CROP WATER REQUIREMENT FOR BAKRAJO AREA IN SULAIMANYIA GOVERNORATE

A THESIS
SUBMITTED TO THE COUNCIL OF THE
COLLEGE OF ENGINEERING
UNIVERSITY OF SULAIMANIA
AS
A PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR
MASTER DEGREE
IN
IRRIGATION ENGINEERING

BY

NAWROZ MAHMOOD AZIZ
B.Sc. In Irrigation Engineering
UNIVERSITY OF SULAIMANIA
June, 1999

Supervised by

Prof. Dr. Rozgar Baban

And

Ass. Prof. Basil Y. Mustafa

2007 ***2707***

بسم الله الرحمن الرحيم

يا أيها الناس إن كنتم في ريب من البعث فإنا خلقناكم من تراب ثم
من نطفة ثم من علقة ثم من مضغة مخلقة وغير مخلقة لنبين لكم
ونقر في الأرحام ما نشاء إلى أجل مسمى ثم نخرجكم طفلا ثم لتبلغوا
أشدكم ومنكم من يتوفى ومنكم من يرد إلى أرذل العمر لكيلا يعلم من
بعد علم شيئا وترى الأرض هامدة فإذا أنزلنا عليها الماء اهتزت
وربت وأنبتت من كل زوج بهيج

صدق الله العظيم

سورة الحج
الآية 5

I certify that this thesis was prepared under my supervision at the University of Sulaimnyia as a partial requirement for the degree of Master in Irrigation Engineering.

Signature: …………………………

Advisor name: Basil Y. Mustafa.
Title: Assistant Professor.

Date: ………..,………….., 2008

In the view of the available recommendation, I forward this thesis for debate by the examining committee.

Signature: …………………………
Name: Prof. Dr. Sheirko Shakir Fettah
Head of Post-Graduate Studies committee

Date:………..…..,………….., 2008

We certify that we have read this thesis and as examining committee, examined the student in its contents and in what connected with it and that in our opinion it meets the standard of a thesis for the Master degree in Irrigation Engineering Sciences.

Signature:…………………

Name: Dr. Rafa H. Al-Suhaily
Professor
(Member)

Date:…………,…….., 2008

Signature:…………………

Name: Dr. Numa H. Imara
Professor
(Member)

Date: ………. , ...….., 2008

Signature:……………..…………

Name: Dr. Karim K. Al-Jumaily
Professor
(Chairman)

Date: ………..,………….., 2008.

Signature:……………..…………

Name: Basil Y. Mustafa.
Assistant Professor.
(Supervisor)

Date: ………..,………….., 2008.

Approval of the college of Engineering:

Signature:…………………

Name: Dr. Kamal Ahmad Rashed
Dean of the College of Engineering.

…………../…..………../2008

Dedicated to:

-The soul of the late Dr. Rozgar Baban
My supervisor
- My father and Mother,
-My brother and sister,
-My Wife and my son,
- My relatives
And
-All my friends.

ACKNOWLEDGMENTS

My great thanks to the creator "Allah", for giving me power and ability to finish this study.

Sincere thanks and appreciation are extended to my supervisor the late Dr. Rozgar Baban and assistant professor Mr. Basil Y. Mustafa for their scientific suggestions and continuous support during the entire period of the study.

Iam greatly indebted to my co. advisor, assistant professor Mr. Basil for his persistent encouragement and boundless help which made this work performed.

I would like to express my deep gratitude and thanks to Dr. Kamal Ahmad Rasheed, the dean of engineering college for his support to accomplish this study.

I express my thanks to the Presidency of Sulaimnyia University, and all the staff member of irrigation department for their help.

Special thank to each member of the examination committee for revising the thesis and offering constructive suggestions.

Finally, many thanks to my father and to all friends who support me to perform this study.

ABSTRACT

Effective use of water supplies via irrigation requires good methods for determining crop water needs, and to implement irrigation scheduling, an estimation of water consumption for the crop is essential.

Because full climatological data and weather variables are not available most of the time, therefore, in this research, two methods which require minimum climatological data were used as Hargreaves and Blaney-Criddle methods to calculate the crop water requirements. The obtained result can be used in the design of the hydraulic structures waterway (Weir, Barrage, and intake structure) also in defining the irrigation conveyance canal parameters such as its width or depth.

The procedure of calculation depends on minimum climatological data especially minimum and maximum daily air temperature to obtain the average reference evapo-transpitaion (ETo).The results show a good accuracy when the mean average values of this two method is compared with other basic methods such as Penman equations.

Frequency analysis is used to extend the values of rainfall, effective rainfall and average reference evapo-transpitaion to find water crop requirement for different return periods to overcome any unforeseen and unexpected weather variation in the future.

TABLE OF CONTENT

Acknowledgements ……………………… …………………………VII
Abstract ………………………………..……………………………VIII
Table of contents ………………………………………………..……IX
List of symbols ……………………………………………...……XV
List of tables ……..…………………………………………….…..…XVII
List of figures and photos........…………………………………….XVIII.

CHAPTER ONE/ INTRODUCTION…….……….…………….1.

1.1 General……………...…………………………………..…..…1
1.2 Components of irrigation scheduling………...………………………4
1.3 The aim of the study……………………...……………………...4

CHAPTER TOW/ LITERATURE REVIEW………...……..…5

2.1 Introduction………..…………………………………………………5
2.2 Methods and formulas used to calculate evapotraspiration (ETo)………5
2.2.1 Penman formula (1948) and Modified Penman method (1977)...……5
2.2.2 Thornthwaite formula (1948)………………….. …………………7
2.2.3 Blaney – Criddle formula (1950) and modified Blaney – Criddle method (1975) ……………………………………………….……….8
2.2.4 Radiation method (1957)………………….. ……………………..10

2.2.5 Oliver method (1961) ……………………………...………….. . . 11

2.2.6 Evaporation method (1968)…………………….. ………………..11

2.2.7 Hargreaves Method (1985)…...……………………...……………...12

2.2.8 Energy Balance Method ………………..……………..…………..13

2.3 Researches on evapotraspiration (ETo) ……………..……………..14

2.3.1 Evapotraspiration estimation under deficient water supplies [J. L.]…14

2.3.2 Computation of ETO under non ideal conditions [Jensen, Hargreaves, Fellow, B. Temesegan and Allen, 1995] …………..……………………...15

2.3.3 Decision support system for estimating reference evapotraspiration [George, Reddy, Raghuwanshi and Wallender, 1995]……….. …………...16

2.3.4 Comparison of methods for estimating reference ET [S. Mohan and N. Arumugam, 1995] …………………………..……………………...16

2.3.5 Hourly grass evapotraspiration in modified maritime environment [Samuel O. Ortege – Farias, H. Cuenca and M. English, 1996]………. ….17

2.3.6 Analytical estimation of modified Penman equation parameters [Kotsopoulos and C. Babjimopoulos, 1998] …………………..…..17

2.3.7 Estimating solar radiation and evapotraspiration using minimum climatologically data [Zohrab Samani, 2000] ………..………....19

2.3.8 Estimating actual evapotraspiration form limited climatic data using neural computing technique (ANN), [Sudheer, Gosain and Ramasastri, 2000] ……………………………………..………...20

2.3.9 Reference evapotraspiration estimation in highly advective semiarid.

A- Methods based on temperature measurements……………………..…..21

1. Hargreaves equation (equation 2.12) as proposed by [Hargreaves and Samani, 1985]…………………………….. ……………………………21

2. FAO -24 Blaney Criddle as proposed by [Allen and Pruitt, 1988]….. …21

B- Methods based on radiation……………………………………...……...22

1. Makkink (1957) as proposed by [Frevert, 1983] below……………..….22

2. Ritchie type as proposed by [Jones and Ritchie, 1990] …………..…….22

3. Priestley – Taylor (1972) as proposed by [Jury and Tanner, 1975]……..22

C .Methods based on combination equation – Energy balance and aerodynamic transport of water vapor (Penman, 1948)……..……. ……23

CHAPTER THREE/ DATA COLLECTION AND FIELDWORK……………………………….……………….......24

3.1 Introduction……………………..…………………………………..24

3.2 Geology and geomorphology for the study area…………………...…..25

3.3 Data Collection…………………………………………………………26

3.4 Field works…………………………………...…………………...27

3.4.1 Soil sample collections ……………………….…………...……………27

3.4.2 Land survey ……………………………………………….……………27

3.4.3 Cropping pattern and crop intensity with its growing period for the area under study……………………………………………….…………28

CHAPTER FOUR/ APPLICATION OF METHODS TO BAKRAJO AREA AND RESULTS DISCUSSIONS…………29

4.1 Introduction …………………………...……………………………......29

4.2 Methodology, Data Analysis and Calculations ……………………..……30

4.2.1 Stage procedure for calculating crop water requirements …..………30

4.2.2 Calculating the net depth of irrigation (In) and monthly water requirements for each crop types …………………………...…………...39

4.2.2.1 Effective rainfall (Pe)…………………………….. ……………40

4.2.2.2 Ground water contribution (Ge)……………………… …..…....42

4.2.2.3 Sorted soil water or Abstraction from soil moisture (Wb) ……..…42

4.2.2.4 Leaching Requirements (LR)……………………… ………..….43

4.2.2.5 Irrigation Efficiency …………………………………...….45

4.2.3 Frequency distribution analysis …………………………...………47

4.3 Results & Discussion ……………………………………...……...49

4.3.1 Comparison of calculated seasonal ETcrop with standard seasonal ETcrop values …………………………………………..……………49

4.3.2 Checking the calculated average ETO by Hargreaves and Blaney Criddle with modified Penman method ……...…………………….………50

CHAPTER FIVE /CONCLUSIONS AND RECOMENDATIONS………………………………………..52

5.1 Conclusions……………………..……………….………………..52

5.2 Recommendations …………………………………...………......53

Annexes………………………………………………………

References ………………………………………………………..54

Annex 1 (Tables)……………………………………………………….59

Annex 2 (Figures)……………………...…………………………….85

LIST OF SYMBOLS

SYMBOLS	DESCRIPTIONS	UNITS	DIMENSIONS
ETo	Reference evapotraspiration	mm/day	L/T
ETcrop	Reference crop evapotraspiration	mm/day	L/T
C	Adjustment factor	unit less	N/A
Δ	Slope of saturation vapor pressure	Millibars/C^o	FL^{-2}/t
γ	Psychometric constant .	Millibars/C^o	FL^{-2}/t
U	Wind function.	unit less	N/A
e_s ,e_d	Saturation and actual vapor pressure.	Millibars	FL^{-2}
R_N	Net radiation.	mm/day	L/T
R_a	Extraterrestrial radiation.	Unit less	N/A
e	Unadjusted evapotraspiration.	cm/month	L/T
t	Means air temperature.	C^o	T
I	Annual or seasonal heat index	unit less	N/A
a	An empirical exponent.	unit less	N/A
T	Mean daily temperature.	C^o	T
P	Mean daily percentage of total annual daytime hours.	unit less	N/A
Rs	Solar radiation in equivalent evaporation.	mm/day	L/T
W	Cyclic factor	unit less	N/A
Kp	Pan coefficient. ...	unit less	N/A
ΔT	Tem. Range between mean daily max. & min.	C^o	T
T_{ave}	Daily mean air temp.	C^o	T
Rn	Radiation balance at the surface (net radiation)	mm/day	L/T
G	Rate at which the heat content of the soil or water columns change.		N/A
H	Seasonable heat transfer.	mm/day	L/T
LE	Latent heat flux.	mm/day	L/T
ΔF	Net sub – surface horizontal flux of sensible heat out of the column.		N/A
α	Priestley- Taylor coefficient.	unit less	N/A

SYMBOLS	DESCRIPTIONS	UNITS	DIMENSIONS
RH_{max}	Max relative humidity	unit less	N/A
U_d	Mean wind velocity during day hours	m/sec	L/T
U_r	Day to night wind ratio between daytime	unit less	N/A
TD	Max. daily temperature	C^o	T
KT	Empirical coefficient.	unit less	N/A
TC	Average daily temperature.	C^o	T
ET_{ANN}	Particular evapotraspiration	mm/day	L/T
b_o & b_1	Regression coefficients.	unit less	N/A
RH_{min}	Minimum relative humidity	unit less	N/A
n/N	Ratio of actual and maximum sunshine hours.	unit less	N/A
Ta	Average air temperature.	C^o	T
b	Empirical coefficient.	unit less	N/A
T_{max}	Maximum minimum air temperature	C^o	T
T_{min}	Minimum air temperature	C^o	T
In	Net depth of irrigation	mm	L
Pe	Effective rainfall	mm	L.
Ge	Ground water contribution	mm	L
Wb	Stored soil water	mm	L
Ep	Project irrigation efficiency	unit less	N/A.
A	Acreage under a given crop.	unit less	N/A
ETcrop	Crop evapo-transpitaion.	mm/day	L/T
LR	Leaching requirements.	mm/day	L/T
ECw	Electrical conductivity of irrigation water	mmhos/cm	E/L
ECe	Electrical conductivity of the soil saturation.	mmhos/cm	E/L
X	Values of the variant , which has a return period (T).	unit less	N/A
$X^/$	Mean of the variant.	unit less	N/A
K	Frequency factor	unit less	N/A
$б_x$	Standard deviation of the variant.	unit less	N/A
YT	Reduced variant.	unit less	N/A
Sn	Reduced mean.	unit less	N/A

LIST OF TABLES

TABLE NO. TITLE PAGE NO.

1………………………Average daily air temperature…………………..……..……….59

2………………… ETo calculation by Hargreaves…….……………………..…………..60.

3………………… ETo calculation by Blaney……..……………………….…..……..61.

4…………………Average ETo values……...…………………….………………………..62.

5……… ………..ETo calculation by Penman method.…….…………………….…….63

6………………...ETo comparison…….…………………………………………………..64.

7……………….. frequency analysis for ETo.…………………………...…………..65.

8………………… Average ETo values ……………………………...…………..66.

9………………… Average monthly rainfall values ………..………..…………..67.

10…...................... frequency analysis for rainfall … ……………………..………… 68.

11……….……… Effective rainfall calculations……………………………...….…..69

12………………. Monthly effective rainfall with crop periods……..…………..……..70

13… …………….Leaching requirements for crops.……………………………..……..71

14……………….Monthly ETcrop calculations.…………………..……..……………..72

15……………..... Monthly and seasonal water supply calculations.…..…………….……..78

15………………. Monthly and seasonal water supply calculations..………..………..79

16…………….......Total monthly ETcrop and water supply.……………………….……..80

17…………….......Monthly daily percent (p)……………...………………………..……..81

18…………….....................Radiation (Ra)……………...……………………….……..82

19…………….......Soil sample test result ….………………...……………………..……..83

20…………….......Summary table of ETo….………………...……………………..……..84

LIST OF MAPS, FIGURES AND PHOTOS

MAP NO. DESCRIPTIONS PAGE NO.

Fig. 1…………………………......Site contour map……………….……………………85
Fig. 2…………….………….......Satellite Image for the research Area………………..86
Fig. 3…………….………….......Crops types with their area…………………………..87
Fig. 4 &5…..………………………..Irrigation land photos…………………………….88
Fig 6 &7……….…..... ………….Irrigation land photos………………………………89
Fig.8………............................ ETo graph by Hargreaves………………….……..……90
Fig. 9…..……………………. ETo graph by Blaney……………..………...…………...91
Fig. 10….………….……….…… Average ETo…..…………………….………......92
Fig. 11……………….……………Crop coefficient curves……………………………93
Fig. 12……….……………………..Frequency curve for ETo……………..………...94

CHAPTER ONE

INTRODUCTION

1.1 *General:*

Crop water requirements (C.W.R) is defined as the water depth needed to meet the water losses through Evapotraspiration (ETcrop) of a diseases – free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment [Doorenbos, 1992].

In order to maintain the optimum level of water in the root zone and to schedule irrigation, the assessment of water requirement is essential. Water requirement of crop will vary depending on crop types, soil types, and atmospheric demand for the water.

Natural resources, soil, water, plants, and wildlife are the major sources of the national wealth, but today population development has caused an extensive use of such resources in different locations. For BAKRAJO area the, most challenges which face the farmers are weather change, especially in regularity of rainfall and air temperature changes, which affects on their product intern, therefore conservations of such the existing resources necessitate their wise uses in such away that great benefits are derived through providing regulated and clean water supply, controlling damaging floods and keeping plant productivity at the desired levels. The wise use of water supply implies their proper managements.

The need for calculating and estimating the crop water requirements in a specific location is usually realized through repeated requests of a group of farmers to the local authorities, to solve some problems which usually follow the deterioration of their crop. Wherever a group of farmers actually have problems maintaining the crop yield, it can be observed that they themselves have tried in traditional ways to overcome their dilemma. Visiting the proposed location and questioning the farmers about their living conditions reveal many social and economic factors which have to be considered before any investment is committed to the project.

Survey and investigations are needed to pinpoint major problems and establish management policies and priorities. Most of the investigations include characterization of the existing water resources with reference to climate, hydrology, geology, vegetation, soil, land use, socio-economic conditions and wildlife. Gathering information on the climatic parameters for defining the crop water requirements is a key factor to obtain the optimum use of water and subsequently obtain the maximum crop yield productions.

The growth of the most of crops is retarded by either excessive or deficient amount of soil moisture content. The excessive moisture content in the soil results in filling the soil pore spaces completely with water, thus driving out air from the soil in the root zone. Since for satisfactory plant growth the presence of air is essential, and the absence of enough air retards the plant growth and finally the crop production. Therefore, to overcome this matter an adequate estimation of crop water demand is essential [Michael, 1978].

It appears that a crop water requirement plays an important role in the natural economy of the country; therefore there must be a policy of the regional government to strengthen efforts to regain the water sources through rehabilitation programs.

A crop usually requires certain amount of water at certain fixed intervals throughout its period of growth. The objective of determining the crop water requirements is to make water available to cultivators with respect to location, time and quantity per the crop requirements [Sharma, 2004].

Crop evapotraspiration (ETcrop) is the key component in hydrological studies, irrigation scheduling, regional water balance and agro metrological zoning; therefore, effective use of water supply via irrigation requires good methods for determining crop water requirements (C.W.R) as it is essential for the plant growth with its development and basically influences the crop productions.

Crop water requirements vary widely from crop to crop and during the growing period of an individual crop; therefore, the concept of reference crop (ETO) is introduced to avoid ambiguities that exist in the definition of the potential ETO and the need to calibrate a separate ET equation from each crop and stage of growth.

The implementation of an irrigation schedule requires an accurate estimate of water used by the crop. The cropping pattern is usually decided on social, economic and soil type basis, while the size of the irrigated area is based on the availability of land and water resources, in which the availability of the land is estimated from topographic map of the area and the water resources from the all the time [GUPTA, 1999], Therefore, Crop water requirements (C.W.R) or consumptive use is thus the sum of two terms:

- Transpiration, which is the water entering the plant roots and used to build plant tissues or being passed through the leaves of plant into the atmosphere air. Transpiration is essentially confined to daylight hours and the rate of transpiration depends upon the growth periods of the plant.
- Evaporation, which is the water evaporating from adjacent soil, water surface or from surfaces of leaves of the plant. And it continues to proceed through the day and night although the rates are different [Subramanya, 1984].

Finally establishing the evapotraspiration curve is an important prerequisite for any irrigation development undertaking. However, the conversion of the values thus obtained into region-wide, standardized water requirement figures is bound to cause hardship and injustice to some of farmers in an irrigated farm community [Josef, 1966].

1.2 *Components of irrigation scheduling:*

Irrigation scheduling requires four essential components [Allen, 1995]:

1. An estimation of the water extracted from the available root zone moisture.
2. The projected rate of depletion of remaining soil water.
3. An accurate measure of the water supplied by precipitations.
4. An accurate estimate of the amount of water applied through irrigation.

1.3 *The aim of the study:*

This research program initiates after selecting BAKRAJO land area in Sulaimnyia governorate because of its high agricultural potential, and the main objectives are:

1. To determine the crop water required for BAKRAJO area.

2. To characterize the selected area in Sulaimnyia city with particular references to climate, geology, vegetation, soil, and crop rotation with its intensity.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction:

The crop water requirement has received a great concern from many researchers who tried to find a mathematical expression showing the effect of the different variables and climatological data on the route of crop water requirements. However these trails of the researchers are still limited.

The researches reviewed in this chapter are of practical pattern as a number of researchers tried to identify the importance of crop water requirement and also to overcome the restrictions resulted from shortage in the climatological data.

Various equations are available for estimating (ETo). These equations range from the most complex energy balance equation requiring detailed climatologically data (Allen, 1989) to simpler equation requiring limited data (Blaney and Criddle, 1950; Hargreaves and Samani, 1982-1985).

2.2 Methods and formulas used to calculate evapotraspiration (ETo):

The following methods for determining (ETo) are presented in chronological:

2.2.1 Penman formula (1948) and Modified Penman method (1977).

For areas where measured data of temperature, humidity and sunshine duration or radiation are available, an adaptation of the Penman method (1948) is suggested.

The original Penman method (1948) equation predicted evaporation losses from an open water surface. Experimentally determined crop coefficients were ranging from (0.6) in winter to (0.8) in summer months.

The Penman equation consists of two terms; the energy (radiation) term and the aerodynamic (wind and humidity) term. The relative importance of each term varies with climatic conditions. Under calm weather conditions the aerodynamic term is usually less important than the energy term. In such conditions the original Penman ETo equations using a crop coefficient 0.8 has been shown to predict ETo closely, not only in cool, humid regions but also in very hot, and semi- arid regions.

Under windy conditions and particularly in more arid regions that the aerodynamic term becomes relatively more important and thus errors can result in predicting ETo when using 0.8 ETo.

The procedure to calculate ETo may seem rather complicated. This is due to the fact that the formula contains components which need to be derived from measured related climatic data when no direct measurements of needed variables are available. For instance, for places where no direct measurements of net radiation are available, these can be obtained from measured solar radiation, sunshine duration or cloudiness observation, together with measured humidity and temperature.

The recommended modified Penman relationship representing mean value over the given period is expressed as [Doorenbos and Pruitt, 1977].

$$ETo = C \left[\Delta/(\Delta+\gamma) * R_N + \gamma/(\Delta+\gamma) * f\,(u)\,(e_s - e_d)\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where:

ETo = Reference crop evapotraspiration (mm/day).

C = Adjustment factor to incorporate the difference between day and night weather condition.

Δ = slope of saturation vapor pressure – temperature curve (millibars/^{o}C).

γ = psychometric constant (millibars/^{o}C).

f researches (u) = Wind function.

$e_s - e_d$ = saturation and actual vapor pressure (millibars).

R_N = Net radiation (mm/day) and it is estimated as a function of the extraterrestrial radiation (R_a) and the maximum sunshine hours (N) [Doorenbos and Pruitt, 1977].

Compared to other methods presented below method likely to provide the most satisfactory results (Doorenbos, 1992).

The Penman equation is widely recommended because of its detailed theoretical base and its accommodation of minor periods. However the detailed climatologically data required by Penman are not often available, especially in developing countries, On the other hand, the instruments used to measure the weather parameter, especially solar radiation and humidity, are often subjected to stability errors.

In this method ET crop are computed using the principal of energy budget method and mass transfer theory. Hence it is more sophisticated than other methods, and then it is complicated to compute [B.L.GUPTA, 1999].

2.2.2 Thornthwaite formula (1948).

Thornthwaite (1948) assumed that the amount of water lost through evapotraspiration from a soil surface covered with vegetation is governed by climate factors and is independent of species when moisture supply is not limiting [R.D. Misra, 1973].The drawback of this formula was enumerated by Chang, 1968. The formula into original forms is:

$$e=1.6\,(10t/I)^a \qquad \text{.....................} (2.2)$$

Where:

(e) = unadjusted evapotraspiration cm/month.

