀ at Peradeniya using Pan evaporation method	63
4.4.1.1	Reference crop evapotranspiration at Mahalluppallama for varying wind speeds	64
4.6.1	Reference crop evapotranspiration at Batticaloa for varying wind speeds	66
4.4.2.1	Estimated evapotranspiration of soya beans	70
5.5.1	Ratio root of difference between maximum and minimum temperatures to Relative Humidity for all the months from 1979 to 1985 at various stations	80
A-1	Crop coefficient (kc) for field and vegetable crops for different stages of crop growth and prevailing climatic conditions	90
A-2	Length of growing seasons and crop devel- opment stages of selected field crops	93
A-3	Crop coefficient (kc) for rice	97

LIST OF TABLES (CONTINUED)

Table		Page
C-1	Wind speed data at 2m height for station Mahalluppallama	101
C-2	-do- for station Batticaloa.	102
C-3	-do- for station Peradeniya.	103
C-4	Relative Humidity data for station Mahalluppallama	104
C-5	-do- for station Peradeniya.	105
C-6	-do- for station Batticaloa.	106
D-1	Pan evaporation data for station Mahalluppallama.....	108
D-2	-do- for station Unnichchi ..	109
D-3	-do- for station Peradeniya .	111
E-1 to E-7	Agro meteorological data from year 1979 to 1985 for station Peradeniya	113
E-8 to E-14	-do- for station Mahalluppallama	120
E-15 to E-21	Agro meteorological data from year 1979 to 1985 for station Batticaloa	127



LIST OF FIGURES

Figure	Page
2.1.1 Prediction of ETO from Blaney-Criddle f factor for different conditions of minimum Relative Humidity, daily sun shine hours and day time wind	7
2.2.1 Relationships for obtaining ETO from calculated values of W.Rs and general knowledge of mean relative Humidity and day time wind	14
2.3.1 Correction on calculated ETO* (Penman) for day and night time wind and Humidity conditions	27
3.3.1 Measured and estimated potential evapotra- nspiration at Aspendale, Australia	38
3.4.1 Measured and estimated potential evapotra- nspiration at Lompoc, California	38
3.5.1 Measured and estimated potential evapotra- nspiration at Seabrook, New Jersey	39
4.6.1 Crop coefficient curve for soya beans .	69
5.1.1 Reference crop evapotranspiration at Mahailuppallama from different methods	75
5.2.1 Reference crop evapotranspiration at Batticaloa from different methods	76
5.3.1 Reference crop evapotranspiration at Peradeniya from different methods	77
5.4.1 Reference crop evapotranspiration at Mahailuppallama for varying wind speeds	78
5.4.2 Reference crop evapotranspiration at Batticaloa for varying wind speeds	79
5.5.1 Relation between square root of diffe- rence between maximum and minimum tem- peratures, relative humidity, wind speed and the value (ET Hargreaves - ET Pan evaporation) for different months	81
A-1 Average crop coefficient (kc) for unit- ill stage as a function of average ETO level and frequency of irrigation or of significant rain	88

LIST OF FIGURES (CONTINUED)

Figure		Page
A-2	Example of crop coefficient curve for Maize	89



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

ea	-	saturated vapour pressure at mean air temperature
ed	-	mean actual vapour pressure
ET	-	evapotranspiration
ETcrop	-	crop evapotranspiration
Epan	-	pan evaporation
ET0	-	reference crop evapotranspiration
ET0*	-	reference crop evapotranspiration not adjusted
f	-	consumptive use factor
f(ed)	-	function of ed
f(n/N)	-	function of n/N
f(t)	-	function of temperature
f(u)	-	function of wind
k	-	consumptive use crop factor
kc	-	crop coefficient
kp	-	pan coefficient
L	-	reflection coefficient
n	-	measured bright sunshine hours
N	-	maximum possible sunshine hours
p	-	percentage of day time hours
Ra	-	extraterrestrial radiation
RH	-	relative humidity
RH mean	-	mean relative humidity
RH min	-	minimum relative humidity
Rn	-	net radiation
Rnl	-	net long wave radiation
Rns	-	net short wave radiation
Rs	-	solar radiation
t	-	temperature
Tc	-	mean temperature
TD	-	difference of maximum and minimum temperatures
U	-	wind speed
U2	-	wind speed at 2m height
w	-	temperature related weighting factor

ABBREVIATIONS

c	-	celsius
cm	-	centimetre
dia	-	diameter
ft	-	feet
F.A.O.	-	food and agricultural organisation
hr	-	hour
Ha	-	hectare
in	-	inch
km	-	kilometre
km/day	-	kilometres per day

km/hr	-	kilometres per hour
m	-	meter
m	-	meter square
m.bars	-	millibars
mm	-	millimetre
mm/d	-	millimetres per day
m/sec	-	meters per second
M.S.L.	-	mean sea level
°N	-	northing
T	-	tonne



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

ABSTRACT

Considering the problems associated with the availability and reliability of climatic data in developing countries and the possible errors in the more sophisticated methods for estimating crop water requirements, it has become necessary to develop a computational procedure which requires least and widely available data.

The method of estimating reference crop evapotranspiration (ET₀) from measured temperature introduced by professor Hargreaves of Utah State University in 1982 has given satisfactory results in many regions of the world. The study of its applicability to Sri-Lanka could do much to improve irrigation and agricultural sectors.