(t) = mean air temperature C^o.

(I) = annual or seasonal heat index, the summation of 12 values of monthly heat indices.

ANNEX 2 - Figures

ANNEX 1 - Tables

REFERENCES

1. A.M. Michael ; "Irrigation theory and practice", second Edition, Vikas publishing house PVT, 1999.

2. Ahmed S. A. Hussein; "Grass ET estimation using Penman - type equation", Journal of Irrigation and Drainage Engineering, **Vol.** 125, Paper No. (6), February 1999.

3. Al – Khalid; "Hydrologic studies for Goizha – Dabashan and other water sheds in Sulaimani governorate", M. Sc. thesis submitted to Sulaimani University, college of Agriculture, 2003.

4. B.L. Gupta, "Engineering Hydrology", Third Edition, Jain publishing distributors, 1999.

5. Berengena and P.Gavilan; "Reference evapotraspiration estimation in highly advective semiarid environment", Journal of Irrigation and Drainage Engineering, **Vol. 131**, paper no. (2), 2003.

6. Biju A. George, B. R. S. Reddy, N. S. Raghuwanshi and W. W. Wallender, "Decision support system for estimating reference evapotraspiration", Journal of Irrigation and Drainage Engineering, **Vol. 128**, Paper no. (1), 2001.

7. Bekele Temesgen, Simon Eching, "Baryohay Davidoff and Kent Frame; Comparison of some reference evapotraspiration equations", Journal of Irrigation and Drainage Engineering , **Vol. 131**, paper no. (1). 2004

8. Chow, V.T, "Hand book of applied hydrology" second Edition,. Mc Graw – Hill book Co., New York, 1964.

9. C. M. Burt, A. Mutziger, R. G. Allen and T. A. Howell; "Evaporation research, review and interpolation", Journal of Irrigation and Drainage Engineering, Vol. 131, Paper no. (1). 2003

10. J. Doorenbos and W.O. Pruitt; "Crop water requirement", second Edition, FAO Irrigation and Drainage paper no. (24), 1992.

11. D.T. Hargreaves, Fellow, B. Temesegan and Allen; "Computation of ETo under non ideal conditions", Journal of Irrigation and Drainage Engineering, Vol. 128, no. (5), 2005

12. Daniel Itenfisu, Ronald L. Elliott, Richard G. Allen and Ivan A. Waller; "Comparison of reference evapotraspiration calculations as part of the ASCE standardization effort", Journal of Irrigation and Drainage Engineering, Vol. 129, paper no. (6), 2003

13. Harold M. Kautz and James A. Aull; "Engineering field manual", First Edition, 1982.

15. Josef D. Zimmermsn; "Irrigation" , First Edition, John Wiley & Sons, Inc., New York. London, 1966.

17. K. Subramanya; "Engineering hydrology", Second Edition, McMraw-Hill Publishing Company, 1984.

18. Kari Vandernden, J. V. Giraldez and M. Van Meirvenne, Assessing reference evapotraspiration by the Hargreaves method, Journal of Irrigation and Drainage Engineering, Vol. 130, Paper no. (3), 2002.

19. Kotsopoulos and C. Babjimopoulos, "Analytical estimation of modified Penman equation parameters", Journal of Irrigation and Drainage Engineering, Vol. 123, Paper. (4), 1997.

20. K. P. Sudheer, Gosain and Ramasastri; "Analytical estimation of modified Penman equation parameters", Journal of Irrigation and Drainage Engineering, Vol. 129, Paper no. (3), 2003.

21. Luis S. Pereira, Richard G. Allen and Isabel Alves; Evapotraspiration concept and future trends Journal of Irrigation and Drainage Engineering, Vol. 125, Paper no. (2), 1998.

22. P.N. Midi; "Irrigation water recourses and water power engineering", 3rd Edition, Jain Publishing, 1995.

24. P. Jaya Rami Reddy; "Text book of hydrology" 1st Edition, Laxmi Publishing 2004.

25. Pencol E. C., "Design manual of irrigation and organization of land reclamation" 1st Edition 1983.

26. R.K. Sharama and T.K. Sharama; "Irrigation engineering including hydrology" 2nd Edition 2004.
27. R.D. Misra and M. Ahmed; "Manual of irrigation agronomy" 1st Edition 1978.

28. Rozgar Baban; "Design of diversion weirs" 1st Edition 1995.

29. Richard Van Klaveren; "National irrigation hand book and irrigation guide" 2nd Edition 1997.

30. Richard G. Allen, Luis S. Pereira, Martin Smith; "Crop evapotraspiration" 2nd edition 1998, FAO Paper no. (56).

31. Richard G. Allen, Luis S. Pereira, Martin Smith, Dirk Raes and James L. Wright, FAO-56 Dual crop coefficient method for estimating evaporation from soil and application extensions, Journal of Irrigation and Drainage Engineering, Vol. 131, Paper no. (1), 2003.

32. Richard G. Allen, Albert J. Clemmens, Charies M. Burt, Ken Solomon and Tim O. Halloran, "Prediction accuracy for project wide evapotraspiration using crop coefficients and reference evapotraspiration", Journal of Irrigation and Drainage Engineering , Vol. 131, Paper no. (4), 2004.

33. Richard G. Allen, William O. Pruitt, Dirk Raes, Martin Smith and Luis S. Pereira ;"Estimation evaporation from bare soil and the crop coefficient for the initial period using common soils information", Journal of Irrigation and Drainage Engineering, Vol. 131, Paper no. (1), 2003.

34. Samuel O. Ortege – Farias, H. Cuenca and M. English, "Hourly grass evapotraspiration in modified maritime environment", Journal of Irrigation and Drainage Engineering, Vol. 121, Paper no. (6), 1994.

35. S. Mohan and N. Arumugam, "Comparison of methods for estimating reference ET", Journal of Irrigation and Drainage Engineering, Vol. 121, Paper no. (6), 1995.

36. Vazquez and Feyen; "Potential evapotraspiration for the disturbed modeling", Journal of Irrigation and Drainage Engineering, Vol. 130, Paper no. (1), 2003.

37. X. Jia, E. C. Martian and D. C. Slack; "Temperature adjustment for reference evapotraspiration calculation", Journal of Irrigation and Drainage Engineering, Vol. 130, Paper no. (5), 2004.

38. Zohrab Samani, "Estimating solar radiation and evapotraspiration using minimum climatologically data", Journal of Irrigation and Drainage Engineering, Vol. 126, Paper no. (4), 1999.

(a)= an empirical exponent.

$I = (t/5)^{1.164}$ …………. (2.3)

And

$a = 0.0000000675\,\boldsymbol{I}^3 - 0.0000771\boldsymbol{I}^2 + 0.01792\boldsymbol{I} + 0.49239$ ………….. (2.4)

The factor (e) is an adjusted value based on a 12 hour day and 30 day month and is corrected by actual day length in hours (h) and days in a month (M), to give the adjusted potential evapotraspiration (ETo).

$ETo = e\,(h/12)\,(M/30)$ …………. (2.5)

2.2.3 *Blaney – Criddle formula (1950) and modified Blaney – Criddle method (1975).*

This method is suggested for areas where available climatic data cover air temperature data only [Pruitt, 1992].

The original Blaney – Criddle equation (1950) involves the calculation of the consumptive use factor (f) for mean temperature (T) and percentage (P) of the total annual daylight hours occurring during the period being considered.

An empirically determined consumptive use crop coefficient (K) is then applied to establish the consumptive water requirements (CU).

$CU = K.f = K\,(p.T/100)$ ……………. (2.6)

With T in F^o.

(CU) is defined as the amount of water potentially required to meet the evapotraspiration needs of vegetative area so that plant production will not be limited by lack of water.

The effect of climate on crop water requirements will vary widely between climates having similar values of T and P. Consequently the consumptive use crop coefficient (K) will need to vary not only with the crop but also with climatic conditions.

For better definition of the effect of climate on C.W.R, but still employing the Blaney – Criddle temperature and day length related (f) factor; a method is presented to calculate reference crop evapotraspiration (ETO). Using measured temperature data as well as general levels of humidity, sunshine and wind, an improved prediction of the effect of climate on evapotraspiration should be considered.

The recommended modified relationship representing mean value over the given month is expressed as [Doorenbos and Pruitt, 1975]:

$$ETo = C\,[p\,(0.46T + 8)] \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.7)$$

Where:

ETO = reference crop evapotraspiration in mm/day for the month considered.

T= mean daily temperature in C° over the month considered

P = mean daily percentage of total annual daytime hours and obtained from FAO paper 24 [J. Doorenbos, 1992], as shown in annex 1 table. (17).

C = adjustment factor and equal to one in this research, because the ratio of wind velocity of day time to that of night for Sulaimani city is approximately equal to one, and this factor depends on minimum relative humidity, sunshine, hours, and daytime wind estimates.

The Blaney Criddle method, based on temperature and day length, is widely used in irrigated semiarid and arid regions. This empirically developed method gives an estimate of actual evapotraspiration, because it is based on correlation with the existing irrigation practice.

(Taylor and Ashcroft, 1972) state that this method "is probably adequate for many estimate of seasonal ETo under conditions similar to those for which crop coefficient and consumptive use factors have been determined".

(Doorenbos and Pruitt, 1970) suggested that Blaney – Criddle method should be used with skepticism in the costal areas and in the mid latitude climates with wide variability in sunshine hours.

The Blaney – Criddle method has been shown to be one of the best temperature-based methods for humid location [Jensen et.Al. 1990; Parmele and McGuiness 1974].

2.2.4 Radiation method (1957).

The radiation method is essentially an adaptation of the Makkink formula (1957). This method is suggested for areas where available climatic data include measured air temperature and sunshine, cloudiness or radiation, but not measured wind or humidity. Knowledge of general levels of humidity and wind is required, and these are to be estimated using published weather descriptions, extrapolation from nearby areas or from local sources.

The radiation method should be more reliable than presented Blaney – Criddle approach. In fact, in equatorial zones, on small islands, or at high altitudes, the radiation method may be more reliable even if measured sunshine or cloudiness data are not available [Jaya, 2004]; in this case solar radiation maps prepared from most locations in the world should provide the necessary solar radiation data.

The recommended relationship representing mean value over the given period is expressed as [W.O. Pruitt, 1992].

$$ETo = C\ (W\ Rs) \qquad \ldots\ldots\ldots\ldots\ldots\ (2.8)$$

and

$$Rs = (0.25 + 0.50\ n/N)\ Ra \qquad \ldots\ldots\ldots\ldots\ldots\ (2.9)$$

Where:

ETo = reference crop evapotraspiration in mm/day for the period considered.

Ra = Extraterrestrial radiation (mm/day) and obtained from FAO paper 24 [J. Doorenbos, 1992], and as shown in table (2-2).

Rs = solar radiation in equivalent evaporation in mm/day.

C = adjustment factor which depends on mean humidity and daytime and wind Conditions.

2.2.5 Oliver method (1961):

Oliver (1961) presented a simple formula for estimating ETo as [R.D. Misra 1973]:

ETo = CW ……………. (2.10)

Where:

ETo = evapotraspiration in mm/day.

C = average wet bulb depression in C^o.

W = cyclic factor for specific latitude.

2.2.6 Evaporation method (1968):

Evaporation pans provide a measurement of integrated effect of radiation, wind, temperature and humidity on evaporation from a specific open water surface. In similar fashion the plant responds to the same climatic variables but, several major factors may produce significant difference in loss of water. Reflection of solar radiation from water surface is only 5-8 percent, from most vegetative surface 20 -25 percent.

Storage of heat within the pan can be appreciable and may causes almost equal evaporation during night and day; most crops transpire only during daytime also the difference in water losses from pans and from crops can be caused by differences in turbulence, temperatures and humidity of air immediately above the surface. Heat transfer through the sides of the pan can occur, which may be severe for sunken pans [Sharma and Dastane, 1968]. Also the color of the pan and the use of screens will affect water losses. The silting of the pan and the pan environment influence the measured results, especially when the pan is placed in fallow rather than cropped area.

The recommended relationship representing mean value is expressed as:

$$ETo = Kp.\ Epan \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.11)$$

Where:

ETo = reference crop evapotraspiration in mm/day and represent the Mean Daily Value for the considered period

Kp = pan coefficient.

2.2.7 *Hargreaves method (1985):*

Most weather stations lack the intensive input data, and errors in measuring the required weather data are common, therefore, equations with few parameters are recommended, such as Hargreaves equation.

Hargreaves method enables reference crop evapotraspiration (ET_O) estimation in areas where metrological data is scare [Jensen et al. 1997]. The Hargreaves equation recommend as one of the simple and accurate empirical method [Jensen et al. 1997]. This equation requires measured values of only maximum and minimum daily air temperature in combination with the extraterrestrial radiation (Ra) in (mm/day) as an indication of the incoming global radiation.

Moreover, the daily temperatures range ($\Delta T\ C^o$) can be related to relative humidity (RH) and cloudiness [Samani and Pessarakli 1986] and [Shuttleworth, 1993, Distefane and Ferro, 1997]. Further more, advection depends on the inter action between (RH, Temp., vapour pressure and wind speed, all metrological data that can be related to (ΔT).

[Shuttle worth, 1993] recommended that Hargreaves method should not be used for shorter period than one month, although numerous agricultural and hydrological applications require daily ET_O.

Hargreaves et al. (1985), expressed as:

$ET_{O} = 0.0023 * Ra. * (T_{ave}. + 17.8) * \sqrt{\Delta T}$ .... (2.12)

Where:

Ra = Extraterrestrial radiation (mm/day) and obtained from FAO paper 24 [J. Doorenbos, 1992], as shown in annex 1 table no. (18).

ΔT = Temperature range between mean daily max. & min. air temp. (C^o)

$\Delta T = (T_{max.} - T_{min.})$....... ($C^o$) .... (2.13)

T_{ave} = Daily mean air temp.

$T_{ave} = (T_{max.} + T_{min.})/2$....... ($C^o$) .... (2.14)

It's assumed that daily max. & min. is affected in the same way by the aridity of the site [Allen et al. 1993].

2.2.8 Energy Balance Method:

The energy balance equation applies over any time period from minutes to year. It is an approximate equation, however, since some components (normally quite insignificant) are neglected [R.D. Misra, 1973].

It is difficult to measure sensible heat transfer and the latent heat flux due to evaporation separately. Therefore, an attempt has been made to partition the energy utilized.

The formula was of original forms as:

$Rn + G + H + LE + \Delta F = 0$ .... (2.15)

Where:

Rn = the radiation balance at the surface (net radiation).

G = rate at which the heat content of the soil or water columns change.

H = seasonable heat transfer.

LE = latent heat flux.

ΔF = the net sub – surface horizontal flux of sensible heat out of the column.

2.3 Review of available researches related to (ETo):

The following researches on (ETO) are presented chronologically

2.3.1 Evapotraspiration estimation under deficient water supplies [J. L. Hatfield and R. G. Allen, 1995]

This study was undertaken to compare different forms of evapotraspiration equations that include **Priestley- Taylor** (1972, equation 2-16) below **and Penman** (equation 2-1) for estimating reference (ETo).

$$ET_p = \alpha \left[\Delta/(\Delta+\gamma) * (R_N - G)\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.16)$$

Where:

G = soil heat flux (mm/day).

α = **Priestley- Taylor** coefficient, have been found to range from 1.08 to 1.34 depending on crop type and location.

The estimation of actual (ETo) in this study using **Priestley- Taylor** with an adjusted coefficient for the available soil water and **Penman** with the variable surface resistance were compared to water used by some crops at three locations . Both above models provided acceptable results; however the **Penman** model with daily meteorological data input provided more consistent results over the growing season .The **Priestley- Taylor** overestimated actual ETo when crops were limited in soil water because the adjustment for available soil water was not sensitive to soil-water depletion .Irrigation scheduling using **Penman** model requires daily meteorological data ,an estimate of available soil depletion , and a measurement of crop leaf area. This model would be useful for irrigation scheduling programs.

2.3.2 Computation of ETO under non ideal conditions [Jensen, Hargreaves, Fellow, B. Temesegan and Allen, 1995].

This study compares ETo computed by the following methods:

- The FAO Penman.
- The FAO – PM with VPD.
- The Hargreaves el. Al. (1985).
- The California irrigation management information (CIMIS).
- Hargreaves corrected for temperature bias.
- The PM used by Jensen et. al. (1990).

Theses comparisons were made with the following objectives:

- To determine if FAO-PM method can be simplified without decreasing the desired accuracy.
- To attempt to develop a procedure for computing ETo using weather data from dry and semi arid sites that would be approximately equivalent to ETo using weather data from well watered weather sites.
- To demonstrate the possible errors or differences in computed ETo values when weather data from non-irrigated or arid sites are used in the computations.
- To compare the ETo values computed by various methods under different climatic conditions.
- To investigate the possibility of adding a correction for wind with ETH equations.

Conclusions according to this study are that the differences in ETo values computed by above methods are minor when compared with the uncertainties of estimating actual ETcrop for ETo or from other methods. Also the differences in ETo values computed from different methods frequently may be no larger than those introduced in the measuring and recording of weather variables. The conditions of aridity or humidity of general surroundings of the weather stations have an important influence on the weather measurements at the site of recording. This deficiency should receive major emphasis in the future and additional evaluation of the interactions of wind and temperature on ETo is strongly recommended.

2.3.3 Decision support system for estimating reference evapotraspiration [George, Reddy, Raghuwanshi and Wallender, 1995].

The decision support system (DSS) was developed for estimation the references value. The ETo estimation method is based on combination theory, radiation, temperature, and pan evaporation. The models select the best ETo estimation based on the ASCE ranking. The DSS system is an integrated assemblage of models, data, interpretative routines and other relevant information that efficiently process input data, runs the models, and displays the results in an easy way to interpret format.

The DSS developed for ETo estimation includes a model base with decision making capabilities, a graphical user interface and a data management system.

2.3.4 Comparison of methods for estimating reference ET [S. Mohan and N. Arumugam, 1995].

The author have applied Makkink, Priestley, Turce, Hargreaves – Samani, and Thornthwaite methods to compute reference ETo and compared the estimated ETo by these methods with that by Penman method, which was taken as the standard base.

It is now agreed that the Penman method yields the best results [Chiew et al, 1995].

Conclusions according to this study are that depending on only the slope and intercept parameters the Turce method can be ranked higher than Priestley-Taylor and Makkink methods for daily and monthly estimate.

2.3.5 Hourly grass evapotraspiration in modified maritime environment [Samuel O. Ortege – Farias, H. Cuenca and M. English, 1996].

The penman method using hourly and daily weather data was evaluated to estimate reference evapotraspiration over a well –established stand of Alta fescue under different atmospheric conditions. The performance of the penman equation was evaluated using evapotraspiration measured by the Bowen ratio energy balance method (Brusaert 198; Oke 1987).Good agreement between Bowen ratio energy balance method and Penman using hourly weather data was observed. On hourly basis the overall error of estimate (SEE) and absolute relative error (ARE) were 0.06 mm/hr and 5.2 % respectively. On a daily basis (SEE) was 0.55 mm/day and (ARE) was 6.9%, respectively

Results suggest that the Penman equation could improve if hourly weather data were used as inputs to predict daily reference evapotraspiration for irrigation purposes, and strongly suggest that Penman equation using hourly weather data could be used in the Willamette valley to predict daily ETo. However, it is possible that accuracy problems could occur in the estimation of daily ETo under high wind speed and dry atmospheric conditions.

2.3.6 Analytical estimation of modified Penman equation parameters [Kotsopoulos and C. Babjimopoulos, 1998].

The modified Penman method (equation 2-1) is widely used and preferred for its theoretical soundness and reliability. The use of this method requires that all the essential climatic variables are given either as a pure value or in functional forms. Alternatively some of climatic variables may be taken from tables using interpolation and the adjustment factor (C) which incorporates the difference between day and night weather conditions. In above paper researchers described the parameters of equation (2-1) mathematically and those parameters are derived through non-linear regression procedure.

Accurate estimates for the foregoing parameters are required in order to improve the validity of potential evapotraspiration estimates. While an error introduced in the calculation of (C), it is directly transferred to the estimated evapotraspiration, and an error in the rest of the parameters does not automatically lead to an equivalent estimation error, in such cases, the associated error in calculating evapotraspiration is not only dependent on the error introduced in certain parameters, but also on the parameters magnitude as well as the magnitude of other parameters such as temperature and wind velocity involved in the calculation [Pruitt, 1973]. Under certain circumstances such parameters errors could result in significant error in potential evapotraspiration estimates.

The researchers suggested the following expression for calculating the parameter C of equation (2-1):

$$\begin{aligned} C = {} & 1.5033 - 1.5904(RH_{max}{}^{)-0.2125} + 0.3216(R_s)^{0.2} - 0.2452(U_d)^{2/3} \\ & + 0.03985(U_d)^{0.4}(U_r) + 0.02215(U_d)^{0.55}(RH_{max})^{0.45} + 0.002548(R_s)^{1.45}(U_d)^{2/3} \\ & - 2.3464\text{x}10^{-6}(U_d)^{0.4}(RH_{max})^{1.5}(R_s)^{1.5} - 1.01086\text{x}10^{-7}(R_s)^{1.5}(RH_{max})^{1.5}(U_r) \\ & - 8.15849\text{x}10^{-6}(RH_{max})^{1.5}(U_d)^{0.4}(U_r) - 0.000496(R_s)^{1.5}(U_d)^{0.4}(U_r) \\ & + 1.19257\text{x}10^{-6}(RH_{max})^{1.5}(R_s)^{1.5}(U_d)^{0.4}(U_r) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.17) \end{aligned}$$

Where

RH_{max} : max relative humidity (%)

R_s : Solar radiation (mm/day)

U_d : Mean wind velocity during day hours (m/sec)

U_r : day to night wind ratio between daytime (7:00 am-7:00 pm) and nighttime (7:00 pm-7:00 am)

For second parameter of equation (2-1), saturation vapor pressure (e_s) in (mill bars) they suggested the following expression:

$e_s = 6.1051e^{(18.0788T-0.00254T^2/248.57+T)}$ ……………. (2.18)

Where:

T: Air Temperature in (^oC)

The slope of saturation vapor (Δ) with respect to (T), may be calculated equation (2.19) and has the following from:

$\Delta = e_s [\{4650.79/ (T+248.57)^2\}-0.00254]$ ……………. (2.19)

According to this research comparisons of above parameters expressions were made with those found in literature showed that they undoubtedly give more reliable results.

2.3.7 Estimating solar radiation and evapotraspiration using minimum climatologically data [Zohrab Samani, 2000].

A procedure is introduced to estimate solar radiation and subsequently reference evapo-transpitaion using minimum climatological data. This method describes the modification to the original equation that uses maximum and minimum temperature to estimate solar radiation and reference crop evapotraspiration. The proposed modification allows for the correction of errors associated with indirect climatological parameters affecting the local temperature range and also improves the accuracy of estimated solar radiation from temperature.

The most important parameters in estimating the reference evapotraspiration are the temperature and solar radiation [Jesen, 1985].

According to [Hargreaves and Samani, 1982] they proposed a simple equation to estimate solar radiation (Rs):

$Rs = (KT) (Ra) (TD)^{0.5}$ ……………. (2.20)

Where:

TD = maximum daily temperature minus minimum daily temperature (C^o).

Ra = extraterrestrial radiation (mm/day).

KT = empirical coefficient.

$KT = 0.00185(TD)^2 – 0.0433(TD) + 0.4023$ .... (2.21)

Combining last equation with the original Hargreaves equation [Hansen et al. 1979] resulted in a simplified equation requires only temperature and latitude [Hargreaves and Samani, 1985].

$ETo = 0.0135\ (KT)\ (Rs)\ (TD)^{0.5}\ (TC + 17.8)$ .... (2.22)

Where:

TC = average daily temperature (C^o).

2.3.8 Estimating actual evapotraspiration from limited climatic data using neural computing technique (ANN), [Sudheer, Gosain and Ramasastri, 2000].

This method examines the potential neural networks (ANN) in estimating actual evapotraspiration (ETo) from limited climatological data. The study employed radial-basis function (RBF) type for computing daily values of (ETo).

Six RBF networks, each using varied input combinations of climatic variables, have been trained and tested. The model estimates are compared with measured lysimeter ET. The results of the study clearly demonstrate the proficiency of the ANN method in estimating ET. The analysis suggests that the crop ET could be computed from air temperature using ANN approach.

An (ANN) is a nonlinear mathematical structure capable of representing arbitrary complex nonlinear process that related to the inputs and outputs of any system. The main advantage of the ANN approach over the traditional methods is that it does not require information about the complex nature of the underlying process under consideration to be explicitly described in the mathematical forms.

The success of the ANN has been used to model dynamic system in many fields of science. Engineering suggests that the ANN approach may prove to be an effective and efficient way to model the evapotraspiration process [Daniel, 1991].

According to the method the regression equation is evaluated:

$$ETo = b_o + b_1 (ET_{ANN}) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.23)$$

Where:

ETo = lysimeter measured evapotraspiration.

ET_{ANN} = particular evapotraspiration estimated from ANN model.

b_o & b_1 = regression coefficients.

2.3.9 Reference evapotraspiration estimation in highly advective semiarid environment, [Berengena and P. Gavilan, 2003].

According to this study the Hourly evapotraspiration (ETo) rates were measured during the irrigation season in highly detective area using a precision weighing lysimeter. Close to the lysimeter, an automatic weather station was located to register hourly values of the most relevant climatic variables. Several methods to estimate ETo were evaluated for hourly and daily estimate. Accuracy was assessed from ordinary regression and from error analysis of the comparison against measured values. The following equations and methods are used on the following bases:

A- Methods based on temperature measurements:

1. Hargreaves equation (equation 2.12) as proposed by [Hargreaves and Samani, 1985].

2. FAO -24 Blaney Criddle as proposed by [Allen and Pruitt, 1988] below:

$$ETo = \{0.0043RH_{min} - (n/N) - 1.41\} + b^*\{p^*(0.46^*T_a + 8.1)\} \quad \ldots. (2.24)$$

Where:

ETo = Reference evapotraspiration (mm/day).

RH_{min} = Minimum relative humidity expressed as %.

n/N = Ratio of actual and maximum sunshine hours..

Ta = Average air temperature (C^o).

b = empirical coefficient.

B- Methods based on radiation:

1. Makkink (1957) as proposed by [Frevert, 1983] below:

$ETo = bwR_s - 0.3$ ………………….… (2.25)

Where:

ETo = Reference evapotraspiration (mm/day).

R_s = Extraterrestrial solar radiation (mm/day).

b = empirical coefficient.

2. Ritchie type as proposed by [Jones and Ritchie, 1990] blow:

$ETo = \alpha \{3.87*10-3.\ R_s (0.6 * T_{max.} + 0.4T_{min} + 29\}$ ………………….… (2.26)

Where:

ETo = Reference evapotraspiration (mm/day).

R_s = Extraterrestrial solar radiation (mm/day).

α = empirical coefficient.

$T_{max.}$ and T_{min} = Maximum and minimum air temperature (Co).

3. Priestley – Taylor (1972) as proposed by [Jury and Tanner, 1975] below:

$ETo = \alpha.\ W.\ (R_n - G)$ ………………….… (2.27)

Where:

ETo = Reference evapotraspiration (mm/day).

α = empirical coefficient.

W =Temperature - related weighting factor.

R_N = Net radiation (mm/day).

G = soil heat flux (mm/day).

C .Methods based on combination equation – Energy balance and aerodynamic transport of water vapor (Penman, 1948):

1. Penman equation (equation 2.1).

Conclusions according to this study are that the FAO-24 methods should show a strongly tendency to over predict daily ETo under the semiarid, highly advective conditions prevailing during the irrigation seasons and this advection of sensible heat increases.

Priestly –Taylor, as expected, is very sensitive to advection while Hargreaves and Ritchie –type equation showed both a similar behavior with tendency to under predict for high ETo values.

Penman equation performs very well on daily basis when every thing is measured, the equation consistently under estimates ETo over the whole range.

Finally the rest of the methods evaluated are clearly sensitive to advection and the estimation errors tend to decrease as advection severity increases.

CHAPTER THREE
DATA COLLECTION AND FIELD WORK

3.1 Introduction:

Many field trips were made to the study area to characterize the crop water requirement under study with particular references to climate, hydrology, geology, vegetation cover, soil, land use and the socio-economic conditions.

Most of the characterizations such as type of vegetation, land use, crop rotation and socio-economic were made by visual observations.

For collecting extra data several farmers were interviewed from the surrounding villages. Some relevant data especially related to climate data were obtained from governmental agencies such as Ministry of Agriculture and Irrigation/ General Directorate of Research and Agricultural extension/Agro metrological center.

Climatological data are needed for the determination of crop water requirements to deduce the analyses of some significant parameters. These parameters are reference evapotraspiration and ET at the proposed location.

To obtain these values, the climatological data record for as many years as possible is required, so that one would be able to carry out the frequency analysis. However design engineers, especially in undeveloped countries, is not always so fortunate to obtain these climatological data and consequently they faced real problems about this matter.

The climate of Iraq is of Semi-arid type designated as continental or subtropical. It is chiefly characterized by:

1. Wide diurnal and annual ranges of temperature.
2. A high mean annual temperature due to location (latitude).

3. Low relative humidity, especially during summer months.
4. Scanty rainfall over lower parts of the country.
5. The summer season is hot and rainless (June to September), while the winter season (October to May) is cold and dry.
6. The coldest and hottest months of the year are (January) and July or August respectively.

3.2 Geology and geomorphology for the study area:

Figure shows that the study area situated in the northeast of Iraq in Sulaimnyia Governorate, it is located between latitudes 350 and 360 north and longitudes 4433 and 4343 east.

Geologically, the area is a part of the geological description of Sulaimnyia city area, tectonically of BAKRAJO area is located at High folded Zone (Buday and Jassim, 1987) and depends on Numan (1997) it is located on Foreland Basin.

Geomorphologically the study area is a northern part of the Sulaimnyia syncline which is the breakdown of Glazarda anticline, the Balchogh permanent stream is running through the area.

The main geological Formation that covers the studied area is two main stratigraphical types, First aluviam (recent) deposit which covers most part of the studied area and composed of clay and conglomerate, average thickness (3) to (10) meters. The second is Tanjero Formation which is composed of turbidite lithofacies (Karim, 2004) that mean composed of marl shale siltstone and sandstone.

3.3 Data Collection:

Collection of existing data is the first step towards comprehensive planning and survey of any watershed project. Historical data such as rainfall, air temperature, stream flow measurements and so on are not available for BAKRAJO area therefore, were obtained from files of the appropriate agencies Sulaimnyia city.

The collected data including hydrological and metrological information for Sulaimnyia center from 1973 to 2006 are obtained from Agro metrological center. There units are shown in table (3.1).

Table (3.1): Units of hydrological and metrological data.

S.N	***Climatological nomenclature***	***Units***
1	***Air temperature***	***C^o***
2	***Air humidity***	***%***
3	***Vapor pressure***	***mbar***
4	***Precipitation***	***mm***
5	***Sunshine duration***	***hr***
6	***Wind speed***	***m/sec***
7	***Pan evaporations***	***mm***
8	***Soil temperature***	***C^o***
9	***Cloud cover***	***Oktas***

Full Climatological data for Sulaimnyia city are available from 2001 to 2006 i.e., all the necessary data such as "air temperature, air humidity, vapor pressure, precipitation, wind speed, pan evaporation sunshine duration, soil temperature and cloud cover". However, from 1973 to 2000 the available climatological data are strongly suffered from missing data presentations.

Some portable instruments and tools were used such as (GPS) to define the study land area with its latitude and longitude coordination and using digital camera to obtain photos for the irrigated land (Fig No. 1 and 2). In addition, data were collected regarding the soil type, crop type with its intensity and their growing periods, and it is clearly described in the field work.

3.4 Fields work:

The fields work includes site research visiting involving and including the following performance:

3.4.1 Soil sample

For the irrigated land, defining the soil texture type is done through defining soil liquid limit, plastic limit, plasticity index and sieving analysis for the soil and the results is shown in annex 1 table (19) Then according to Casagrandy plasticity chart [Principal of geotechnical eng. By DAS, 1985] the soil type of BAKRAJO irrigated land area is defined as of the type of (OH & OL) i.e. organic clay of high plasticity and Organic silts of low plasticity.

3.4.2 Land survey

Field surveying for the irrigated land was taken using portable GPS instrument, to determine the total irrigated land area of (342 hectares).The work includes defining the area of each sub cropped land independently and finally representing the location of the irrigated land on the contour maps, Fig.(2).

3.4.3 Cropping pattern and crop intensity with its growing period for the area under study:

This includes field information about the type, intensity and growing period for each type of crops, and usually (10 to 12) types of crops in the land were cropped and their growing periods vary from January to December.

The cropping intensity for all the crop type is (100%) and this means that each type of the crop will be cropped once in a year, and as clarified in table (3.2).

Table (3.2): Crop types, intensity, growth period and areas for BAKRAJO Irrigated land

After

Conducting field survey to the study area.

S.N	*Crop type*	*Crop Intensity*	*Crop growth period*		**Crop area (hac.)**
			Planting Date	*Harvesting Date*	
1	*Rice*	*100%*	*May*	*September*	**32.4**
2	*Wheat and barley*	*100%*	*November*	*April*	**16.2**
3	*Cucumber*	*100%*	*July*	*August*	**29.16**
4	*Sunflower*	*100%*	*May*	*August*	**42.12**
5	*Vegetables*	*100%*	*April*	*June*	**32.4**
6	*Onion*	*100%*	*April*	*June*	**22.68**
7	*Tomato*	*100%*	*May*	*August*	**38.88**
8	*Peppers*	*100%*	*April*	*July*	**22.68**
9	*Egg plant*	*100%*	*April*	*July*	**22.68**
10	*Radish*	*100%*	*August*	*October*	**12.96**
11	*Sweet melons*	*100%*	*May*	*August*	**25.92**
12	*Cowpeas*	*100%*	*May*	*August*	**25.92**
Total irrigated land area					**324**

CHAPTER FOUR

APPLICATION OF METHODS TO BAKRAJO AREA AND RESULTS DISCUSSION.

4.1 Introduction:

In this chapter the method of calculating the crop water requirement (C.W.R) with data presentation will be displayed. Prediction methods for crop water requirement are used owing to the difficulty of obtaining accurate field measurements. The methods often need to be applied under climatic and agronomic conditions; which are different from those under which they were originally developed.

Testing the accuracy of the method under a new set of conditions is laborious, time consuming and costly, and yet crop water data are frequently needed at a short notice for project planning. To meet this need, guidelines are presented to calculate C.W.R under different climatic and agronomic conditions, based on the recommendations formulated by FAO group.

Now according to (Allen et al. 1994, Doorenbos and Pruitt 1977), they define the evapotraspiration ETo rate as "the rate of evapotraspiration from an extensive surface of 8 to 15cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water. Later, (Allen et al. 1994), define the grass reference evapotraspiration as "the rate of evapotraspiration from hypothetical reference crop with an assumed crop height.

While the reference ET or reference crop ET has been defined as “the rate at which water, if readily available, would be removing from the soil and plant surface of specific crop, arbitrary called a reference crop [Jensen et. Al, 1990].

4.2 Methodology, Data Analysis and Calculations:

4.2.1 *Stage procedure for calculating crop water requirements:*

Daily ETcrop are calculated for each crop type using the general ETcrop equation (4.1) as clarified below,

ETcrop = Kc * ETo ………………. (4.1)

Where:

ETcrop = Crop evapo-transpitaion (mm/day)

Kc = Crop coefficient.

ETo = Reference evapotraspiration (mm/day).

To apply the above equation a three-stage procedure recommended by [J. Doorenbos, (1975)] are:

A. The effect of climate on C.W.R is given by the reference crop evapotraspiration, and represent:

- ☒ The loss of water to the atmosphere by the combined processes of evaporation from the soil and plant surfaces and transpiration from the plant.

- ☒ The major consumptive use of irrigation water and rainfall on agricultural land. Because the transpiration (T) is the portion of

ETO that flows through the plant system, it is the main component of ETO that impact the ETO yield relationship. Nerveless, the evaporation (E) component within and outside the crop-growing season can be a significant component of the total ETO.

☒ The major component of hydrologic cycle and its accurate estimation is essential for hydrological studies such as hydrologic water balance, irrigation scheduling, water recourses planning and managements.

There are many factors affecting ET, including:

1. Weather parameters such as solar radiation, air temperature, humidity, wind speed.
2. Crop factors, including crop type, Varity, density, stage of growth and management.
3. Environmental conditions such as soil condition, salinity, fertility, crop disease and pests [Allen et. al 1998].

Because of the interdependence of the most of these factors with their spatial and temporal variability, it is virtually impossible to formulate an equation that can be used to estimate actual ET from various crops under different conditions. Therefore, the standardizing ET equation using what is termed as reference evapotraspiration (ETO) was introduced [Jensen 1968; Jensen et. al 1971; Doorenbos and Pruitt 1975].

The rate of evapotraspiration (ET) from soil and vegetated surface is dependant upon the atmospheric demand for water and the surface characteristics. The atmospheric demand is quantified through the calculation of reference ET_O, and the surface characteristic is incorporated into a crop coefficient. The product of these two parameters provides an estimate of the actual ET.

In this study, the reference evapotraspiration (ETo) was calculated using Blaney Criddle and Hargreaves method using equations (2.7, and 2.12) respectively. The climatological data including maximum and minimum daily air temperature for Sulaimnyia city are periodically arranged from 1973 to 2006, then the average and daily air temperature differences for the aforementioned years were calculated and determined, and the systematized results were shown in the annex 1, tables No. (1).

In accordance with the organized daily climatological data and after calculating the mean daily percentage of annual daytime hours (P), and the daily extraterrestrial radiation (Ra) using tables (2-1 and 2-2), the reference evapotraspiration was calculated by Hargreaves and Blaney Criddle method using the above mentioned equations respectively for the period from 1973 to 2006, and the mean average values of the two methods were determined.

Finally the result of the two methods with their mean average values are shown in annex 1, tables (2), (3) and (4), while their graphs are presented in the annex 2 figs. (1 to 12).

B. The effect of the crop characteristic on C.W.R is given by crop coefficient (Kc) which presents the relation between reference (ETo) and crop evapotraspiration (ETcrop). The value of Kc varies with the crop, its stage of growth, growing season and prevailing weather conditions.

The crop coefficient (Kc) basically represents the ratio of the ETcrop to the reference ETo, and it represents an integration of the effects of the four primary characteristics that distinguish the crop references grass [Richard, 1998], and these characteristics are:

- ✓ Crop height: The crop heights influence the aerodynamic resistance term and the turbulent transfer of vapour from the crop into the atmosphere.

- ✓ Albedo (reflectance) of the crop-soil surface. The Albedo is affected by the fraction of ground cover by vegetation and by the soil surface wetness. The Albedo of the crop-soil surface influences the net radiation of the surface, which is primary source of the energy exchange for evaporation process.

- ✓ Canopy resistance: The resistance of the crop to vapour transfer is affected by leaf area (number of stomata), leaf age and condition, and the degree of stomata control. The canopy resistances influence the surface resistance.

- ✓ Evaporation from soil, especially exposed soil.

In this study and after selecting the method of calculation, the crop growth stages length is determined in table (3.2) with their corresponding coefficients and crop curve were constructed as shown in annex 2 figs (13 and 14) respectively.

The curve represents the changes in the crop coefficient over the length of the growing season, and the shape of the curve represents the change

in the vegetation and ground cover during plant development and maturation that affect the ratio of ETcrop to ETo.
From the curve, the Kc factor and hence ETcrop can be derived for any period within the growing season.

As the crop develops, the ground cover, crop height and the leaf area change and due to differences in evapotraspiration during various growth stages, the Kc for a given crop will vary over the growing period. The growing period can be divided into four distinct growth stages [Luis and Marten, 1998]:

☒ The initial stage runs from planting date to approximately 10% ground cover. The length of the initial period is highly dependent on the crop, the crop variety, the planting date and the climate. The end of the initial period is determined as the time, when approximately 10% of the ground surface is covered by green vegetation. For perennial crops, the planting date is replaced by the Greenup date, i.e., the time when the initiation of new leaves occurs. During the initial period, the leaf area small, and evapotraspiration is predominately in the form of soil evaporation. Therefore, the Kc value during this period is large when the soil is wet from irrigation and low when the soil surface is dry.

☒ The crop development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering. For row crops where rows commonly interlock leaves, the effective cover can be defined as the time when some leaves of plants in adjacent rows begin to intermingle so that soil shading becomes nearly complete, or when plants reach nearly full size if no intermingling occurs.

- ☒ It runs from effective full cover to start maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit to the degree that the crop evapotraspiration is reduced relative to reference ETO. The mid-season stage is the longest stage for perennials and for many annuals, but it may be relatively short for vegetable crops that are harvested fresh for their green vegetation. At the mid-season stage the Kc reaches its maximum value. The value for Kc is relatively constant for most growing and cultural conditions.

- ☒ The late season stage runs from the start of maturity to harvest or full senescence. The Kc value at the end of the late season stage reflects crop water management practices. The Kc value at this stage is high if the crop is frequently irrigated until harvested fresh. If the crop allowed to senesce and to dry out in the field before harvest, the Kc value will be small.

The cropping patterns represent the sequence of different crops that are growing in regular order on any particular field or group of fields, and it is also the percentage of the net cultivable area on which crops are growing during a given period, usually one year of winter and summer season. The planned cropping patterns and intensities for a project are developed by agricultural specialist in consultation with design engineers, farmers' representative and other interested parties.

According to this study, the cropping pattern intensity for BAKRAJO irrigated land is 100%, and this means that various crop types are planted only once in the entire year. As a result, weighting approach for estimating crops water volume is not required. Finally the crops type with their intensities is shown in table (3.2).

In planning cropping pattern the following points are taken into account [Pencol, 1983].

- ✓ The existing farm system and crops.
- ✓ Crop properties incorporated in national economic development plans.
- ✓ The compatibility of crop rotations with respect to growing season, soils, water availability, field layouts and pest hazard.
- ✓ The maximum of returns from agricultural procedure.

C. The effect of local conditions and agricultural practices on C.W.R including the local effect of variations in climate over time, distance and altitude , size of fields, advection, soil water availability, salinity, method of irrigation , cultivation methods and practices for which local field data are required.

In this study, the effect of the following conditions is taken into account:

1) Variations with time: Due to weather changes, ETcrop will vary from year to year and for each period within the year, therefore, to overcome this variation the mean climatological data are used in this study, and finally no correction is required because of using mean climatological data.

2) Variation with distance: In calculating ETcrop, the climatic data are sometimes used from stations located in some distance away from the study area, but in this study the collected data from the metrological station are not far from the study area, and this means that correction for distance is not required.

3) Variation with size of irrigation development: Climatological data used are often collected prior to irrigation development in stations located in rain fed or uncultivated areas, therefore, ETcrop may not be equal to predicted values based on these data. This principal is more pronounced for large scheme in arid climates, but in this study the effect of this condition is eliminated because the study area is located in semiarid region and no adjustment for ETcrop is done.

4) Variation with altitude: For a given climatic zone, ETcrop will vary with altitude and this is not caused by difference in altitude as much but, mainly associated with temperature changes, humidity and wind. But according to Doorenbos, 1975 this adjustment may be applied for altitude 1000m above sea level. Because the study area located in a place less than 1000m above sea level, the effect of this variation is not taken into account.

5) Variation of soil water availability level: After irrigation or rain, the soil water content will be reduced primarily by evapotraspiration. As the soil dries, the rate of water transmitted through the soil will reduce. The effect of soil water content on evapotraspiration varies with crop and conditioned primarily by the type of soils and water holding characteristics, cropping rooting characteristics and metrological factors determining the level of transpiration.

In this study, according to the soil water level and the analyzed soil samples (3.4.1), variation of soil water has little affect because the soil texture is fine not coarse.

6) Salinity variation: ETcrop can be affected by soil salinity since the soil water uptake by the plant can be drastically reduced due to higher osmotic potential of the saline ground water. Poor crop growth may be due to adverse physical characteristics of some saline soils. In this study the effect of soil salinity is taken into account by considering the leaching requirements factor using equation (4.6) to overcome this deficiency action and the values of the leaching requirements according to the crop types presented in the annex 1 table no. (13).

7) Method of irrigation: ETcrop is affected little by the method of irrigation if the system is properly designed, installed and operated. In this study surface irrigation is used which has a very inconsiderable effect on ETcrop and therefore, no safety factor is taken into account.

4.2.2 Calculating the net depth of irrigation (In) and monthly water requirements for each crop types:

The net depth of irrigation is calculated for each crop types using field water balance [Doorenbos, 1975] and expressed as:

$In = ETcrop - Pe - Ge - Wb$ ………………. (4.2)

$= Losses - Gain$

Where:

In = Net depth of irrigation (mm).

ETcrop = Crop evapo-transpitaion (mm).

Pe = effective rainfall (mm).

Ge = groundwater contribution (mm).

Wb = Stored soil water (mm).

While the monthly water volume required for each crop types is calculated using the below equation [Pruitt, 1992]:

$V = 10/Ep\ [(A * (ETcrop - Pe - Ge - Wb)/ (1-LR)]$ ……………. (4.3)

Where:

Ep = Project irrigation efficiency.

A = Area under a given crop (HC).

ETcrop = Crop evapo-transpitaion (mm).

Pe = effective rainfall (mm).

Ge = ground water contribution (mm).

Wb = Stored soil water (mm).

LR = leaching requirements (unit less).

In this study, the parameters of above equations are calculated as shown below:

4.2.2.1 Effective rainfall (Pe):

Effective rainfall means useful or utilizable rainfall. From view point of crop water requirements [Dastane,1974] has defined the annual or seasonal effective rainfall as that part of the total annual or seasonal rainfall which is useful directly and /or indirectly for crop production at the site where it falls, but without pumping. Therefore, it includes water intercepted by living or dry vegetation, the amount lost by evaporation from the soil surface, that fraction which contributes to leaching or facilities other agricultural operations, either before or after sowing without any harm to yield and quality of the principal crops. The evaluation of effective rainfall involves measuring rainfall and/or irrigation losses by surface runoff, percolation losses beyond the root zone and the soil moisture uptake by the crop for evapotraspiration.

On the other hand according to [Pencol,1983], the effective rainfall term, is difficult to assess because only part of total rainfall finds its way to the crop root zone where it can be used by the plants or through the root zone for leaching out harmful salts.

Winter rainfall contribute to crop growth in Iraq and therefore rainfall should be taken into account in irrigation planning and design where there is concern over present and future surface water allocations to project area [Pencol, 1983].

In this study, to calculate the effective monthly rainfall (Pe), the climatological data including the average monthly rainfall (P) for Sulaimnyia center are periodically arranged from 1973 to 2006, then, frequency distribution analysis using equations (4.7, 4.8. 4.9 and 4.10) are performed on the basis of different return periods. Finally, the (Pe) is calculated using equations (4.4 and 4.5), and the results shown in the annex 1 in tables no. (9, 10, and 11) respectively.

The following factors impact the effective rainfall:

i. Land slope.
ii. Characteristic of the soil.
iii. Groundwater characteristics.
iv. Management practices.
v. Crop characteristics.
vi. Carry-over soil moisture.
vii. Surface and sub-surface in outflows.
viii. Deep percolation.