Three stations from different climatic regions of Sri-Lanka were selected with the intention of studying the applicability of this new method. ET₀ estimates from Modified Penman, Hargreaves and Pan evaporation methods were computed for seven years and the average values were compared. The results indicated that the Hargreaves method provides satisfactory results for Yala seasons in dry zone. The application of Hargreaves method can be extended even to Maha seasons in dry coastal regions.

The ET₀ estimates from Modified Penman method have given over predictions specially for high wind velocities.

Two average years were selected for station Mahailuppallama and Batticaloa. ET₀ estimates from Modified Penman were computed for varying wind speeds. The results have shown that a local calibration is required for the aerodynamic term of Modified Penman equation.

A relationship has been developed between maximum and minimum temperatures, relative humidity, wind speed and the deviation of ET₀ values of Hargreaves method from pan evaporation method. This indicated that for given temperatures and relative humidity, Hargreaves method provides better results only for a particular range of wind speed.

Estimated crop evapotranspiration (ET crop) for soya beans from Hargreaves and Pan evaporation methods were compared with lysimeter measurements for Agricultural Research Station Mahailuppallama. The total estimated ET crop from Hargreaves method has only varied 5.6 % from the measured lysimeter values.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

INTRODUCTION

With limited water and fertile land and with the increase in population, the need for more and better food production has become an important matter for most regions of the world.

The fundamental questions to be asked from a person who is trying to solve this problem are regarding the avenues available to improve food production. These avenues could be summarised as follows.

1. Development of new fertile land that can be made productive with the available water resources.
2. Suitable practices to use fertilisers and pesticides.
3. Use of improved varieties of plants and crops.
4. Proper management of irrigation water, both in conveyance and field levels.
5. Conversion from surface to drip or sprinkle systems whenever conditions of soils, topography and economics indicate clear advantages.
6. Looking for improved estimates of crop water requirements.

This study deals with the last of the six avenues.

For effective planning, scheduling and operation of irrigation systems and for feasibility studies of proposed irrigation projects, the accurate quantitative prediction of crop water plays a major role.

Several methods are available for the estimation of potential evapotranspiration of a reference crop or reference crop evapotranspiration (ET₀). Evapotranspiration for other crops can be estimated using ET₀ and established crop coefficients which are presented accounting crop characteristics, time of planting or sowing, the general climatic conditions and stages of crop development.

Four widely used methods recommended by Food and Agricultural Organisation for the computation of reference crop evapotranspiration are Blaney-Cridde, Modified Penman, Radiation and Pan evaporation. These methods require measured and estimated data for a reference area. But in many developing countries data may be incomplete and estimates or data from other locations are used for computations. For example, climatic data for estimating ET₀ may be taken from

airports, arid hilly locations or from other irrigated areas dissimilar to the areas for which ETO computations are needed. Therefore it has become important to develop computational procedures which require minimum and widely available data. These procedures should provide reliable results.

Mcvicker(1982) calibrated 12 methods for estimating Reference crop evapotranspiration (ET₀) which are based on air temperature and incoming solar radiation (R_s). He compared their performances for two locations Davis, California and Logan, Utah. The best six methods ranked in order of the smaller root mean square error are Hargreaves, Jensen-Haise, Stephens and Stewart, Makkink, Turc and Grassi. All these performed better than Penman equation.

Shih (1984) evaluated the data requirements for evapotranspiration estimates. The estimates from nine climatic variables were compared with calculated values using two variables of air temperature and solar radiation. The two variables provided satisfactory estimates for Southern Florida.

Several methods for estimating reference crop evapotranspiration (ET₀) were compared by Salih and Sendil (1984) using ET₀ data from Alfalfa for two sites in Al-Hassa region of Saudi Arabia. Field plot technique was used at one site and a lysimeter at the other. Statistically based evaluation was done. The results ranked are Jensen-Haise and the class-A Pan methods in first place, Hargreaves method next and then Penman & Modified Penman.

The study by Mcvicker (1982), the comparisons made by Shih (1984) and those by Salih and Sendi (1984) indicated that two climatic variables of mean air temperature and global solar radiation can be used to provide satisfactory estimates of potential evapotranspiration (ET₀) at most locations. However some judgement or local calibration may be desirable for advective conditions of wind which provides significant cooling or heating of the reference area. The study of the applicability of these new methods to Sri-Lanka could be much useful and could do much to improve irrigation planning, designs and scheduling.

OBJECTIVE

Considering the problems associated with the availability and reliability of climatic data and the possible errors in the more sophisticated methods for estimating crop water requirements, it is very much useful to study a method of estimating reference crop evapotranspiration with minimum and widely available data and which provides reliable results.

The general objectives of this study are as follows

- (a) Determine and compare the reference crop evapotranspiration (ET₀) from Hargreaves method (1982) with other methods for Agricultural Research Station Mahalluppallama.
- (b) Repeating the above, for weather station Batticaloa and Research Station Peradeniya.
- (c) Study of the applicability of Hargreaves method (1982) for specific areas in Sri-Lanka.



University of Moratuwa, Sri Lanka

Electronic Theses & Dissertations

www.lib.mrt.ac.lk