Effective rainfall can be estimated by the evapo-transpiration-precipitation ratio method. The relationship between average monthly effective rainfall and mean monthly rainfall is shown for different values of average monthly ETcrop. At the time of irrigation the net depth of irrigation water that can be stored effectively over the root zone is assumed equal to 75mm [R.D. MISRA, 1972].

On the other hand effective rainfall can be estimated using the empirical equation [Berg, 1992] as declared below:

$Pe = 0.6*p -10$ ……….. If $P < 75$mm/month …………………. (4.4)
$Pe = 0.8*P -25$ ……….. If $P > 75$mm/month ………………... (4.5)

Where:

Pe = effective rainfall (mm).

P = precipitation (mm).

Careful use of rainfall can conserve irrigation supplies, and therefore effective rainfall can be taken into account where irrigation water is limited or from view of economical consideration [Pencol, 1983].

4.2.2.2 Groundwater contribution (Ge):

The contribution from the groundwater table is determined by its depth below the root zone, the capillary properties of the soil and the soil water content in the root zone. For heavy soils, distance of movement is high and the rate is low, for coarse soils the distance of movement is small and the rate is high. Very detailed experiments will be required to determine the groundwater distribution under field conditions [J. Doorenbos, 1975].

Special cases in the ground water contribution must be included in the calculation of water requirements of roadside tree belts [Pencol, 1983].

In this study the effect of groundwater contributions (Ge) is assumed equal to zero, because very detailed experiments will be required to determine the ground water contribution under field conditions.

4.2.2.3 Stored soil water or Abstraction from soil moisture (Wb):

Winter rains, melting snow or flooding may cause the soil profile to be near or at field capacity at the start of growing seasons, which may be equivalent to full irrigation. Also some water may be left from the previous irrigation season. It can be deducted when determine seasonal irrigation requirements. Excess winter rain will leach salts accumulated in the root zone in the summer season and as such can be assumed effective [W.O. Pruitt, 1977].

As a general rule of irrigation, application replace the water removed by the plant from the soil since the previous irrigation, then Wb = 0. However, changes in the soil moisture storage can be used to balance irrigation requirements through the irrigation season i.e. within the limits of available soil moisture, Wb can be adjusted to equalize or control incremental values of net depth of irrigation requirements [Pencol, 1983].

In this study the effect of stored soil water is assumed equal to zero, because very detailed experiments will be required to determine the stored soil water contribution under field conditions.

4.2.2.4 Leaching Requirements (LR):

Leaching requirement (LR) is the minimum amount of irrigation water supplied that must be drained through the root zone to control soil salinity at the given specific level [Doorenbos, 1975].

On the other hand, land which is saline is reclaimed by leaching i.e. by flushing unwanted salts through the drainage system. Reclaimed land, which is irrigated with water containing dissolved salts, requires regular continuous leaching to maintain low levels of soil salinity. It's found that salt concentration is, for practical purposes, proportional to the electrical conductivity of the saturation extract of the soil [Pencol, 1983].

The salinity problem is of paramount importance in most of the irrigated soil in Iraq, and generally increases from north to south [Pencol, 1983].

Soil salinity affected by water quality, irrigation methods and practices, soil condition and rainfall. Salinity in the soil generally increases as the growing season advance. Leaching can be practiced during, before or after the crop season depending on available water supply, but provided that salt accumulations in the soil does not exceed the crop tolerance level [W. Pruitt, 1975].

Crop tolerance levels are usually given as electrical conductivity of the soil saturation extract in mmhos/cm.

Poor water quality, frequent irrigation and excessive leaching water may be required to obtain acceptable yields.

Crop salt tolerance levels for different crops can be obtained according to leaching requirements calculated for:

$$L.R = ECw / (5ECe - Ecw) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (4.6)$$

Where:

ECw = is electrical conductivity of irrigation water in (mmhos/cm).

ECe = is electrical conductivity of the soil saturation extract for a given crop appropriate to the tolerable degree of yield reduction.

And both of (ECw) with (ECe) is obtained form FAO paper 24.

In this study, the effect of leaching requirements is taken into account by taking the consideration of each crop type with their correspondence salt tolerance level according to the standard table by Ayers and Westcott, 1976, and the leaching requirements are calculated using equation (4.6) as shown in table (13).

4.2.2.5 Irrigation Efficiency:

To account for the losses of water incurred during conveyance and application to the field, an efficiency factor should be included when calculating the project irrigation requirements. Project efficiency is normally subdivided into three stages, each of which is affected by a different set of conditions [Dastane, 1992]:

- ✓ Conveyance efficiency (Ec): ratio between water received at inlet to a block fields and that released at the project head works and its value is equal to (0.8).
- ✓ Field canal efficiency (Eb): ratio between water received at the field inlet and that received at the inlet of the block of fields and its value is equal to (0.7).

- ✓ Field application efficiency (Ea): ratio between directly available to the crop and that received at the field inlet and its value is equal to (0.7).
- ✓ Project efficiency (Ep): ratio between water made directly available to the crop and that released at headwork
- ✓ I.e. Ep = Ea. Eb. Ec.= 0.4

Water losses can be high at field application. Low application efficiency (Ea) will occur when rate of water applied exceeds the infiltration rate and excess is lost by rainfall; when depth of water applied exceeds the storage capacity of the root zone, excess is lost by deep drainage.

With surface irrigation, field layout and land grading are essential; uneven distribution of water will cause drainage losses in one part and possibly under irrigation in the other part of the field resulting in very low efficiency.

In the planning stage, efficiency values for various stage distribution and application are estimated on the basis of experience. When estimated too high-water deficiencies will occur and either selective irrigation and/or improvement in operational and technical control (i.e. lining, additional structures ….etc.) will be required. When estimated too low the irrigation area is reduced, and the system is therefore over designed and probably wasteful irrigation is practiced, however the former is commonly the case [Dastane, 1992].

Factors which are directly affecting the irrigation efficiencies are:

- ✓ Size of the irrigated acreage.
- ✓ Size of rotational units.
- ✓ Number and types of crops requiring adjustments in the supply.
- ✓ Canal lining and the technical managerial facilities of water control.
- ✓ Method and control of operation.
- ✓ Type of soils in respect of seepage looses.
- ✓ Length of canals.
- ✓ Size of irrigation block and the fields.
- ✓ Quality of technical and organizational operation procedures.
- ✓ Operation of the main supply system in meeting with the actual field supply requirements as well as by the irrigation skill of the farmers.

In this study and according to the aforementioned above reasons the project irrigation efficiency is estimated based on experience and assumed equal to (0.40).

4.2.3 Frequency distribution analysis:

It has been shown by [Chow, 1964] that the theoretical distribution applicable to the hydrologic frequency can be expressed by the following equation:

$X = X^{/} + K\, б_x$ ………………. (4.7)

Where:

X = Values of the variant of X which has a return period (T).

$X^{/}$ = Mean of the variant.

K = Frequency factor which depends on the assumed frequency
Distribution, return period and size of the sample.

$б_x$ = Standard deviation of the variant.

Gumbel distribution was used in this study to extend the value of effective rainfall, average evapotraspiration to future period, and this method is expressed as:

$б_x = \sqrt{\Sigma(X - X^{/})^2/(N-1)}$ ………………. (4.8)

And

$K = (YT - Yn) / Sn$ ………………. (4.9)

$YT = - \ln \{-\ln (1- 1/T)\}$ ………………. (4.10)

Where:

YT = reduced variant.

Yn = reduced mean.

Sn = Reduced mean.

Therefore, frequency analysis for climatological data is a statistical method used to show that events of certain magnitudes may on average is expected once every n year. To obtain the probability of data in series, being equaled or exceed, first the data arranged in descending order, then the probability of each event is calculated. It should be noted here that when two or more data have the same magnitude, the probability is to be calculated for the largest order in the arranged list. Probability calculated from the arranged type is also the plotting position calculated on probability scale of the event against probability graph.

ETo will, however, vary from year to year and frequency distribution analysis of ETo for each year of climatic record is recommended; the selected ETo value for planning is thus not based on average conditions but on the likely range of conditions and on an assessment of tolerable risk of not meeting C.W.R. [W. Pruitt, 1992].

In this study, the frequency analysis using Gumbel distribution equations (4.7, 4.8, 4.9 and 4.10) are used to extend the effect of the mean averages reference evapotraspiration (ETo) to future ones based on different return periods of (5, 10, 15, 20 and 25) years respectively, and summarizing the result for these return periods as shown in the annex 1 tables (7) and (8) respectively.

Afterwards the frequency analysis using Gumbel distribution equations (4.7, 4.8, 4.9 and 4.10) is used to extend the effect of the averages mean monthly rainfall (P) to future one based on different return periods of (5, 10, 15, 20 and 25) years respectively, and summarizing the result as shown in tables (9 and 10). Then the monthly effective rainfall (Pe) based on return periods of (5, 10, 15, 20 and 25) years respectively are calculated using equations (4.1 and 4.2) and the results shown in table (11).

Finally , and according to equations (4.4) and (4.5) the ETcrop with net depth of irrigation and the monthly crops water requirements were calculated for current time and for different return periods and as shown in the annex 1 table (14, 15, 16) and (17) respectively.

4.3 Results & Discussion:

4.3.1 Comparison of calculated seasonal ETcrop with standard seasonal ETcrop values:

The calculated and determined seasonal (ETcrop) as shown in annex one table (14), are compared with the standard and approximate range of seasonal (ETcrop) in mm according to FAO - Irrigation and Drainage Paper/24 by [Doorenbos and Pruitt, 1992] as declared in table (4:1) below:

Table no. (13)

Calculation of leaching requirements (R.L) according to the crop types

S.N	Crop Types	ECe	ECw	factor	ECe-ECw	(5ECe-ECw)	L.R = ECw /(5ECe-ECw)
1	Rice	5.1	3.4	5	1.7	8.5	0.40
2	Wheet and Barley	9.5	6.4	5	3.1	15.5	0.41
3	Cucumber	4.4	2.9	5	1.5	7.5	0.39
4	Sunflower	7.6	5	5	2.6	13	0.38
5	Celery	3.2	2.1	5	1.1	5.5	0.38
6	Onion	2.8	1.8	5	1	5	0.36
7	Tomatos	5	3.4	5	1.6	8	0.43
8	Pepers	3.3	2.2	5	1.1	5.5	0.40
9	Egg plant	3.8	2.5	5	1.3	6.5	0.38
10	Radish	3.1	2.1	5	1	5	0.42
11	Sweet melons	3.8	2.5	5	1.3	6.5	0.38
12	Cowpeas	2.3	1.5	5	0.8	4	0.38

Table (14)

Monthly ETcrop Calculations

Crop No. (1) rice for T = current time

	Month											
Month	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*
ETo(mm/day)	*1.36*	*2.18*	*3.01*	*4.19*	*5.47*	*6.63*	*7.14*	*6.65*	*5.39*	*3.89*	*2.52*	*1.84*
crop Kc					*1.05*	*1.07*	*1.10*	*1.10*	*0.60*			
ET crop (mm/day)					*5.75*	*7.10*	*7.86*	*7.32*	*3.23*			
ET crop (mm/month)					*86.19*	*212.93*	*235.70*	*219.49*	*48.52*			
ET crop (mm/Season)	*803*											
Ave. ET crop mm/growing seasons	*161*											

Crop No. (1) rice for T = 25 Years

	Month											
Month	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*
ETo(mm/day)	*1.75*	*2.76*	*3.60*	*5.10*	*6.13*	*7.30*	*7.85*	*7.04*	*6.60*	*4.31*	*3.00*	*2.26*
crop Kc					*1.05*	*1.07*	*1.10*	*1.10*	*0.60*			
ET crop (mm/day)					*6.44*	*7.81*	*8.64*	*7.74*	*3.96*			
ET crop (mm/month)					*96.55*	*234.33*	*259.05*	*232.32*	*59.40*			
ET crop (mm/Season)	*882*											
Ave. ET crop mm/growing seasons	*176*											

Monthly ETcrop Calculations

Crop No. (2) Wheat and Barley for T= current time

	Month											
Month	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*
ETo(mm/day)	*1.36*	*2.18*	*3.01*	*4.19*	*5.47*	*6.63*	*7.14*	*6.65*	*5.39*	*3.89*	*2.52*	*1.84*
crop Kc	*0.95*	*1.15*	*1.15*	*0.35*							*0.30*	*0.80*
ET crop (mm/day)	*1.29*	*2.50*	*3.46*	*1.47*							*0.76*	*1.48*
ET crop (mm/month)	*38.76*	*75.09*	*103.87*	*43.95*							*11.36*	*44.27*
ET crop (mm/Season)	*317.31*											
Ave. ET crop mm/growing seasons	*53*											

Crop No. (2) Wheat and Barley for T= 25 years

	Month											
Month	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*
ETo(mm/day)	*1.75*	*2.76*	*3.60*	*5.10*	*6.13*	*7.30*	*7.85*	*7.04*	*6.60*	*4.31*	*3.00*	*2.26*
crop Kc	*0.95*	*1.15*	*1.15*	*0.35*							*0.30*	*0.80*
ET crop (mm/day)	*1.66*	*3.17*	*4.14*	*1.79*							*0.90*	*1.81*
ET crop (mm/month)	*49.88*	*95.22*	*124.20*	*53.55*							*13.50*	*54.24*
ET crop (mm/Season)	*390.59*											
Ave. ET crop mm/growing seasons	*65*											

Table (14)

Monthly ETcrop Calculations												
Crop No. (3) Cucumber for T= Current time												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc							0.80	0.95				
ET crop (mm/day)							5.71	6.32				
ET crop (mm/month)							114.28	195.88				
ET crop (mm/Season)	310.16											
Ave. ET crop mm/growing seasons	155											
Crop No. (3) Cucumber for T= 25 years												
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc							0.80	0.95				
ET crop (mm/day)							6.28	6.69				
ET crop (mm/month)							125.60	207.33				
ET crop (mm/Season)	332.93											
Ave. ET crop mm/growing seasons	166											

Monthly ETcrop Calculations												
Crop No. (4) Sunflower for T= Current time												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc					0.40	0.85	1.00	0.80				
ET crop (mm/day)					2.19	5.64	7.14	5.32				
ET crop (mm/month)					21.89	169.15	221.42	53.21				
ET crop (mm/Season)	465.67											
Ave. ET crop mm/growing seasons	116											
Crop No. (4) Sunflower for T= 25 years												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc					0.40	0.85	1.00	0.80				
ET crop (mm/day)					2.45	6.21	7.85	5.63				
ET crop (mm/month)					24.52	186.15	243.35	56.32				
ET crop (mm/Season)	510.34											
Ave. ET crop mm/growing seasons	128											

Table (14)

Monthly ETcrop Calculations

Crop No. (5) Celery for T=Current time

	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc				0.70	0.95	1.00						
ET crop (mm/day)				2.93	5.20	6.63						
ET crop (mm/month)				29.30	155.97	66.33						
ET crop (mm/Season)	251.60											
Ave. ET crop mm/growing seasons	84											

Crop No. (5) Celery for T= 25 Years

	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc				0.70	0.95	1.00						
ET crop (mm/day)				3.57	5.82	7.30						
ET crop (mm/month)				35.70	174.71	73.00						
ET crop (mm/Season)	283.41											
Ave. ET crop mm/growing seasons	94											

Monthly ETcrop Calculations

Crop No. (6) Dry onions for T= Current time

	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc				0.70	1.00	1.05						
ET crop (mm/day)				2.93	5.47	6.97						
ET crop (mm/month)				58.60	164.17	139.30						
ET crop (mm/Season)	362.08											
Ave. ET crop mm/growing seasons	121											

Crop No. (6) Dry onions for T= 25 Years

	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc				0.70	1.00	1.05						
ET crop (mm/day)				3.57	6.13	7.67						
ET crop (mm/month)				71.40	183.90	153.30						
ET crop (mm/Season)	408.60											
Ave. ET crop mm/growing seasons	136											

Table (14)

Monthly ETcrop Calculations												
Crop No. (7) Tomato for T=Current time												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc					0.60	0.85	1.15	0.70				
ET crop (mm/day)					3.28	5.64	8.21	4.66				
ET crop (mm/month)					59.10	169.15	246.41	23.28				
ET crop (mm/Season)	497.95											
Ave. ET crop mm/growing seasons	124											
Crop No. (7) Tomato for T= 25 years												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc					0.60	0.85	1.15	0.70				
ET crop (mm/day)					3.68	6.21	9.03	4.93				
ET crop (mm/month)					66.20	186.15	270.83	24.64				
ET crop (mm/Season)	547.82											
Ave. ET crop mm/growing seasons	137											

Monthly ETcrop Calculations												
Crop No. (8) Peppers for T = Curretnt time												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc				0.60	0.70	1.05	0.90					
ET crop (mm/day)				2.51	3.83	6.97	6.43					
ET crop (mm/month)				25.12	114.92	208.95	32.14					
ET crop (mm/Season)	381.13											
Ave. ET crop mm/growing seasons	95											
Crop No. (8) Peppers for T= 25 years												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc				0.60	0.70	1.05	0.90					
ET crop (mm/day)				3.06	4.29	7.67	7.07					
ET crop (mm/month)				30.60	128.73	229.95	35.33					
ET crop (mm/Season)	424.61											
Ave. ET crop mm/growing seasons	106											

Table (14)

Monthly ETcrop Calculations												
Crop No. (9) Egg plant for T= Current time												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc				0.60	0.70	1.05	0.90					
ET crop (mm/day)				2.51	3.83	6.97	6.43					
ET crop (mm/month)				25.12	114.92	208.95	64.28					
ET crop (mm/Season)	413.27											
Ave. ET crop mm/growing seasons	103											
Crop No. (9) Egg plant for T= 25 years												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc				0.60	0.70	1.05	0.90					
ET crop (mm/day)				3.06	4.29	7.67	7.07					
ET crop (mm/month)				30.60	128.73	229.95	70.65					
ET crop (mm/Season)	459.93											
Ave. ET crop mm/growing seasons	115											

Monthly ETcrop Calculations												
Crop No. (10) Radish for T= Current time												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc								0.70	0.90	0.95		
ET crop (mm/day)								4.66	4.85	3.70		
ET crop (mm/month)								139.68	145.57	110.90		
ET crop (mm/Season)	396.14											
Ave. ET crop mm/growing seasons	132											
Crop No. (10) Radish for T= 25 years												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc								0.70	0.90	0.95		
ET crop (mm/day)								4.93	5.94	4.09		
ET crop (mm/month)								147.84	178.20	122.84		
ET crop (mm/Season)	448.88											
Ave. ET crop mm/growing seasons	150											

Table (14)

Monthly ETcrop Calculations												
Crop No. (11) Sweet melons for T = Current time												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc					0.50	0.70	1.05	0.75				
ET crop (mm/day)					2.74	4.64	7.50	4.99				
ET crop (mm/month)					27.36	139.30	224.99	24.94				
ET crop (mm/Season)	416.59											
Ave. ET crop mm/growing seasons	104											
Crop No. (11) Sweet melons for T= 25 years												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc					0.50	0.70	1.05	0.75				
ET crop (mm/day)					3.07	5.11	8.24	5.28				
ET crop (mm/month)					30.65	153.30	247.28	26.40				
ET crop (mm/Season)	457.63											
Ave. ET crop mm/growing seasons	114											

Monthly ETcrop Calculations												
Crop No. (12) Cowpeas for T = Current time												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
crop Kc					0.60	0.85	1.05	0.40				
ET crop (mm/day)					3.28	5.64	7.50	2.66				
ET crop (mm/month)					32.83	169.15	224.99	13.30				
ET crop (mm/Season)	440.28											
Ave. ET crop mm/growing seasons	110											
Crop No. (12) Cowpeas for T= 25 years												
	Month											
Month	January	February	March	April	May	June	July	August	September	October	November	December
ETo(mm/day)	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
crop Kc					0.60	0.85	1.05	0.40				
ET crop (mm/day)					3.68	6.21	8.24	2.82				
ET crop (mm/month)					36.78	186.15	247.28	14.08				
ET crop (mm/Season)	484.29											
Ave. ET crop mm/growing seasons	121											

Table no. (15)

Monthy and seasonal water supply calculations

Item Descriptions	*Crop No. Tweleve - Cowpeas Crop*			
	Probability analysis based on current return time			
	Month			
	May	*June*	*July*	*August*
Crop growing period	🟥	🟥	🟥	🟥
Ave. ET0 (mm/days)	*5.47*	*6.63*	*7.14*	*6.65*
Crop Coeff. (Kc)	*0.60*	*0.85*	*1.05*	*0.40*
*ETcrop (mm/day) = ETo * Kc*	*3.28*	*5.64*	*7.50*	*2.66*
*ETcrop (mm/month) =ETcrop (mm/day) * No. of days per month*	*32.83*	*169.15*	*224.99*	*13.30*
Effective rainfall Pe(mm)	*13.80*	*0*	*0*	*0*
ground water Ge (mm)	*0*	*0*	*0*	*0*
Wb (mm)	*0*	*0*	*0*	*0*
Leaching req. (LR)	*0.38*	*0.38*	*0.38*	*0.38*
1-LR	*0.62*	*0.62*	*0.62*	*0.62*
Project eff. (Ep)	*0.40*	*0.40*	*0.40*	*0.40*
10/Ep	*25*	*25*	*25*	*25*
In = ETcrop - Pe-Ge-Wb	*19.04*	*169.15*	*224.99*	*13.30*
Crop area = 32.4 hac	*25.92*	*25.92*	*25.92*	*25.92*
*A * (ETcrop - Pe-Ge-Wb)*	*493.41*	*4384.46*	*5831.65*	*344.81*
*[A * (ETcrop - Pe-Ge-Wb)] / 1-LR*	*795.821*	*7071.714*	*9405.884*	*556.139*
*Monthly water supply (m3/month) V = 10/Ep [(A * (ETcrop - Pe-Ge-Wb))/1-LR]*	*19895.53*	*176792.84*	*235147.10*	*13903.48*
Water duity (WD) liter/sec/hec.	*0.30*	*2.63*	*3.50*	*0.21*
Ave. W.D per growing period (l/sec/hec)	*1.66*			

Table no.(15)

Monthy and seasonal water supply calculations

Item Descriptions	Crop No. 0ne - Rice Crop				
	Probability analysis based on current return time				
	Month				
	May	June	July	August	September
Crop growing period	🟥	🟥	🟥	🟥	🟥
Ave. ET0 (mm/days)	5.47	6.63	7.14	6.65	5.39
Crop Coeff. (Kc)	1.05	1.07	1.10	1.10	0.60
ETcrop (mm/day) = ETo * Kc	5.75	7.10	7.86	7.32	3.23
ETcrop (mm/month) =ETcrop (mm/day) * No. of days per month	86.19	212.93	235.70	219.49	48.52
Effective rainfall Pe(mm)	14	0	0	0	0
ground water Ge (mm)	0	0	0	0	0
Wb (mm)	0	0	0	0	0
Leaching req. (LR)	0.40	0.40	0.40	0.40	0.40
1-LR	0.60	0.60	0.60	0.60	0.60
Project eff. (Ep)	0.40	0.40	0.40	0.40	0.40
10/Ep	25	25	25	25	25
In = ETcrop - Pe-Ge-Wb	72.39	212.93	235.70	219.49	48.52
Crop area = 32.4 hac	32.4	32.4	32.4	32.4	32.4
A * (ETcrop - Pe-Ge-Wb)	2346	6899	7637	7112	1572
[A * (ETcrop - Pe-Ge-Wb)] / 1-LR	3909	11498	12728	11853	2620
Monthly water supply (m3/month) V = 10/Ep [(A * (ETcrop - Pe-Ge-Wb))/1-LR]	97730	287462	318195	296318	65505
Water duity (WD) liter/sec/hec.	1.16	3.42	3.79	3.53	0.78
Ave. W.D per growing period (l/sec/hec)	2.54				

Table no. (16)

Total monthly required ETcrop on the basis of current time analysis

Crop types	*Item descriptions*	*Month*												*Total required ETcrop (mm/day) for each type of crops*
		January	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*	
Rice	*Monthly required ETcrop (mm/month)*					86.19	212.93	235.70	219.49	48.52				*802.84*
Wheat and barley		38.60	75.09	103.87	43.95							11.36	44.27	*317.15*
Cucumber								114.28	195.88					*310.16*
Sunflower						21.89	169.15	221.42	53.21					*465.67*
Celery					29.30	155.97	66.33							*251.60*
Onion					58.60	164.17	139.30							*362.08*
Tomatoes						59.10	169.15	246.41	23.28					*497.95*
Peppers					25.12	114.92	208.95	32.14						*381.13*
Egg plant					25.12	114.92	208.95	64.28						*413.27*
Radish									139.68	145.57	110.90			*396.14*
Sweet melons						27.36	139.30	224.99	24.94					*416.59*
Cowpeas						32.83	169.15	224.99	13.30					*440.28*
Total ETcrop for all the crop type (mm/year/ growing seasons)		38.60	75.09	103.87	182.09	777.37	1483.25	1364.20	669.79	194.09	110.90	11.36	44.27	

Table no. (17)

Mean daily percentage (P) of annual daytime hours for different latitudes

Latitude	North	January	February	March	April	May	Jun	July	August	September	October	November	December
	South	Jun	July	August	September	October	November	December	January	February	March	April	May
60		0.15	0.20	0.26	0.32	0.38	0.41	0.40	0.34	0.28	0.22	0.17	0.13
58		0.16	0.21	0.26	0.32	0.37	0.40	0.39	0.34	0.28	0.23	0.18	0.15
56		0.17	0.21	0.26	0.32	0.36	0.39	0.38	0.33	0.28	0.23	0.18	0.16
54		0.18	0.22	0.26	0.31	0.36	0.38	0.37	0.33	0.28	0.23	0.19	0.17
52		0.19	0.22	0.27	0.31	0.35	0.37	0.36	0.33	0.28	0.24	0.20	0.17
50		0.19	0.23	0.27	0.31	0.34	0.36	0.35	0.32	0.28	0.24	0.20	0.18
48		0.20	0.23	0.27	0.31	0.34	0.36	0.35	0.32	0.28	0.24	0.21	0.19
46		0.20	0.23	0.27	0.30	0.34	0.35	0.34	0.32	0.28	0.24	0.21	0.20
44		0.21	0.24	0.27	0.30	0.33	0.35	0.34	0.31	0.28	0.25	0.22	0.20
42		0.21	0.24	0.27	0.30	0.33	0.34	0.33	0.31	0.28	0.25	0.22	0.21
40		0.22	0.24	0.27	0.30	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21
35		0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.30	0.28	0.25	0.23	0.22
30		0.24	0.25	0.27	0.29	0.31	0.32	0.31	0.30	0.28	0.26	0.24	0.23
25		0.24	0.26	0.27	0.29	0.30	0.31	0.31	0.29	0.28	0.26	0.25	0.24
20		0.25	0.26	0.27	0.28	0.29	0.30	0.30	0.29	0.28	0.26	0.25	0.25
15		0.26	0.26	0.27	0.28	0.29	0.29	0.29	0.28	0.28	0.27	0.26	0.25
10		0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.28	0.28	0.27	0.26	0.26
5		0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.27	0.27
0		0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27

Table no. (18)

Extra Terresttrail Radiation (Ra) expressed in equivalent evaporation in (mm/day)

Northern Hemisphere

Latitude	*January*	*February*	*March*	*April*	*May*	*Jun*	*July*	*August*	*September*	*October*	*November*	*December*
50	3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.0	7.4	4.5	3.2
48	4.3	6.7	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7
46	4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3
44	5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7
42	5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2
40	6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7
38	6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1
36	7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6
34	7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2
32	8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8
30	8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3
28	9.3	11.1	13.4	15.3	16.5	6.8	16.7	15.7	14.1	12.0	9.9	8.8
26	9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3
24	10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7
22	10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2
20	11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7
18	11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1
16	12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6
14	12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0
12	12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5
10	13.2	14.2	15.3	15.7	1.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9
8	13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3
6	13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7
4	14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1
2	14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4
0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

Table (19)

Soil Sample No. (1)

Liquid limit test

S.N	Item Descriptions	Measured Data
1	Can No. or Can name	A3
2	No. of blows (N)	21
3	Self Can weight (empity) - W1	22.89
4	Can weight + Wet sample - W2	63.40
5	Can weight + dry sample - W3	49.66
6	Moisture content (Mc %) = (W2-W3)/(W3-W1)*100	51.33
7	Liquid limit (L.L) = Mc% *(N/25) $^{0.121}$	50.25

Plastic limit test

S.N	Item Descriptions	Measured Data
1	Can No. or Can name	A
2	Self Can weight (empity) - W1	13.63
3	Can weight + Wet sample - W2	21.25
4	Can weight + dry sample - W3	19.47
5	Moisture content (Mc %) = (W2-W3)/(W3-W1)*100	30.48
6	Plastic limit (P.L) = Mc%	30.48
7	Placicity Index = L.L - P.L	19.78

Soil Sample No. (2)

Liquid limit test

S.N	Item Descriptions	Measured Data
1	Can No. or Can name	D10
2	No. of blows (N)	29
3	Self Can weight (empity) - W1	16.2
4	Can weight + Wet sample - W2	90.98
5	Can weight + dry sample - W3	67.46
6	Moisture content (Mc %) = (W2-W3)/(W3-W1)*100	45.88
7	Liquid limit (L.L) = Mc% *(N/25) $^{0.121}$	46.72

Plastic limit test

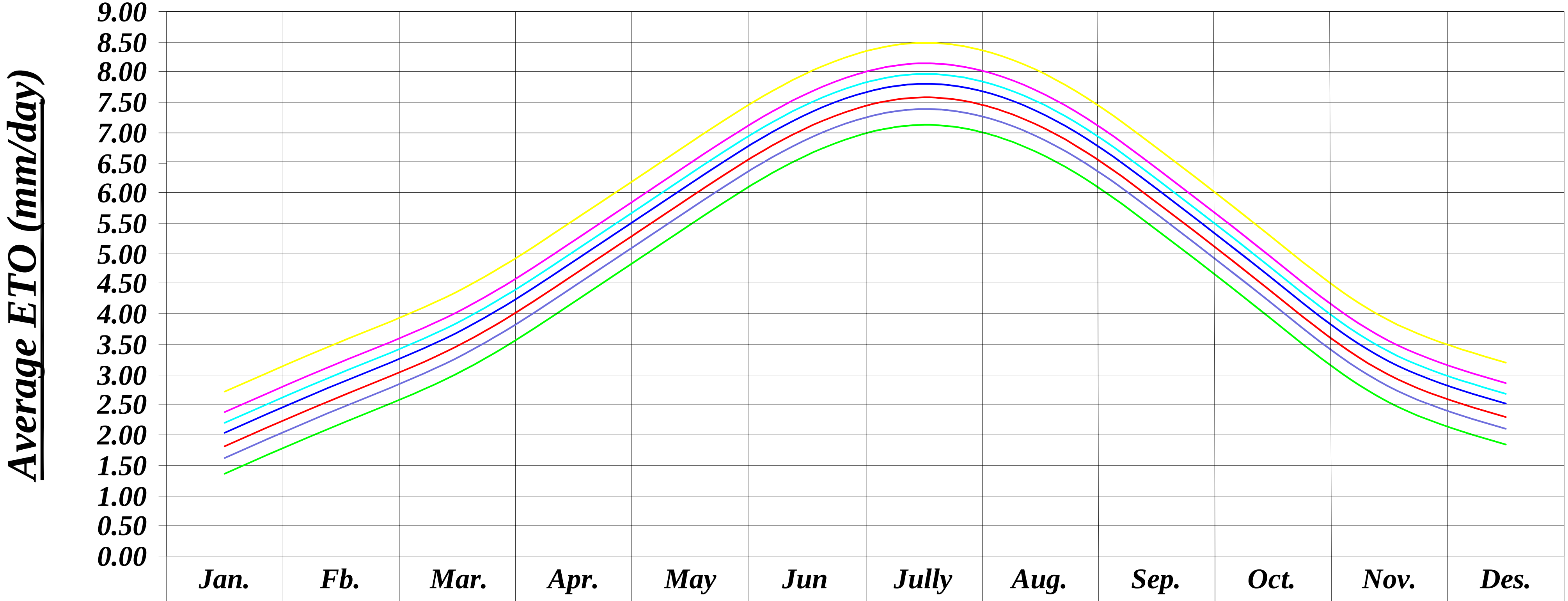
S.N	Item Descriptions	Measured Data
1	Can No. or Can name	B3
2	Self Can weight (empity) - W1	18.48
3	Can weight + Wet sample - W2	28.33
4	Can weight + dry sample - W3	26.23
5	Moisture content (Mc %) = (W2-W3)/(W3-W1)*100	27.10
6	Plastic limit (P.L) = Mc%	27.10
7	Placicity Index = L.L - P.L	19.62

Table (20)

Summary Table for calculating evapotraspiration

No.	**Methods**	**Years**	**Required climatological data**							**remarks**
			Mean air temperature C^{o}	**Humidity %**	**Pan evaporation (mm)**	**Wind velocity (m/sec.)**	**Cloudiness**	**Sunshine duration (hr.)**	**average wet bulb depression in C^{o}**	
1	***Penman formula and Modified Penman method***	***1948 to1977***	▨	▨	▨	▨	▨	▨	▨	***Require full climatologically data and complicate for using using but, give the most reliable results.***
2	***Thornthwaite formula***	***1948***	▨							***Adjustment should be done to the calculate results.***
3	***Blaney – Criddle formula and modified Blaney – Criddle method***	***1950 to 1957***	▨							***Widely used for semiarid and arid regon.***
4	***Radiation method***	***1957***	▨				▨	▨		***This method may be more reliable even if sunshine or cloudiness are not available.***
5	***Oliver method***	***1961***							▨	***Is very simple formula***
6	***Evaporation method***	***1968***			▨					***Sunshine has the main affact on this method.***
7	***Hargreaves method***	***1985***	▨							***Require minmum climatologically data.***
8	***Energy Balance Method:***	***1973***	***Net radiation, rate at which heat content of the soil and latent heat flux***							***This method applies over any time period.***

Frequencey Analysis curve for average ETo (mm/day)



	Jan.	Fb.	Mar.	Apr.	May	Jun	Jully	Aug.	Sep.	Oct.	Nov.	Des.
△ Current time	1.36	2.18	3.01	4.19	5.47	6.63	7.14	6.65	5.39	3.89	2.52	1.84
□ 25 years	1.75	2.76	3.60	5.10	6.13	7.30	7.85	7.04	6.60	4.31	3.00	2.26
△ 50 years	1.85	2.91	3.75	5.34	6.31	7.48	8.04	7.15	6.20	4.43	3.12	2.37
75 years	1.91	3.00	3.84	5.48	6.41	7.58	8.15	7.21	6.30	4.49	3.20	2.44
+ 100 years	1.95	3.06	3.91	5.58	6.48	7.65	8.23	7.25	7.24	4.54	3.25	2.48
○ 125 years	1.99	3.11	3.95	5.65	6.54	7.71	8.29	7.28	7.34	4.57	3.29	2.52
+ 150 years	2.01	3.15	3.99	5.72	6.58	7.75	8.39	7.31	7.43	4.60	3.32	2.55

Fig (12): Frequency distribution analysis for ETo by Gumble method

Fig. (2): Satellite Image for the research Area

Irrigated land photos

Irrigated land photos (Fig.4)

Irrigated land photos (Fig.5)

Irrigated land photos, continued

Irrigated land photos (Fig.6)

Irrigated land photos (Fig. 7)

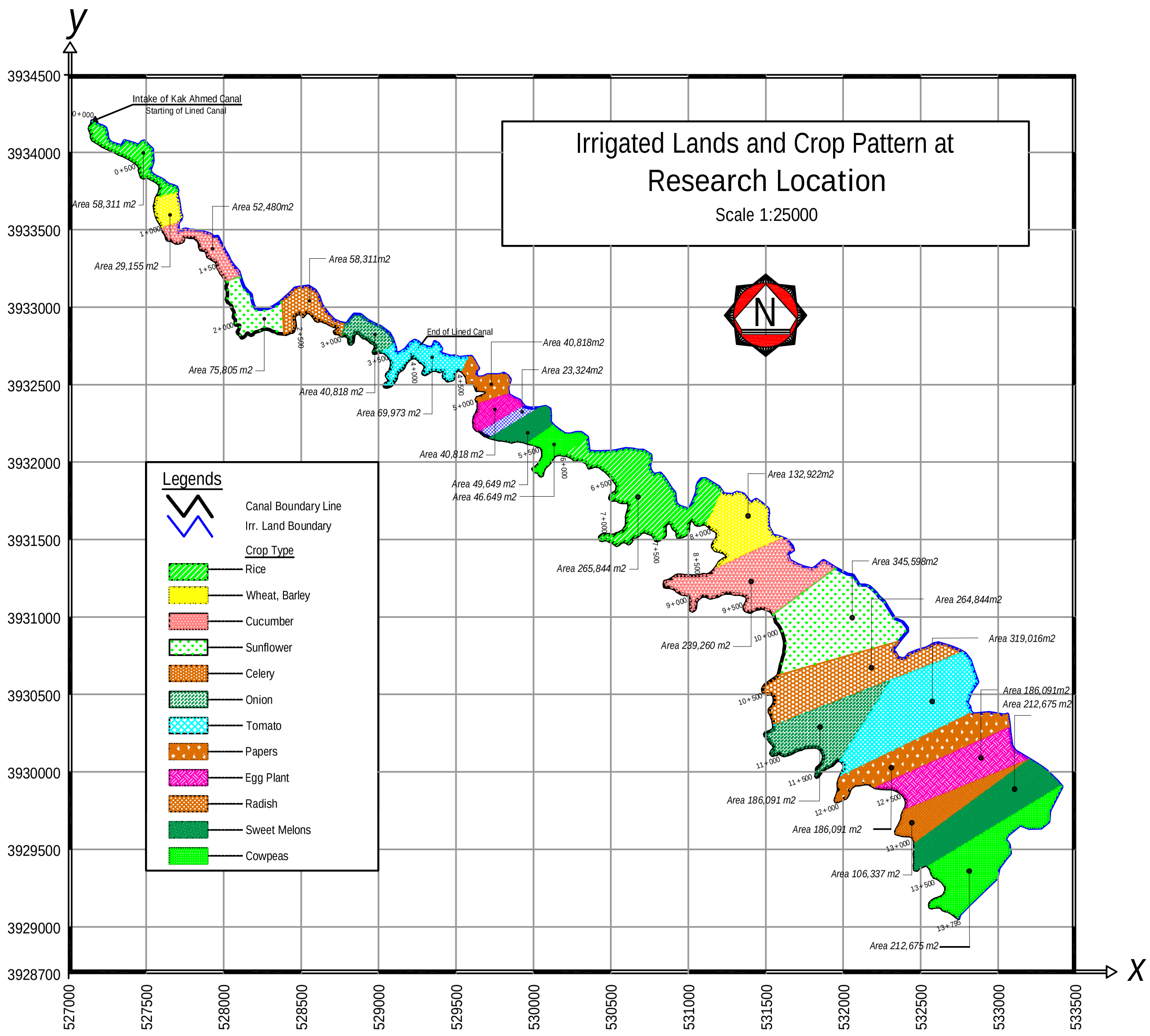
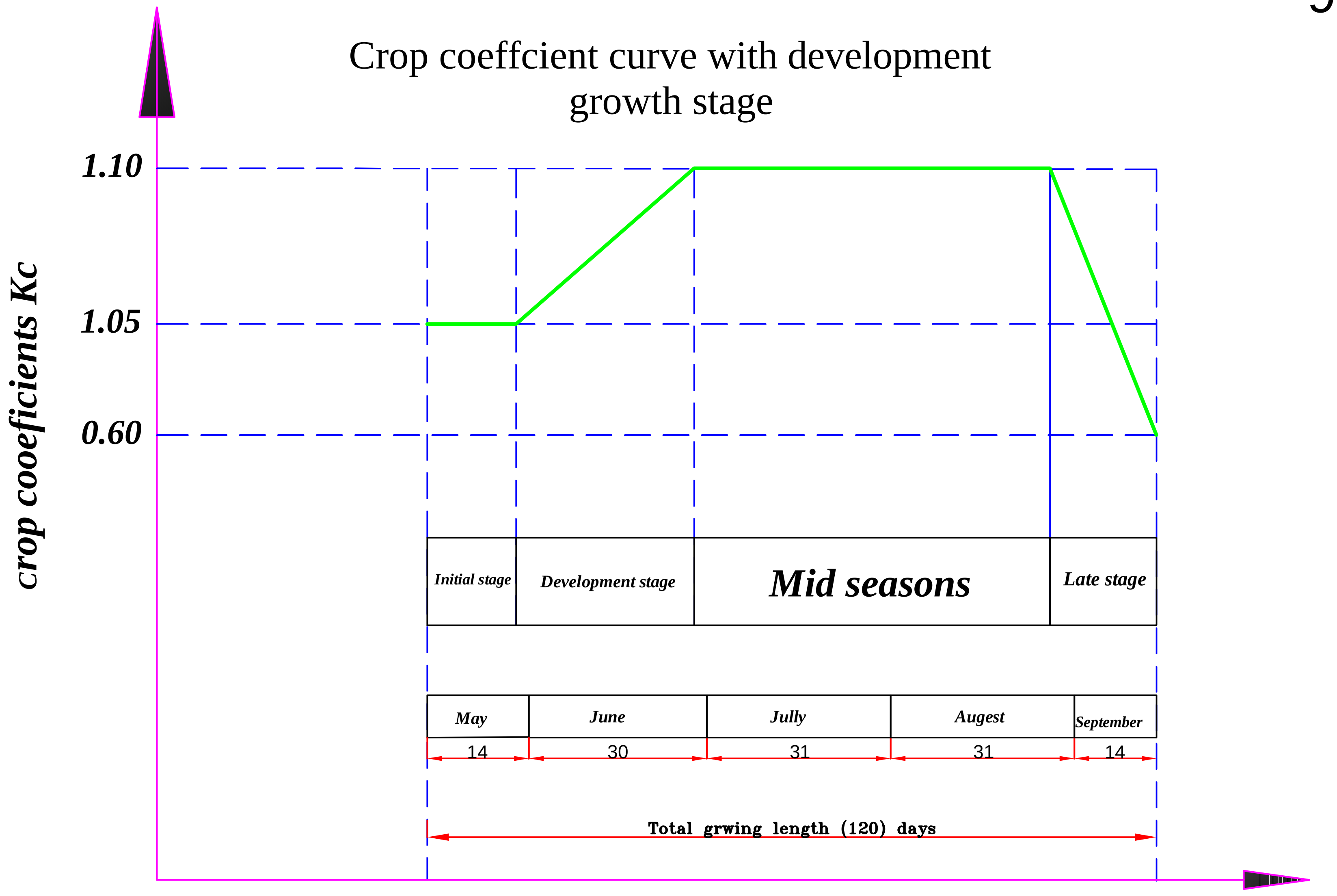


Fig (3): Prepared map for the study area showing different crop types with their sub area



Crop coefficent curve (Rice crop)

Fig. (11)

Table (1)

Average Daily Air Temperature for Sulaimnyia Center (C^o)

Months		Years																																	
		1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Jan.	Max.	6.2	5.7	9.3	9.5	5.3	10.5	9	6.7	10.8	8.9	5.1	12.1	12.6	11.2	13.2	8.7	6.2	8.2	6.3	4.4	8.8	12.5	12.9	10	11.1	7.6	13.2	9.4	11.4	8.8	11.1	10.8	10	9.1
	Min.	-2.9	-0.4	1.3	1.3	-1.5	2.4	2.3	0.6	2.8	0.2	-1.9	3.1	3.7	2.8	2.8	3.6	-1.9	1	-0.25	-1.5	1.1	5.1	4.6	3.1	3	0.7	5	1	2.8	1.7	3.4	4	2.5	1.6
	Ave.	1.7	2.7	5.3	5.4	1.9	6.5	5.7	3.7	6.8	4.6	1.6	7.6	8.2	7.0	8.0	6.2	2.2	4.6	3.0	1.5	5.0	8.8	8.8	6.6	7.1	4.2	9.1	5.2	7.1	5.3	7.3	7.4	6.3	5.4
	ΔT	9.1	6.1	8.0	8.2	6.8	8.1	6.7	6.1	8.0	8.7	7.0	9.0	8.9	8.4	10.4	5.1	8.1	7.2	6.6	5.9	7.7	7.4	8.3	6.9	8.1	6.9	8.2	8.4	8.6	7.1	7.7	6.8	7.5	7.5
Feb.	Max.	13.4	7.8	8.7	7.9	15.9	13.8	14.3	10.1	11.2	7	9.2	13.3	8.1	12.3	15.4	10.9	10.4	9.3	7.6	5.9	10.4	9.8	13.5	14	9.8	10.6	14.8	15.2	12.5	13.4	9.9	11.2	10.2	12.4
	Min.	3.9	0.1	1.3	-0.1	5	4.4	5.5	2.5	3.7	-1.4	0.8	4.1	0.1	4.6	5.4	2.6	1.9	2.6	1.2	-0.2	2.4	2.3	5.4	3.2	0	2.4	4.2	2.7	3.8	4.6	2.2	2.9	2.6	4.3
	Ave.	8.7	4.0	5.0	3.9	10.5	9.1	9.9	6.3	7.5	2.8	5.0	8.7	4.1	8.5	10.4	6.8	6.2	6.0	4.4	2.9	6.4	6.1	9.5	8.6	4.9	6.5	9.5	9.0	8.2	9.0	6.1	7.1	6.4	8.4
	ΔT	9.5	7.7	7.4	8.0	10.9	9.4	8.8	7.6	7.5	8.4	8.4	9.2	8.0	7.7	10.0	8.3	8.5	6.7	6.4	6.1	8.0	7.5	8.1	10.8	9.8	8.2	10.6	12.5	8.7	8.8	7.7	8.3	7.6	8.1
Mar.	Max.	16.4	13.9	15.4	12	17.7	16.5	15.4	15.5	16.3	13.6	14.2	16.9	13.4	16	12.3	14.3	16.6	17	14.5	11.9	15	16.7	17.6	14.4	11.5	16	19.3	15.9	19.9	18.4	18.4	19.8	16.1	19.7
	Min.	4.3	6.8	4.8	3.8	8.1	7.2	6.2	6.5	6.8	4.2	4.4	7.4	3.8	7.2	4.6	5.7	7.5	9.3	6.15	3	5.3	10.1	7.7	5.3	3.5	6.3	7.4	5.2	9.5	9	9	9.4	7.4	8.8
	Ave.	10.4	10.4	10.1	7.9	12.9	11.9	10.8	11.0	11.6	8.9	9.3	12.2	8.6	11.6	8.5	10.0	12.1	13.2	10.3	7.5	10.2	13.4	12.7	9.9	7.5	11.2	13.4	10.6	14.7	13.7	13.7	14.6	11.8	14.3
	ΔT	12.1	7.1	10.6	8.2	9.6	9.3	9.2	9.0	9.5	9.4	9.8	9.5	9.6	8.8	7.7	8.6	9.1	7.7	8.3	8.9	9.7	6.6	9.9	9.1	8.0	9.7	11.9	10.7	10.4	9.4	9.4	10.4	8.7	10.9
Apr.	Max.	19.7	18.8	24	18.9	20.7	21.4	22.1	21.2	20.2	22.3	21.1	21.7	22.2	22.7	21.4	21.5	26.8	20.8	20.1	19.4	20.3	23.5	20.8	23.5	20.3	23.6	23.9	23.7	23.4	19.1	21.7	21.1	24	25.3
	Min.	9.6	9.4	12.8	10.1	10.9	10.1	12.2	10.8	9.8	12.1	10.6	11.3	12	12.6	10.1	11.4	14.7	13.1	12.3	11.5	10.7	10.5	9.9	9.7	10	12.2	12.4	13	12.2	10.7	12.2	11.3	13.7	12
	Ave.	14.7	14.1	18.4	14.5	15.8	15.8	17.2	16.0	15.0	17.2	15.9	16.5	17.1	17.7	15.8	16.5	20.8	17.0	16.2	15.5	15.5	17.0	15.4	16.6	15.2	17.9	18.2	18.4	17.8	14.9	17.0	16.2	18.9	18.7
	ΔT	10.1	9.4	11.2	8.8	9.8	11.3	9.9	10.4	10.4	10.2	10.5	10.4	10.2	10.1	11.3	10.1	12.1	7.7	7.8	7.9	9.6	13.0	10.9	13.8	10.3	11.4	11.5	10.7	11.2	8.4	9.5	9.8	10.3	13.3
May	Max.	27.9	29.6	26.5	25.4	27.8	28.9	28	28.8	25.6	27.9	27.8	25.5	30.1	26.7	31.1	29.1	30.7	29.6	27.2	24.7	25	29.4	29.3	31.6	29.3	30.3	31.3	29.9	29	28.3	29.5	26	29.4	29.5
	Min.	15.4	17.1	14.9	14.4	16.7	16.6	16.9	16.8	14.4	17	16.9	14.8	17.9	14.8	17.4	16.6	18.6	16.9	15.8	14.7	15	17.8	17.8	18.4	17.4	16.4	19.9	18	16.8	16.8	18.2	5.8	18.1	18
	Ave.	21.7	23.4	20.7	19.9	22.3	22.8	22.5	22.8	20.0	22.5	22.4	20.2	24.0	20.8	24.3	22.9	24.7	23.3	21.5	19.7	20.0	23.6	23.6	25.0	23.4	23.4	25.6	24.0	22.9	22.6	23.9	15.9	23.8	23.8
	ΔT	12.5	12.5	11.6	11.0	11.1	12.3	11.1	12.0	11.2	10.9	10.9	10.7	12.2	11.9	13.7	12.5	12.1	12.7	11.4	10.0	10.0	11.6	11.5	13.2	11.9	13.9	11.4	11.9	12.2	11.5	11.3	20.2	11.3	11.5
June	Max.	34	35.5	35.3	34.3	34.8	33	34.2	35.9	34	34.8	34.1	36.4	35.8	33.8	36.3	33.5	35.7	36.1	34.6	33.1	34.4	30.5	34.6	34.9	34.8	38.5	36	32.5	35.8	34.6	35	34.9	35.4	37.8
	Min.	20.2	22.8	22.6	21.8	21.9	21.2	21.9	23.5	22.2	21.9	21.4	22.8	22.1	21.4	22.4	21.9	21.5	21.4	19.9	18.3	21.3	21	22.6	22	23.4	24.3	24.7	25.9	26	23.6	23.4	22.7	23.6	24.5
	Ave.	27.1	29.2	29.0	28.1	28.4	27.1	28.1	29.7	28.1	28.4	27.8	29.6	29.0	27.6	29.4	27.7	28.6	28.8	27.2	25.7	27.9	25.8	28.6	28.5	29.1	31.4	30.4	29.2	30.9	29.1	29.2	28.8	29.5	31.2
	ΔT	13.8	12.7	12.7	12.5	12.9	11.8	12.3	12.4	11.8	12.9	12.7	13.6	13.7	12.4	13.9	11.6	14.2	14.7	14.8	14.8	13.1	9.5	12.0	12.9	11.4	14.2	11.3	6.6	9.8	11.0	11.6	12.2	11.8	13.3
July	Max.	37.8	38.3	38.7	36.8	37.9	39.4	38.6	41.4	35.3	37.6	38.8	40.9	33.8	41.3	39.2	39.2	41.3	40.2	39.8	39.4	39.9	38.8	38.8	40.5	38.6	40.6	38.7	41.8	39.3	38	38.4	38.8	40.8	38.6
	Min.	24.1	25.4	25.3	24.4	25.2	26.8	24.9	27.6	27.2	23.7	24.8	27.3	24.1	27.2	26.8	27.2	26.7	27.4	27.6	27.8	27.9	26.4	28.4	28.7	25.4	27	27.2	29.9	27.6	27.3	26.3	26.2	28.3	21.6
	Ave.	31.0	31.9	32.0	30.6	31.6	33.1	31.8	34.5	31.3	30.7	31.8	34.1	29.0	34.3	33.0	33.2	34.0	33.8	33.7	33.6	33.9	32.6	33.6	34.6	32.0	33.8	33.0	35.9	33.5	32.7	32.4	32.5	34.6	30.1
	ΔT	13.7	12.9	13.4	12.4	12.7	12.6	13.7	13.8	8.1	13.9	14.0	13.6	9.7	14.1	12.4	12.0	14.6	12.8	12.2	11.6	12.0	12.4	10.4	11.8	13.2	13.6	11.5	11.9	11.7	10.7	12.1	12.6	12.5	17.0
Aug.	Max.	39.9	36.6	38.6	39.1	39	37.8	39.2	39.1	37.7	37.2	37.8	37.4	39.4	40.4	38.7	38.2	39.1	37.5	37.5	37.4	38.8	39	40.2	40	38.6	41.9	40.5	39.8	39.6	37.4	37.8	38.1	39.2	40.8
	Min.	26.8	24.1	24.4	24.9	26	24.1	26.9	25.7	25.3	23.9	23.5	22.7	27.4	26.8	25.2	26.2	25.1	24	23.9	23.8	26.3	26	25.8	25.6	23.6	28.5	28.2	26	26.8	25	25	25	28.3	29.5
	Ave.	33.4	30.4	31.5	32.0	32.5	31.0	33.1	32.4	31.5	30.6	30.7	30.1	33.4	33.6	32.0	32.2	32.1	30.8	30.7	30.6	32.6	32.5	33.0	32.8	31.1	35.2	34.4	32.9	33.2	31.2	31.4	31.6	33.8	35.2
	ΔT	13.1	12.5	14.2	14.2	13.0	13.7	12.3	13.4	12.4	13.3	14.3	14.7	12.0	13.6	13.5	12.0	14.0	13.5	13.6	13.6	12.5	13.0	14.4	14.4	15.0	13.4	12.3	13.8	12.8	12.4	12.8	13.1	10.9	11.3
Sep.	Max.	35	33.2	34.2	32.4	33.7	34.5	36.5	33.5	35.5	34.6	38.8	36.3	35.8	37.3	37.8	33.9	33.9	35.4	34.9	34.3	33.6	35.2	34.3	35	32.5	36	34	34.1	34.6	34.6	34.9	35.1	34.6	33
	Min.	21.5	20	11.4	19.4	21.8	20.8	24.9	20.1	22.2	22	20.8	20.9	21.3	24.8	26.6	20.4	19.8	20.2	20.9	21.6	21.5	23.6	20.9	20.7	20.6	21.7	21.9	21.3	22.1	21.6	22.3	22.9	21.4	20
	Ave.	28.3	26.6	22.8	25.9	27.8	27.7	30.7	26.8	28.9	28.3	29.8	28.6	28.6	31.1	32.2	27.2	26.9	27.8	27.9	28.0	27.6	29.4	27.6	27.9	26.6	28.9	28.0	27.7	28.4	28.1	28.6	29.0	28.0	26.5
	ΔT	13.5	13.2	22.8	13.0	11.9	13.7	11.6	13.4	13.3	12.6	18.0	15.4	14.5	12.5	11.2	13.5	14.1	15.2	14.0	12.7	12.1	11.6	13.4	14.3	11.9	14.3	12.1	12.8	12.5	13.0	12.6	12.2	13.2	13.0
Oct.	Max.	29.6	29.3	26.2	25.2	24.5	28.8	27.3	27.1	27.6	23.1	27.8	26.9	26.5	28.3	24	27.2	29	27.1	28.8	28.3	27.9	29.6	27.9	25.9	27	30.2	28.4	25.4	27.6	28.9	29	29	27.7	26
	Min.	17.7	17.1	13.5	13.9	13.3	16.7	16.1	14.8	16.9	13	14.6	15.1	14.5	16.5	14.3	14.2	16.8	15.5	14.6	15.4	16.9	17.4	15.2	15.3	16.3	15.8	17.4	14.6	17.1	18	17.6	17.1	15.3	14
	Ave.	23.7	23.2	19.9	19.6	18.9	22.8	21.7	21.0	22.3	18.1	21.2	21.0	20.5	22.4	19.2	20.7	22.9	21.3	21.7	21.9	22.4	23.5	21.6	20.6	21.7	23.0	22.9	20.0	22.4	23.5	23.3	23.1	21.5	20.0
	ΔT	11.9	12.2	12.7	11.3	11.2	12.1	11.2	12.3	10.7	10.1	13.2	11.8	12.0	11.8	9.7	13.0	12.2	11.6	14.2	12.9	11.0	12.2	12.7	10.6	10.7	14.4	11.0	10.8	10.5	10.9	11.4	11.9	12.4	12.0
Nov.	Max.	16.3	19.7	18.2	20	18.7	15.1	21.1	18.3	17.5	13.9	20.4	15.9	21.2	15.1	19.3	16.2	18.2	22.3	20.2	16.1	15.6	16.1	18.9	21	18.2	24.6	17.7	18.7	17	18.6	16	15.7	19.4	18
	Min.	6.8	9	7.8	10.2	7.8	4.5	10.6	9.4	7.4	5.7	10.9	8.8	10.3	7.7	9.7	6.7	8.9	10.5	10	8.4	7.5	8	7.7	10.5	9.5	11.5	9	8.2	8.3	10.6	9	8.6	9.2	9
	Ave.	11.6	14.4	13.0	15.1	13.3	9.8	15.9	13.9	12.5	9.8	15.7	12.4	15.8	11.4	14.5	11.5	13.6	16.4	15.1	12.3	11.6	12.1	13.3	15.8	13.9	18.1	13.4	13.5	12.7	14.6	12.5	12.2	14.3	13.5
	ΔT	9.5	10.7	10.4	9.8	10.9	10.6	10.5	8.9	10.1	8.2	9.5	7.1	10.9	7.4	9.6	9.5	9.3	11.8	10.2	7.7	8.1	8.1	11.2	10.5	8.7	13.1	8.7	10.5	8.7	8.0	7.0	7.1	10.2	9.0
Dec.	Max.	11.8	10.8	9.1	13.7	11.3	12.4	10.6	13.4	14.4	9.4	12.5	9.6	11.4	11.1	10.8	11.7	12.8	12	9.9	8.7	13.5	8.2	12.1	15.2	11.8	19	14.4	12.1	12.2	9.3	9	10.9	16.8	16
	Min.	2.8	2.2	1.8	5.7	3.8	4.5	3.3	4.5	5.4	0.9	4.3	2	3.3	2.5	4.6	3.8	4	3.8	2.6	2.5	5.5	0.7	2.6	7.1	4.5	7.7	6	4.8	5.1	3.6	3.2	2.9	6.3	6.1
	Ave.	7.3	6.5	5.5	9.7	7.6	8.5	7.0	9.0	9.9	5.2	8.4	5.8	7.4	6.8	7.7	7.8	8.4	7.9	6.3	5.6	9.5	4.5	7.4	11.2	8.2	13.4	10.2	8.5	8.7	6.5	6.1	6.9	11.6	11.1
	ΔT	9.0	8.6	7.3	8.0	7.5	7.9	7.3	8.9	9.0	8.5	8.2	7.6	8.1	8.6	6.2	7.9	8.8	8.2	7.3	6.2	8.0	7.5	9.5	8.1	7.3	11.3	8.4	7.3	7.1	5.7	5.8	8.0	10.5	9.9

Table (2)

ETo calculation by Hargreaves method (mm/day)

Mon.	Ra (mm/day)	Temp. C^0	Years																																	
			1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Jan.	7.513	Tave.	1.7	2.7	5.3	5.4	1.9	6.5	5.7	3.7	6.8	4.6	1.6	7.6	8.2	7.0	8.0	6.2	2.2	4.6	3.0	1.5	5.0	8.8	8.8	6.6	7.1	4.2	9.1	5.2	7.1	5.3	7.3	7.4	6.3	5.4
		ΔT	9.1	6.1	8.0	8.2	6.8	8.1	6.7	6.1	8.0	8.7	7.0	9.0	8.9	8.4	10.4	5.1	8.1	7.2	6.6	5.9	7.7	7.4	8.3	6.9	8.1	6.9	8.2	8.4	8.6	7.1	7.7	6.8	7.5	7.5
		$\sqrt{\Delta T}$	3.0	2.5	2.8	2.9	2.6	2.8	2.6	2.5	2.8	2.9	2.6	3.0	3.0	2.9	3.2	2.3	2.8	2.7	2.6	2.4	2.8	2.7	2.9	2.6	2.8	2.6	2.9	2.9	2.9	2.7	2.8	2.6	2.7	2.7
		(Tave.+17.8)	19.5	20.5	5.3	5.4	1.9	6.5	5.7	3.7	6.8	4.6	1.6	7.6	8.2	7.0	8.0	6.2	2.2	4.6	3.0	1.5	5.0	8.8	8.8	6.6	7.1	4.2	9.1	5.2	7.1	5.3	7.3	7.4	6.3	5.4
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			1.01	0.87	0.26	0.27	0.09	0.32	0.25	0.16	0.33	0.23	0.07	0.39	0.42	0.35	0.45	0.24	0.11	0.21	0.13	0.06	0.24	0.41	0.44	0.30	0.35	0.19	0.45	0.26	0.36	0.24	0.35	0.33	0.30	0.25
Feb.	9.49	Tave.	8.7	4.0	5.0	3.9	10.5	9.1	9.9	6.3	7.5	2.8	5.0	8.7	4.1	8.5	10.4	6.8	6.2	6.0	4.4	2.9	6.4	6.1	9.5	8.6	4.9	6.5	9.5	9.0	8.2	9.0	6.1	7.1	6.4	8.4
		ΔT	9.5	7.7	7.4	8.0	10.9	9.4	8.8	7.6	7.5	8.4	8.4	9.2	8.0	7.7	10.0	8.3	8.5	6.7	6.4	6.1	8.0	7.5	8.1	10.8	9.8	8.2	10.6	12.5	8.7	8.8	7.7	8.3	7.6	8.1
		$\sqrt{\Delta T}$	3.1	2.8	2.7	2.8	3.3	3.1	3.0	2.8	2.7	2.9	2.9	3.0	2.8	2.8	3.2	2.9	2.9	2.6	2.5	2.5	2.8	2.7	2.8	3.3	3.1	2.9	3.3	3.5	2.9	3.0	2.8	2.9	2.8	2.8
		(Tave.+17.8)	26.5	21.8	22.8	21.7	28.3	26.9	27.7	24.1	25.3	20.6	22.8	26.5	21.9	26.3	28.2	24.6	24.0	23.8	22.2	20.7	24.2	23.9	27.3	26.4	22.7	24.3	27.3	26.8	26.0	26.8	23.9	24.9	24.2	26.2
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			1.78	1.32	1.35	1.34	2.04	1.80	1.79	1.45	1.51	1.30	1.44	1.75	1.35	1.59	1.95	1.54	1.52	1.34	1.23	1.11	1.49	1.43	1.69	1.89	1.55	1.52	1.94	2.06	1.67	1.74	1.44	1.56	1.46	1.62
Mar.	12.168	Tave.	10.4	10.4	10.1	7.9	12.9	11.9	10.8	11.0	11.6	8.9	9.3	12.2	8.6	11.6	8.5	10.0	12.1	13.2	10.3	7.5	10.2	13.4	12.7	9.9	7.5	11.2	13.4	10.6	14.7	13.7	13.7	14.6	11.8	14.3
		ΔT	12.1	7.1	10.6	8.2	9.6	9.3	9.2	9.0	9.5	9.4	9.8	9.5	9.6	8.8	7.7	8.6	9.1	7.7	8.3	8.9	9.7	6.6	9.9	9.1	8.0	9.7	11.9	10.7	10.4	9.4	9.4	10.4	8.7	10.9
		$\sqrt{\Delta T}$	3.5	2.7	3.3	2.9	3.1	3.0	3.0	3.0	3.1	3.1	3.1	3.1	3.1	3.0	2.8	2.9	3.0	2.8	2.9	3.0	3.1	2.6	3.1	3.0	2.8	3.1	3.4	3.3	3.2	3.1	3.1	3.2	2.9	3.3
		(Tave.+17.8)	28.2	28.2	27.9	25.7	30.7	29.7	28.6	28.8	29.4	26.7	27.1	30.0	26.4	29.4	26.3	27.8	29.9	31.0	28.1	25.3	28.0	31.2	30.5	27.7	25.3	29.0	31.2	28.4	32.5	31.5	31.5	32.4	29.6	32.1
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			2.74	2.10	2.54	2.06	2.66	2.53	2.43	2.42	2.53	2.29	2.37	2.58	2.29	2.44	2.04	2.28	2.52	2.40	2.27	2.11	2.44	2.24	2.68	2.33	2.00	2.52	3.01	2.60	2.93	2.70	2.70	2.92	2.44	2.96
Apr.	14.723	Tave.	14.7	14.1	18.4	14.5	15.8	15.8	17.2	16.0	15.0	17.2	15.9	16.5	17.1	17.7	15.8	16.5	20.8	17.0	16.2	15.5	15.5	17.0	15.4	16.6	15.2	17.9	18.2	18.4	17.8	14.9	17.0	16.2	18.9	29.2
		ΔT	10.1	9.4	11.2	8.8	9.8	11.3	9.9	10.4	10.4	10.2	10.5	10.4	10.2	10.1	11.3	10.1	12.1	7.7	7.8	7.9	9.6	13.0	10.9	13.8	10.3	11.4	11.5	10.7	11.2	8.4	9.5	9.8	10.3	18.7
		$\sqrt{\Delta T}$	3.2	3.1	3.3	3.0	3.1	3.4	3.1	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.4	3.2	3.5	2.8	2.8	2.8	3.1	3.6	3.3	3.7	3.2	3.4	3.4	3.3	3.3	2.9	3.1	3.1	3.2	4.3
		(Tave.+17.8)	32.5	31.9	36.2	32.3	33.6	33.6	35.0	33.8	32.8	35.0	33.7	34.3	34.9	35.5	33.6	34.3	38.6	34.8	34.0	33.3	33.3	34.8	33.2	34.4	33.0	35.7	36.0	36.2	35.6	32.7	34.8	34.0	36.7	47.0
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			3.49	3.31	4.10	3.24	3.56	3.82	3.72	3.69	3.58	3.79	3.69	3.75	3.77	3.82	3.82	3.69	4.54	3.27	3.22	3.16	3.49	4.25	3.71	4.33	3.58	4.08	4.13	4.00	4.03	3.21	3.63	3.60	3.98	6.88
May	16.423	Tave.	21.7	23.4	20.7	19.9	22.3	22.8	22.5	22.8	20.0	22.5	22.4	20.2	24.0	20.8	24.3	22.9	24.7	23.3	21.5	19.7	20.0	23.6	23.6	25.0	23.4	23.4	25.6	24.0	22.9	22.6	23.9	15.9	23.8	23.8
		ΔT	12.5	12.5	11.6	11.0	11.1	12.3	11.1	12.0	11.2	10.9	10.9	10.7	12.2	11.9	13.7	12.5	12.1	12.7	11.4	10.0	10.0	11.6	11.5	13.2	11.9	13.9	11.4	11.9	12.2	11.5	11.3	20.2	11.3	11.5
		$\sqrt{\Delta T}$	3.5	3.5	3.4	3.3	3.3	3.5	3.3	3.5	3.3	3.3	3.3	3.3	3.5	3.4	3.7	3.5	3.5	3.6	3.4	3.2	3.2	3.4	3.4	3.6	3.4	3.7	3.4	3.4	3.5	3.4	3.4	4.5	3.4	3.4
		(Tave.+17.8)	39.5	41.2	38.5	37.7	40.1	40.6	40.3	40.6	37.8	40.3	40.2	38.0	41.8	38.6	42.1	40.7	42.5	41.1	39.3	37.5	37.8	41.4	41.4	42.8	41.2	41.2	43.4	41.8	40.7	40.4	41.7	33.7	41.6	41.6
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			5.27	5.50	4.95	4.72	5.04	5.37	5.07	5.31	4.78	5.02	5.01	4.69	5.51	5.02	5.88	5.43	5.58	5.53	5.00	4.48	4.52	5.33	5.30	5.87	5.36	5.80	5.54	5.44	5.37	5.17	5.29	5.72	5.28	5.32
Jun.	17.178	Tave.	27.1	29.2	29.0	28.1	28.4	27.1	28.1	29.7	28.1	28.4	27.8	29.6	29.0	27.6	29.4	27.7	28.6	28.8	27.2	25.7	27.9	25.8	28.6	28.5	29.1	31.4	30.4	29.2	30.9	29.1	29.2	28.8	29.5	31.2
		ΔT	13.8	12.7	12.7	12.5	12.9	11.8	12.3	12.4	11.8	12.9	12.7	13.6	13.7	12.4	13.9	11.6	14.2	14.7	14.8	14.8	13.1	9.5	12.0	12.9	11.4	14.2	11.3	6.6	9.8	11.0	11.6	12.2	11.8	13.3
		$\sqrt{\Delta T}$	3.7	3.6	3.6	3.5	3.6	3.4	3.5	3.5	3.4	3.6	3.6	3.7	3.7	3.5	3.7	3.4	3.8	3.8	3.8	3.8	3.6	3.1	3.5	3.6	3.4	3.8	3.4	2.6	3.1	3.3	3.4	3.5	3.4	3.6
		(Tave.+17.8)	44.9	47.0	46.8	45.9	46.2	44.9	45.9	47.5	45.9	46.2	45.6	47.4	46.8	45.4	47.2	45.5	46.4	46.6	45.0	43.5	45.7	43.6	46.4	46.3	46.9	49.2	48.2	47.0	48.7	46.9	47.0	46.6	47.3	49.0
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			6.59	6.61	6.58	6.40	6.55	6.09	6.35	6.61	6.23	6.55	6.41	6.91	6.84	6.32	6.95	6.12	6.91	7.05	6.83	6.61	6.53	5.30	6.35	6.56	6.26	7.33	6.39	4.77	6.02	6.15	6.32	6.43	6.42	7.05
Jull.	16.723	Tave.	31.0	31.9	32.0	30.6	31.6	33.1	31.8	34.5	31.3	30.7	31.8	34.1	29.0	34.3	33.0	33.2	34.0	33.8	33.7	33.6	33.9	32.6	33.6	34.6	32.0	33.8	33.0	35.9	33.5	32.7	32.4	32.5	34.6	30.1
		ΔT	13.7	12.9	13.4	12.4	12.7	12.6	13.7	13.8	8.1	13.9	14.0	13.6	9.7	14.1	12.4	12.0	14.6	12.8	12.2	11.6	12.0	12.4	10.4	11.8	13.2	13.6	11.5	11.9	11.7	10.7	12.1	12.6	12.5	17.0
		$\sqrt{\Delta T}$	3.7	3.6	3.7	3.5	3.6	3.5	3.7	3.7	2.8	3.7	3.7	3.7	3.1	3.8	3.5	3.5	3.8	3.6	3.5	3.4	3.5	3.5	3.2	3.4	3.6	3.7	3.4	3.4	3.4	3.3	3.5	3.5	3.5	4.1
		(Tave.+17.8)	48.8	49.7	49.8	48.4	49.4	50.9	49.6	52.3	49.1	48.5	49.6	51.9	46.8	52.1	50.8	51.0	51.8	51.6	51.5	51.4	51.7	50.4	51.4	52.4	49.8	51.6	50.8	53.7	51.3	50.5	50.2	50.3	52.4	47.9
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			6.94	6.86	7.01	6.56	6.76	6.95	7.05	7.47	5.37	6.95	7.14	7.36	5.60	7.52	6.88	6.80	7.61	7.10	6.92	6.73	6.89	6.83	6.38	6.92	6.96	7.32	6.62	7.12	6.74	6.35	6.71	6.87	7.12	7.60
Aug.	15.423	Tave.	33.4	30.4	31.5	32.0	32.5	31.0	33.1	32.4	31.5	30.6	30.7	30.1	33.4	33.6	32.0	32.2	32.1	30.8	30.7	30.6	32.6	32.5	33.0	32.8	31.1	35.2	34.4	32.9	33.2	31.2	31.4	31.6	33.8	35.2
		ΔT	13.1	12.5	14.2	14.2	13.0	13.7	12.3	13.4	12.4	13.3	14.3	14.7	12.0	13.6	13.5	12.0	14.0	13.5	13.6	13.6	12.5	13.0	14.4	14.4	15.0	13.4	12.3	13.8	12.8	12.4	12.8	13.1	10.9	11.3
		$\sqrt{\Delta T}$	3.6	3.5	3.8	3.8	3.6	3.7	3.5	3.7	3.5	3.6	3.8	3.8	3.5	3.7	3.7	3.5	3.7	3.7	3.7	3.7	3.5	3.6	3.8	3.8	3.9	3.7	3.5	3.7	3.6	3.5	3.6	3.6	3.3	3.4
		(Tave.+17.8)	51.2	48.2	49.3	49.8	50.3	48.8	50.9	50.2	49.3	48.4	48.5	47.9	51.2	51.4	49.8	50.0	49.9	48.6	48.5	48.4	50.4	50.3	50.8	50.6	48.9	53.0	52.2	50.7	51.0	49.0	49.2	49.4	51.6	53.0
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			6.57	6.04	6.59	6.66	6.43	6.40	6.33	6.52	6.16	6.25	6.50	6.51	6.29	6.72	6.48	6.14	6.62	6.33	6.33	6.33	6.31	6.43	6.84	6.81	6.72	6.88	6.49	6.68	6.47	6.12	6.23	6.34	6.04	6.31
Sep.	13.168	Tave.	28.3	26.6	22.8	25.9	27.8	27.7	30.7	26.8	28.9	28.3	29.8	28.6	28.6	31.1	32.2	27.2	26.9	27.8	27.9	28.0	27.6	29.4	27.6	27.9	26.6	28.9	28.0	27.7	28.4	28.1	28.6	29.0	28.0	26.5
		ΔT	13.5	13.2	22.8	13.0	11.9	13.7	11.6	13.4	13.3	12.6	18.0	15.4	14.5	12.5	11.2	13.5	14.1	15.2	14.0	12.7	12.1	11.6	13.4	14.3	11.9	14.3	12.1	12.8	12.5	13.0	12.6	12.2	13.2	13.0
		$\sqrt{\Delta T}$	3.7	3.6	4.8	3.6	3.4	3.7	3.4	3.7	3.6	3.5	4.2	3.9	3.8	3.5	3.3	3.7	3.8	3.9	3.7	3.6	3.5	3.4	3.7	3.8	3.4	3.8	3.5	3.6	3.5	3.6	3.5	3.5	3.6	3.6
		(Tave.+17.8)	46.1	44.4	40.6	43.7	45.6	45.5	48.5	44.6	46.7	46.1	47.6	46.4	46.4	48.9	50.0	45.0	44.7	45.6	45.7	45.8	45.4	47.2	45.4	45.7	44.4	46.7	45.8	45.5	46.2	45.9	46.4	46.8	45.8	44.3
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			5.12	4.89	5.87	4.77	4.76	5.09	5.00	4.94	5.15	4.96	6.12	5.51	5.35	5.23	5.07	5.00	5.08	5.38	5.17	4.94	4.78	4.87	5.03	5.23	4.63	5.34	4.82	4.93	4.94	5.01	4.98	4.95	5.04	4.84
Oct.	10.645	Tave.	23.7	23.2	19.9	19.6	18.9	22.8	21.7	21.0	22.3	18.1	21.2	21.0	20.5	22.4	19.2	20.7	22.9	21.3	21.7	21.9	22.4	23.5	21.6	20.6	21.7	23.0	22.9	20.0	22.4	23.5	23.3	23.1	21.5	20.0
		ΔT	11.9	12.2	12.7	11.3	11.2	12.1	11.2	12.3	10.7	10.1	13.2	11.8	12.0	11.8	9.7	13.0	12.2	11.6	14.2	12.9	11.0	12.2	12.7	10.6	10.7	14.4	11.0	10.8	10.5	10.9	11.4	11.9	12.4	12.0
		$\sqrt{\Delta T}$	3.4	3.5	3.6	3.4	3.3	3.5	3.3	3.5	3.3	3.2	3.6	3.4	3.5	3.4	3.1	3.6	3.5	3.4	3.8	3.6	3.3	3.5	3.6	3.3	3.3	3.8	3.3	3.3	3.2	3.3	3.4	3.4	3.5	3.5
		(Tave.+17.8)	41.5	41.0	37.7	37.4	36.7	40.6	39.5	38.8	40.1	35.9	39.0	38.8	38.3	40.2	37.0	38.5	40.7	39.1	39.5	39.7	40.2	41.3	39.4	38.4	39.5	40.8	40.7	37.8	40.2	41.3	41.1	40.9	39.3	37.8
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			3.50	3.51	3.29	3.07	3.01	3.45	3.24	3.33	3.21	2.79	3.47	3.26	3.25	3.38	2.82	3.40	3.48	3.26	3.64	3.49	3.26	3.53	3.43	3.06	3.16	3.79	3.30	3.04	3.19	3.33	3.39	3.45	3.39	3.21
Nov.	8.113	Tave.	11.6	14.4	13.0	15.1	13.3	9.8	15.9	13.9	12.5	9.8	15.7	12.4	15.8	11.4	14.5	11.5	13.6	16.4	15.1	12.3	11.6	12.1	13.3	15.8	13.9	18.1	13.4	13.5	12.7	14.6	12.5	12.2	14.3	13.5
		ΔT	9.5	10.7	10.4	9.8	10.9	10.6	10.5	8.9	10.1	8.2	9.5	7.1	10.9	7.4	9.6	9.5	9.3	11.8	10.2	7.7	8.1	8.1	11.2	10.5	8.7	13.1	8.7	10.5	8.7	8.0	7.0	7.1	10.2	9.0
		$\sqrt{\Delta T}$	3.1	3.3	3.2	3.1	3.3	3.3	3.2	3.0	3.2	2.9	3.1	2.7	3.3	2.7	3.1	3.1	3.0	3.4	3.2	2.8	2.8	2.8	3.3	3.2	2.9	3.6	2.9	3.2	2.9	2.8	2.6	2.7	3.2	3.0
		(Tave.+17.8)	29.4	32.2	30.8	32.9	31.1	27.6	33.7	31.7	30.3	27.6	33.5	30.2	33.6	29.2	32.3	29.3	31.4	34.2	32.9	30.1	29.4	29.9	31.1	33.6	31.7	35.9	31.2	31.3	30.5	32.4	30.3	30.0	32.1	31.3
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			1.69	1.96	1.85	1.92	1.91	1.68	2.03	1.76	1.79	1.47	1.92	1.50	2.07	1.48	1.87	1.68	1.78	2.19	1.96	1.56	1.56	1.59	1.94	2.03	1.74	2.42	1.71	1.89	1.68	1.71	1.50	1.49	1.91	1.75
Des.	6.735	Tave.	7.3	6.5	5.5	9.7	7.6	8.5	7.0	9.0	9.9	5.2	8.4	5.8	7.4	6.8	7.7	7.8	8.4	7.9	6.3	5.6	9.5	4.5	7.4	11.2	8.2	13.4	10.2	8.5	8.7	6.5	6.1	6.9	11.6	11.1
		ΔT	9.0	8.6	7.3	8.0	7.5	7.9	7.3	8.9	9.0	8.5	8.2	7.6	8.1	8.6	6.2	7.9	8.8	8.2	7.3	6.2	8.0	7.5	9.5	8.1	7.3	11.3	8.4	7.3	7.1	5.7	5.8	8.0	10.5	9.9
		$\sqrt{\Delta T}$	3.0	2.9	2.7	2.8	2.7	2.8	2.7	3.0	3.0	2.9	2.9	2.8	2.8	2.9	2.5	2.8	3.0	2.9	2.7	2.5	2.8	2.7	3.1	2.8	2.7	3.4	2.9	2.7	2.7	2.4	2.4	2.8	3.2	3.1
		(Tave.+17.8)	25.1	24.3	23.3	27.5	25.4	26.3	24.8	26.8	27.7	23.0	26.2	23.6	25.2	24.6	25.5	25.6	26.2	25.7	24.1	23.4	27.3	22.3	25.2	29.0	26.0	31.2	28.0	26.3	26.5	24.3	23.9	24.7	29.4	28.9
ETo(mm/day) = 0.0023*Ra (Tave.+17.8)* $\sqrt{\Delta T}$			1.17	1.10	0.97	1.20	1.08	1.14	1.04	1.24	1.29	1.04	1.16	1.01	1.11	1.12	0.98	1.11	1.20	1.14	1.01	0.90	1.20	0.94	1.20	1.28	1.09	1.62	1.26	1.10	1.09	0.90	0.89	1.08	1.47	1.41

Table (3)

ETo calculation by Blaney Criddle method (mm/day)

Mon.	P	Blaney Criddle equation parameters	Years																																	
			1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Jan.	0.229	Tave.	1.7	2.7	5.3	5.4	1.9	6.5	5.7	3.7	6.8	4.6	1.6	7.6	8.2	7.0	8.0	6.2	2.2	4.6	3.0	1.5	5.0	8.8	8.8	6.6	7.1	4.2	9.1	5.2	7.1	5.3	7.3	7.4	6.3	5.4
		0.46Tave.+8	8.76	9.2	10.4	10.5	8.9	11.0	10.6	9.7	11.1	10.1	8.7	11.5	11.7	11.2	11.7	10.8	9.0	10.1	9.4	8.7	10.3	12.0	12.0	11.0	11.2	9.9	12.2	10.4	11.3	10.4	11.3	11.4	10.9	10.5
		ETo=C [P(0.46Tave+8)]	2.01	2.11	2.39	2.40	2.03	2.51	2.43	2.22	2.55	2.31	2.00	2.63	2.69	2.57	2.67	2.48	2.06	2.32	2.15	1.98	2.35	2.76	2.75	2.52	2.57	2.27	2.79	2.38	2.58	2.39	2.60	2.61	2.49	2.40
Feb.	0.249	Tave.	8.7	4.0	5.0	3.9	10.5	9.1	9.9	6.3	7.5	2.8	5.0	8.7	4.1	8.5	10.4	6.8	6.2	6.0	4.4	2.9	6.4	6.1	9.5	8.6	4.9	6.5	9.5	9.0	8.2	9.0	6.1	7.1	6.4	8.4
		0.46Tave.+8	11.98	9.8	10.3	9.8	12.8	12.2	12.6	10.9	11.4	9.3	10.3	12.0	9.9	11.9	12.8	11.1	10.8	10.7	10.0	9.3	10.9	10.8	12.3	12.0	10.3	11.0	12.4	12.1	11.7	12.1	10.8	11.2	10.9	11.8
		ETo=C [P(0.46Tave+8)]	2.98	2.44	2.56	2.44	3.19	3.03	3.13	2.71	2.85	2.31	2.56	2.99	2.46	2.96	3.18	2.77	2.70	2.67	2.50	2.32	2.73	2.68	3.07	2.98	2.55	2.74	3.08	3.02	2.93	3.02	2.68	2.80	2.73	2.95
March	0.27	Tave.	10.4	10.4	10.1	7.9	12.9	11.9	10.8	11.0	11.6	8.9	9.3	12.2	8.6	11.6	8.5	10.0	12.1	13.2	10.3	7.5	10.2	13.4	12.7	9.9	7.5	11.2	13.4	10.6	14.7	13.7	13.7	14.6	11.8	14.3
		0.46Tave.+8	12.76	12.8	12.6	11.6	13.9	13.5	13.0	13.1	13.3	12.1	12.3	13.6	12.0	13.3	11.9	12.6	13.5	14.0	12.7	11.4	12.7	14.2	13.8	12.5	11.5	13.1	14.1	12.9	14.8	14.3	14.3	14.7	13.4	14.6
		ETo=C [P(0.46Tave+8)]	3.45	3.45	3.41	3.14	3.76	3.63	3.50	3.53	3.59	3.27	3.32	3.67	3.23	3.60	3.21	3.40	3.66	3.79	3.44	3.09	3.42	3.82	3.73	3.38	3.09	3.54	3.82	3.47	3.99	3.86	3.86	3.97	3.62	3.93
April	0.291	Tave.	14.7	14.1	18.4	14.5	15.8	15.8	17.2	16.0	15.0	17.2	15.9	16.5	17.1	17.7	15.8	16.5	20.8	17.0	16.2	15.5	15.5	17.0	15.4	16.6	15.2	17.9	18.2	18.4	17.8	14.9	17.0	16.2	18.9	18.7
		0.46Tave.+8	14.74	14.5	16.5	14.7	15.3	15.2	15.9	15.4	14.9	15.9	15.3	15.6	15.9	16.1	15.2	15.6	17.5	15.8	15.5	15.1	15.1	15.8	15.1	15.6	15.0	16.2	16.3	16.4	16.2	14.9	15.8	15.5	16.7	16.6
		ETo=C [P(0.46Tave+8)]	4.29	4.22	4.79	4.27	4.44	4.44	4.62	4.47	4.34	4.63	4.45	4.54	4.62	4.69	4.44	4.53	5.11	4.60	4.50	4.40	4.40	4.60	4.38	4.55	4.36	4.72	4.76	4.78	4.71	4.32	4.60	4.50	4.85	4.82
May	0.311	Tave.	21.7	23.4	20.7	19.9	22.3	22.8	22.5	22.8	20.0	22.5	22.4	20.2	24.0	20.8	24.3	22.9	24.7	23.3	21.5	19.7	20.0	23.6	23.6	25.0	23.4	23.4	25.6	24.0	22.9	22.6	23.9	15.9	23.8	23.8
		0.46Tave.+8	17.96	18.7	17.5	17.2	18.2	18.5	18.3	18.5	17.2	18.3	18.3	17.3	19.0	17.5	19.2	18.5	19.3	18.7	17.9	17.1	17.2	18.9	18.8	19.5	18.7	18.7	19.8	19.0	18.5	18.4	19.0	15.3	18.9	18.9
		ETo=C [P(0.46Tave+8)]	5.59	5.83	5.45	5.33	5.67	5.74	5.70	5.75	5.35	5.70	5.69	5.37	5.92	5.46	5.96	5.76	6.01	5.81	5.56	5.31	5.35	5.86	5.86	6.06	5.83	5.83	6.15	5.91	5.76	5.71	5.90	4.76	5.89	5.89
June	0.322	Tave.	27.1	29.2	29.0	28.1	28.4	27.1	28.1	29.7	28.1	28.4	27.8	29.6	29.0	27.6	29.4	27.7	28.6	28.8	27.2	25.7	27.9	25.8	28.6	28.5	29.1	31.4	30.4	29.2	30.9	29.1	29.2	28.8	29.5	31.2
		0.46Tave.+8	20.47	21.4	21.3	20.9	21.0	20.5	20.9	21.7	20.9	21.0	20.8	21.6	21.3	20.7	21.5	20.7	21.2	21.2	20.5	19.8	20.8	19.8	21.2	21.1	21.4	22.4	22.0	21.4	22.2	21.4	21.4	21.2	21.6	22.3
		P = 0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322
		ETo=C [P(0.46Tave+8)]	6.59	6.89	6.86	6.73	6.78	6.59	6.73	6.98	6.74	6.78	6.69	6.96	6.86	6.66	6.92	6.68	6.81	6.83	6.61	6.38	6.70	6.39	6.81	6.79	6.89	7.23	7.07	6.90	7.15	6.89	6.90	6.84	6.95	7.19
July	0.321	Tave.	31.0	31.9	32.0	30.6	31.6	33.1	31.8	34.5	31.3	30.7	31.8	34.1	29.0	34.3	33.0	33.2	34.0	33.8	33.7	33.6	33.9	32.6	33.6	34.6	32.0	33.8	33.0	35.9	33.5	32.7	32.4	32.5	34.6	30.1
		0.46Tave.+8	22.24	22.7	22.7	22.1	22.5	23.2	22.6	23.9	22.4	22.1	22.6	23.7	21.3	23.8	23.2	23.3	23.6	23.5	23.5	23.5	23.6	23.0	23.5	23.9	22.7	23.5	23.2	24.5	23.4	23.0	22.9	23.0	23.9	21.8
		ETo=C [P(0.46Tave+8)]	7.14	7.27	7.29	7.09	7.23	7.46	7.26	7.66	7.18	7.09	7.26	7.60	6.84	7.63	7.44	7.47	7.59	7.56	7.54	7.53	7.57	7.38	7.53	7.68	7.29	7.56	7.43	7.86	7.51	7.39	7.34	7.37	7.67	7.01
Aug.	0.301	Tave.	33.4	30.4	31.5	32.0	32.5	31.0	33.1	32.4	31.5	30.6	30.7	30.1	33.4	33.6	32.0	32.2	32.1	30.8	30.7	30.6	32.6	32.5	33.0	32.8	31.1	35.2	34.4	32.9	33.2	31.2	31.4	31.6	33.8	35.2
		0.46Tave.+8	23.34	22.0	22.5	22.7	23.0	22.2	23.2	22.9	22.5	22.1	22.1	21.8	23.4	23.5	22.7	22.8	22.8	22.1	22.1	22.1	23.0	23.0	23.2	23.1	22.3	24.2	23.8	23.1	23.3	22.4	22.4	22.5	23.5	24.2
		ETo=C [P(0.46Tave+8)]	7.03	6.61	6.77	6.84	6.91	6.69	6.98	6.89	6.77	6.64	6.65	6.57	7.03	7.06	6.83	6.87	6.85	6.67	6.66	6.64	6.91	6.91	6.98	6.95	6.71	7.28	7.16	6.96	7.00	6.73	6.75	6.78	7.08	7.27
Sep.	0.28	Tave.	28.3	26.6	22.8	25.9	27.8	27.7	30.7	26.8	28.9	28.3	29.8	28.6	28.6	31.1	32.2	27.2	26.9	27.8	27.9	28.0	27.6	29.4	27.6	27.9	26.6	28.9	28.0	27.7	28.4	28.1	28.6	29.0	28.0	26.5
		0.46Tave.+8	21.00	20.2	18.5	19.9	20.8	20.7	22.1	20.3	21.3	21.0	21.7	21.2	21.1	22.3	22.8	20.5	20.4	20.8	20.8	20.9	20.7	21.5	20.7	20.8	20.2	21.3	20.9	20.7	21.0	20.9	21.1	21.3	20.9	20.2
		ETo=C [P(0.46Tave+8)]	5.88	5.67	5.18	5.58	5.81	5.80	6.19	5.69	5.96	5.89	6.08	5.92	5.92	6.24	6.39	5.74	5.70	5.82	5.83	5.84	5.79	6.03	5.79	5.83	5.66	5.96	5.84	5.81	5.89	5.86	5.92	5.98	5.85	5.65
Oct.	0.25	Tave.	23.7	23.2	19.9	19.6	18.9	22.8	21.7	21.0	22.3	18.1	21.2	21.0	20.5	22.4	19.2	20.7	22.9	21.3	21.7	21.9	22.4	23.5	21.6	20.6	21.7	23.0	22.9	20.0	22.4	23.5	23.3	23.1	21.5	20.0
		0.46Tave.+8	18.88	18.7	17.1	17.0	16.7	18.5	18.0	17.6	18.2	16.3	17.8	17.7	17.4	18.3	16.8	17.5	18.5	17.8	18.0	18.1	18.3	18.8	17.9	17.5	18.0	18.6	18.5	17.2	18.3	18.8	18.7	18.6	17.9	17.2
		P = 0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
		ETo=C [P(0.46Tave+8)]	4.72	4.67	4.28	4.25	4.17	4.62	4.50	4.41	4.56	4.08	4.44	4.42	4.36	4.58	4.20	4.38	4.63	4.45	4.50	4.51	4.58	4.70	4.48	4.37	4.49	4.65	4.63	4.30	4.57	4.70	4.67	4.65	4.47	4.30
Nov.	0.229	Tave.	11.6	14.4	13.0	15.1	13.3	9.8	15.9	13.9	12.5	9.8	15.7	12.4	15.8	11.4	14.5	11.5	13.6	16.4	15.1	12.3	11.6	12.1	13.3	15.8	13.9	18.1	13.4	13.5	12.7	14.6	12.5	12.2	14.3	13.5
		0.46Tave.+8	13.31	14.6	14.0	14.9	14.1	12.5	15.3	14.4	13.7	12.5	15.2	13.7	15.2	13.2	14.7	13.3	14.2	15.5	14.9	13.6	13.3	13.5	14.1	15.2	14.4	16.3	14.1	14.2	13.8	14.7	13.8	13.6	14.6	14.2
		ETo=C [P(0.46Tave+8)]	3.05	3.34	3.20	3.42	3.23	2.86	3.50	3.29	3.14	2.86	3.48	3.13	3.49	3.03	3.36	3.04	3.26	3.56	3.42	3.12	3.05	3.10	3.23	3.49	3.29	3.73	3.24	3.25	3.16	3.37	3.15	3.11	3.34	3.25
Des.	0.219	Tave.	7.3	6.5	5.5	9.7	7.6	8.5	7.0	9.0	9.9	5.2	8.4	5.8	7.4	6.8	7.7	7.8	8.4	7.9	6.3	5.6	9.5	4.5	7.4	11.2	8.2	13.4	10.2	8.5	8.7	6.5	6.1	6.9	11.6	11.1
		0.46Tave.+8	11.36	11.0	10.5	12.5	11.5	11.9	11.2	12.1	12.6	10.4	11.9	10.7	11.4	11.1	11.5	11.6	11.9	11.6	10.9	10.6	12.4	10.0	11.4	13.1	11.7	14.1	12.7	11.9	12.0	11.0	10.8	11.2	13.3	13.1
		ETo=C [P(0.46Tave+8)]	2.49	2.41	2.30	2.73	2.51	2.60	2.45	2.65	2.75	2.27	2.60	2.34	2.49	2.44	2.53	2.53	2.60	2.55	2.38	2.32	2.71	2.20	2.49	2.88	2.57	3.10	2.78	2.60	2.62	2.40	2.37	2.45	2.92	2.87

Table (4)

Summary of ETo values (mm/day) by Blaney Criddle & Hargreaves method with their average values

Months	Equations	Years																																		ETo values for current time
		1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
Jan.	Blaney Criddle	2.01	2.11	2.39	2.40	2.03	2.51	2.43	2.22	2.55	2.31	2.00	2.63	2.69	2.57	2.67	2.48	2.06	2.32	2.15	1.98	2.35	2.76	2.75	2.52	2.57	2.27	2.79	2.38	2.58	2.39	2.60	2.61	2.49	2.40	1.36
	Hargreaves	1.01	0.87	0.26	0.27	0.09	0.32	0.25	0.16	0.33	0.23	0.07	0.39	0.42	0.35	0.45	0.24	0.11	0.21	0.13	0.06	0.24	0.41	0.44	0.30	0.35	0.19	0.45	0.26	0.36	0.24	0.35	0.33	0.30	0.25	
	Ave.	1.51	1.49	1.32	1.33	1.06	1.41	1.34	1.19	1.44	1.27	1.04	1.51	1.56	1.46	1.56	1.36	1.08	1.26	1.14	1.02	1.30	1.59	1.59	1.41	1.46	1.23	1.62	1.32	1.47	1.31	1.47	1.47	1.39	1.32	
Feb..	Blaney Criddle	2.98	2.44	2.56	2.44	3.19	3.03	3.13	2.71	2.85	2.31	2.56	2.99	2.46	2.96	3.18	2.77	2.70	2.67	2.50	2.32	2.73	2.68	3.07	2.98	2.55	2.74	3.08	3.02	2.93	3.02	2.68	2.80	2.73	2.95	2.18
	Hargreaves	1.78	1.32	1.35	1.34	2.04	1.80	1.79	1.45	1.51	1.30	1.44	1.75	1.35	1.59	1.95	1.54	1.52	1.34	1.23	1.11	1.49	1.43	1.69	1.89	1.55	1.52	1.94	2.06	1.67	1.74	1.44	1.56	1.46	1.62	
	Ave.	2.38	1.88	1.96	1.89	2.61	2.42	2.46	2.08	2.18	1.81	2.00	2.37	1.91	2.27	2.56	2.15	2.11	2.01	1.86	1.72	2.11	2.06	2.38	2.44	2.05	2.13	2.51	2.54	2.30	2.38	2.06	2.18	2.09	2.29	
Mar.	Blaney Criddle	3.45	3.45	3.41	3.14	3.76	3.63	3.50	3.53	3.59	3.27	3.32	3.67	3.23	3.60	3.21	3.40	3.66	3.79	3.44	3.09	3.42	3.82	3.73	3.38	3.09	3.54	3.82	3.47	3.99	3.86	3.86	3.97	3.62	3.93	3.01
	Hargreaves	2.74	2.10	2.54	2.06	2.66	2.53	2.43	2.42	2.53	2.29	2.37	2.58	2.29	2.44	2.04	2.28	2.52	2.40	2.27	2.11	2.44	2.24	2.68	2.33	2.00	2.52	3.01	2.60	2.93	2.70	2.70	2.92	2.44	2.96	
	Ave.	3.09	2.77	2.98	2.60	3.21	3.08	2.96	2.97	3.06	2.78	2.84	3.13	2.76	3.02	2.62	2.84	3.09	3.10	2.85	2.60	2.93	3.03	3.21	2.86	2.55	3.03	3.41	3.03	3.46	3.28	3.28	3.45	3.03	3.45	
Apr.	Blaney Criddle	4.29	4.22	4.79	4.27	4.44	4.44	4.62	4.47	4.34	4.63	4.45	4.54	4.62	4.69	4.44	4.53	5.11	4.60	4.50	4.40	4.40	4.60	4.38	4.55	4.36	4.72	4.76	4.78	4.71	4.32	4.60	4.50	4.85	4.82	4.19
	Hargreaves	3.49	3.31	4.10	3.24	3.56	3.82	3.72	3.69	3.58	3.78	3.69	3.74	3.77	3.81	3.82	3.69	4.54	3.26	3.21	3.16	3.49	4.25	3.71	4.33	3.58	4.08	4.13	4.00	4.03	3.21	3.63	3.60	3.98	6.88	
	Ave.	3.89	3.76	4.45	3.76	4.00	4.13	4.17	4.08	3.96	4.21	4.07	4.14	4.20	4.25	4.13	4.11	4.82	3.93	3.86	3.78	3.95	4.43	4.04	4.44	3.97	4.40	4.44	4.39	4.37	3.77	4.11	4.05	4.42	5.85	
May	Blaney Criddle	5.59	5.83	5.45	5.33	5.67	5.74	5.70	5.75	5.35	5.70	5.69	5.37	5.92	5.46	5.96	5.76	6.01	5.81	5.56	5.31	5.35	5.86	5.86	6.06	5.83	5.83	6.15	5.91	5.76	5.71	5.90	4.76	5.89	5.89	5.47
	Hargreaves	5.27	5.49	4.95	4.72	5.04	5.37	5.06	5.31	4.78	5.02	5.01	4.69	5.51	5.02	5.88	5.43	5.58	5.52	5.00	4.48	4.51	5.33	5.30	5.87	5.36	5.79	5.53	5.44	5.37	5.17	5.29	5.72	5.27	5.32	
	Ave.	5.43	5.66	5.20	5.03	5.36	5.56	5.38	5.53	5.06	5.36	5.35	5.03	5.72	5.24	5.92	5.59	5.80	5.67	5.28	4.89	4.93	5.59	5.58	5.97	5.59	5.81	5.84	5.68	5.57	5.44	5.59	5.24	5.58	5.60	
Jun	Blaney Criddle	6.59	6.89	6.86	6.73	6.78	6.59	6.73	6.98	6.74	6.78	6.69	6.96	6.86	6.66	6.92	6.68	6.81	6.83	6.61	6.38	6.70	6.39	6.81	6.79	6.89	7.23	7.07	6.90	7.15	6.89	6.90	6.84	6.95	7.19	6.63
	Hargreaves	6.59	6.61	6.58	6.40	6.55	6.09	6.35	6.61	6.23	6.55	6.41	6.90	6.83	6.31	6.94	6.12	6.90	7.05	6.83	6.61	6.52	5.30	6.35	6.56	6.25	7.32	6.39	4.77	6.02	6.14	6.32	6.43	6.42	7.05	
	Ave.	6.59	6.75	6.72	6.57	6.66	6.34	6.54	6.79	6.48	6.66	6.55	6.93	6.85	6.49	6.93	6.40	6.86	6.94	6.72	6.50	6.61	5.85	6.58	6.68	6.57	7.27	6.73	5.83	6.59	6.51	6.61	6.63	6.68	7.12	
July	Blaney Criddle	7.14	7.27	7.29	7.09	7.23	7.46	7.26	7.66	7.18	7.09	7.26	7.60	6.84	7.63	7.44	7.47	7.59	7.56	7.54	7.53	7.57	7.38	7.53	7.68	7.29	7.56	7.43	7.86	7.51	7.39	7.34	7.37	7.67	7.01	7.14
	Hargreaves	6.94	6.86	7.01	6.55	6.76	6.95	7.05	7.47	5.37	6.95	7.14	7.36	5.60	7.52	6.88	6.79	7.61	7.10	6.92	6.73	6.89	6.83	6.37	6.92	6.96	7.32	6.62	7.12	6.74	6.35	6.71	6.87	7.12	7.59	
	Ave.	7.04	7.06	7.15	6.82	6.99	7.20	7.15	7.57	6.28	7.02	7.20	7.48	6.22	7.57	7.16	7.13	7.60	7.33	7.23	7.13	7.23	7.10	6.95	7.30	7.13	7.44	7.03	7.49	7.12	6.87	7.03	7.12	7.39	7.30	
Aug.	Blaney Criddle	7.03	6.61	6.77	6.84	6.91	6.69	6.98	6.89	6.77	6.64	6.65	6.57	7.03	7.06	6.83	6.87	6.85	6.67	6.66	6.64	6.91	6.91	6.98	6.95	6.71	7.28	7.16	6.96	7.00	6.73	6.75	6.78	7.08	7.27	6.65
	Hargreaves	6.57	6.04	6.59	6.66	6.43	6.40	6.32	6.52	6.16	6.25	6.50	6.51	6.29	6.72	6.48	6.14	6.62	6.33	6.33	6.33	6.31	6.43	6.84	6.81	6.72	6.88	6.49	6.68	6.47	6.12	6.23	6.33	6.04	6.31	
	Ave.	6.80	6.32	6.68	6.75	6.67	6.55	6.65	6.71	6.46	6.45	6.57	6.54	6.66	6.89	6.66	6.50	6.74	6.50	6.49	6.49	6.61	6.67	6.91	6.88	6.72	7.08	6.83	6.82	6.74	6.42	6.49	6.56	6.56	6.79	
Sep.	Blaney Criddle	5.88	5.67	5.18	5.58	5.81	5.80	6.19	5.69	5.96	5.89	6.08	5.92	5.92	6.24	6.39	5.74	5.70	5.82	5.83	5.84	5.02	6.03	5.79	5.83	5.66	5.96	5.84	5.81	5.89	5.86	5.92	5.98	5.85	5.65	5.46
	Hargreaves	5.13	4.89	5.87	4.77	4.76	5.10	5.00	4.95	5.15	4.96	6.12	5.52	5.35	5.23	5.07	5.00	5.08	5.39	5.17	4.94	4.78	4.87	5.03	5.23	4.63	5.34	4.82	4.93	4.94	5.01	4.98	4.95	5.04	4.84	
	Ave.	5.50	5.28	5.52	5.17	5.29	5.45	5.60	5.32	5.55	5.42	6.10	5.72	5.63	5.74	5.73	5.37	5.39	5.60	5.50	5.39	4.90	5.45	5.41	5.53	5.15	5.65	5.33	5.37	5.42	5.44	5.45	5.46	5.44	5.25	
Oct.	Blaney Criddle	4.72	4.67	4.28	4.25	4.17	4.62	4.50	4.41	4.56	4.08	4.44	4.42	4.36	4.58	4.20	4.38	4.63	4.45	4.50	4.51	4.58	4.70	4.48	4.37	4.49	4.65	4.63	4.30	4.57	4.70	4.67	4.65	4.47	4.30	3.89
	Hargreaves	3.50	3.50	3.28	3.07	3.01	3.45	3.24	3.33	3.21	2.79	3.47	3.26	3.25	3.38	2.82	3.40	3.48	3.26	3.64	3.49	3.26	3.53	3.43	3.06	3.16	3.79	3.30	3.04	3.18	3.33	3.39	3.45	3.39	3.20	
	Ave.	4.11	4.09	3.78	3.66	3.59	4.03	3.87	3.87	3.88	3.43	3.95	3.84	3.80	3.98	3.51	3.89	4.06	3.85	4.07	4.00	3.92	4.12	3.96	3.71	3.82	4.22	3.97	3.67	3.88	4.01	4.03	4.05	3.93	3.75	
Nov.	Blaney Criddle	3.05	3.34	3.20	3.42	3.23	2.86	3.50	3.29	3.14	2.86	3.48	3.13	3.49	3.03	3.36	3.04	3.26	3.56	3.42	3.12	3.05	3.10	3.23	3.49	3.29	3.73	3.24	3.25	3.16	3.37	3.15	3.11	3.34	3.25	2.52
	Hargreaves	1.69	1.96	1.86	1.92	1.91	1.68	2.04	1.76	1.80	1.48	1.93	1.50	2.07	1.48	1.87	1.68	1.79	2.19	1.96	1.56	1.56	1.59	1.94	2.03	1.74	2.42	1.72	1.89	1.68	1.71	1.50	1.49	1.91	1.75	
	Ave.	2.37	2.65	2.53	2.67	2.57	2.27	2.77	2.53	2.47	2.17	2.70	2.32	2.78	2.26	2.61	2.36	2.52	2.88	2.69	2.34	2.30	2.34	2.59	2.76	2.52	3.08	2.48	2.57	2.42	2.54	2.32	2.30	2.63	2.50	
Des.	Blaney Criddle	2.49	2.41	2.30	2.73	2.51	2.60	2.45	2.65	2.75	2.27	2.60	2.34	2.49	2.44	2.53	2.53	2.60	2.55	2.38	2.32	2.71	2.20	2.49	2.88	2.57	3.10	2.78	2.60	2.62	2.40	2.37	2.45	2.92	2.87	1.84
	Hargreaves	1.17	1.10	0.97	1.21	1.08	1.14	1.04	1.24	1.29	1.04	1.16	1.01	1.11	1.12	0.98	1.11	1.20	1.14	1.01	0.90	1.20	0.94	1.20	1.28	1.09	1.62	1.26	1.10	1.09	0.90	0.89	1.08	1.47	1.41	
	Ave.	1.83	1.76	1.64	1.97	1.79	1.87	1.74	1.95	2.02	1.65	1.88	1.67	1.80	1.78	1.76	1.82	1.90	1.84	1.69	1.61	1.95	1.57	1.85	2.08	1.83	2.36	2.02	1.85	1.86	1.65	1.63	1.77	2.19	2.14	

Table no. (5)

Full metrological data for Sulaimnyia center (2004)						ETo calculations with modified PENMAN equations: ET0 = C { W.Rn + (1-W).f(u).(ea - ed)}																					
Date	Air temp. ^{c}o	Humidity %	Vap. Pressure	Sunshine dura. hours	Wind vlocity (m/sec.)	Month	Saturation Vapor pressure (mbar)	Relative Humidity	Actual Vapor pressure (mbar)	ea-ed	Wind velocity (Km/day)	Wind Function f(u)	Weighting factor	1- weighting factor	Actual sun shine duration(hr)	Max. Sun shine duration (hr)	Ratio of (n/N)	Extra terrestrial radiation (mm/day)	f(t)	F(ed) = 0.34-0.044√ed	f(n/N) = 0.1+0.9*(n/N)	Rn1 =f(t). f(ed). F(n/N)	Rns = 0.75*(0.25+0.5*n/N)*Ra	Rn = Rns - Rn1	C	Eto
	Avg.	Avg.	Avg. mbar				e_a	RH%	$e_d = e_a*(RH/100)$		U	f(u) = o.27 (1+U/100)	W	1-W	n	N	n/N	Ra								
Jan	7.4	74.6	7.9	3.3	0.9	Jan	7.9	74.6	5.89	2.01	77.76	0.48	0.539	0.461	3.3	10.045	0.33	7.513	12.280	0.233	0.396	1.13	2.33	1.20	0.93	1.02
Feb	7.1	68.8	7.5	5.0	3.4	Feb	7.5	68.8	5.16	2.34	293.76	1.06	0.533	0.467	5.0	10.967	0.46	9.490	12.200	0.240	0.510	1.49	3.40	1.91	0.96	2.09
Mar	14.6	44.9	8.2	6.8	1.4	Mar	8.2	44.9	3.68	4.52	120.96	0.60	0.642	0.358	6.8	11.9	0.57	12.168	13.590	0.256	0.614	2.13	4.89	2.76	1.14	3.12
April	16.2	51.3	10.4	7.1	1.0	April	10.4	51.3	5.34	5.06	86.40	0.50	0.66	0.34	7.1	13.122	0.54	14.732	13.840	0.238	0.587	1.94	5.75	3.82	1.17	3.95
May	15.9	51.1	12.8	0.0	0.9	May	12.8	51.1	6.54	6.26	77.76	0.48	0.69	0.31	0.0	14.011	0.00	16.432	14.000	0.227	0.100	0.32	3.08	2.76	1.47	5.17
Jun	28.8	27.4	11.3	11.7	1.7	Jun	11.3	27.4	3.10	8.20	146.88	0.67	0.792	0.208	11.7	14.555	0.80	17.178	16.460	0.263	0.823	3.56	8.40	4.84	1.27	6.31
July	32.5	27.2	13.0	11.2	1.7	July	13.0	27.2	3.54	9.46	146.88	0.67	0.816	0.184	11.2	13.800	0.81	16.943	16.910	0.257	0.830	3.61	8.33	4.72	1.32	6.62
Aug	31.6	25.9	12.2	11.5	2.4	Aug	12.2	25.9	3.16	9.04	207.36	0.83	0.814	0.186	11.5	12.6	0.91	15.900	17.100	0.262	0.921	4.12	8.42	4.30	1.30	6.36
Sep	29.0	22.7	8.6	10.5	2.7	Sep	8.6	22.7	1.95	6.65	233.28	0.90	0.793	0.207	10.5	11.5	0.91	13.967	15.800	0.279	0.922	4.06	7.40	3.34	1.31	5.10
Oct	23.1	30.7	8.9	8.2	1.3	Oct	8.9	30.7	2.73	6.17	112.32	0.57	0.600	0.4	8.2	11.000	0.75	10.210	12.920	0.267	0.771	2.66	4.77	2.11	1.29	3.45
Nov	12.2	74.6	10.4	4.6	1.6	Nov	10.4	74.6	7.76	2.64	138.24	0.64	0.609	0.391	4.6	10.267	0.45	8.113	13.120	0.217	0.503	1.44	2.88	1.45	1.26	1.95
Dec	11.6	65.5	5.9	5.4	2.1	Dec	5.9	65.5	3.86	2.04	181.44	0.76	0.531	0.469	5.4	9.745	0.55	6.735	12.180	0.254	0.599	1.85	2.66	0.81	1.20	1.39

Table no. (6)

Comparison of ETo values (mm/day) by Blaney Criddle and Hargreaves with Modified Penman method for years 2001 to 2005

Months	*Methods*	*Years*				
		2001	*2002*	*2003*	*2004*	*2005*
Jan.	*Blaney Criddle*	2.58	2.39	2.60	2.61	2.49
	Hargreaves	0.36	0.24	0.35	0.33	0.30
	Ave.	1.47	1.31	1.47	1.47	1.39
	PENMAN Method	**1.34**	**1.09**	**1.29**	**1.02**	**1.28**
Feb..	*Blaney Criddle*	2.93	3.02	2.68	2.80	2.73
	Hargreaves	1.67	1.74	1.44	1.56	1.46
	Ave.	2.30	2.38	2.06	2.18	2.09
	PENMAN Method	**2.09**	**1.99**	**1.76**	**2.09**	**1.76**
Mar.	*Blaney Criddle*	3.99	3.86	3.86	3.97	3.62
	Hargreaves	2.93	2.70	2.70	2.92	2.44
	Ave.	3.46	3.28	3.28	3.45	3.03
	PENMAN Method	**3.13**	**3.13**	**3.00**	**3.12**	**3.10**
Apr.	*Blaney Criddle*	4.71	4.32	4.60	4.50	4.85
	Hargreaves	4.03	3.21	3.63	3.60	3.98
	Ave.	4.37	3.77	4.11	4.05	4.42
	PENMAN Method	**4.21**	**3.32**	**3.87**	**3.95**	**4.05**
May	*Blaney Criddle*	5.76	5.71	5.90	4.76	5.89
	Hargreaves	5.37	5.17	5.29	5.72	5.27
	Ave.	5.57	5.44	5.59	5.24	5.58
	PENMAN Method	**5.49**	**5.31**	**5.56**	**5.17**	**5.38**
Jun	*Blaney Criddle*	7.15	6.89	6.90	6.84	6.95
	Hargreaves	6.02	6.14	6.32	6.43	6.42
	Ave.	6.59	6.51	6.61	6.63	6.68
	PENMAN Method	**6.46**	**6.27**	**6.48**	**6.31**	**6.23**
July	*Blaney Criddle*	7.51	7.39	7.34	7.37	7.67
	Hargreaves	6.74	6.35	6.71	6.87	7.12
	Ave.	7.12	6.87	7.03	7.12	7.39
	PENMAN Method	**6.94**	**6.58**	**0.00**	**6.62**	**6.46**
Aug.	*Blaney Criddle*	7.00	6.73	6.75	6.78	7.08
	Hargreaves	6.47	6.12	6.23	6.33	6.04
	Ave.	6.74	6.42	6.49	6.56	6.56
	PENMAN Method	**6.11**	**6.22**	**0.00**	**6.36**	**6.14**
Sep.	*Blaney Criddle*	5.89	5.86	5.92	5.98	5.85
	Hargreaves	4.94	5.01	4.98	4.95	5.04
	Ave.	5.42	5.44	5.45	5.46	5.44
	PENMAN Method	**5.09**	**5.06**	**0.00**	**5.10**	**5.02**
Oct.	*Blaney Criddle*	4.57	4.70	4.67	4.65	4.47
	Hargreaves	3.18	3.33	3.39	3.45	3.39
	Ave.	3.88	4.01	4.03	4.05	3.93
	PENMAN Method	**3.48**	**3.15**	**0.00**	**3.45**	**3.73**
Nov.	*Blaney Criddle*	3.16	3.37	3.15	3.11	3.34
	Hargreaves	1.68	1.71	1.50	1.49	1.91
	Ave.	2.42	2.54	2.32	2.30	2.63
	PENMAN Method	**2.00**	**1.95**	**0.00**	**1.95**	**2.24**
Des.	*Blaney Criddle*	2.62	2.40	2.37	2.45	2.92
	Hargreaves	1.09	0.90	0.89	1.08	1.47
	Ave.	1.86	1.65	1.63	1.77	2.19
	PENMAN Method	**1.18**	**1.08**	**0.00**	**1.39**	**1.98**

Table no. (7)

Frequency distribution analysis for ETo using Gumbel Method

Average ETo for Sulaimnyia center / January

S.N	Year	Ave. ETo(mm/day)	ETo in descending order	ETo descending - ETo mean	$(\text{ETo descending - ETo mean})^2$	Assume (T)	$Yt = - \ln(-\ln(1-1/T))$						K = (Yt - Yn) / Ysn	$\sigma = \sqrt{\sum (ETO - ETO_{mean})^2 / N-1}$			σ * K	ETO = ETO mean + σk
							1/T	1-1/T	ln(1-1/T))	-ln(1-1/T))	$Y_t = \ln(-\ln(1-1/T))$	$Y_t = -\ln(-\ln(1-1/T))$		∑ (ETo - ETO mean)2	∑ (ETo - ETO mean)2 /N-1	$\sigma = \sqrt{\sum (ETO - Eto\ l_{mean})^2 / N-1}$		
1	1973	1.51	1.62	0.26	0.066	5	0.20	0.80	-0.22	0.22	-1.50	1.50	0.86	0.90	0.03	0.16	0.14	1.50
2	1974	1.49	1.59	0.23	0.054	10	0.10	0.90	-0.11	0.11	-2.25	2.25	1.53	0.90	0.03	0.16	0.25	1.61
3	1975	1.32	1.59	0.22	0.050	15	0.07	0.93	-0.07	0.07	-2.67	2.67	1.91	0.90	0.03	0.16	0.31	1.68
4	1976	1.33	1.56	0.20	0.039	20	0.05	0.95	-0.05	0.05	-2.97	2.97	2.17	0.90	0.03	0.16	0.36	1.72
5	1977	1.06	1.56	0.19	0.037	25	0.04	0.96	-0.04	0.04	-3.20	3.20	2.37	0.90	0.03	0.16	0.39	1.75
6	1978	1.41	1.51	0.15	0.023	30	0.03	0.97	-0.03	0.03	-3.38	3.38	2.54	0.90	0.03	0.16	0.42	1.78
7	1979	1.34	1.51	0.15	0.022	35	0.03	0.97	-0.03	0.03	-3.54	3.54	2.68	0.90	0.03	0.16	0.44	1.80
8	1980	1.19	1.49	0.13	0.017	40	0.03	0.98	-0.03	0.03	-3.68	3.68	2.80	0.90	0.03	0.16	0.46	1.82
9	1981	1.44	1.47	0.11	0.012	45	0.02	0.98	-0.02	0.02	-3.80	3.80	2.91	0.90	0.03	0.16	0.48	1.84
10	1982	1.27	1.47	0.11	0.012	50	0.02	0.98	-0.02	0.02	-3.90	3.90	3.00	0.90	0.03	0.16	0.49	1.86
11	1983	1.04	1.47	0.11	0.011	55	0.02	0.98	-0.02	0.02	-4.00	4.00	3.09	0.90	0.03	0.16	0.51	1.87
12	1984	1.51	1.46	0.10	0.010	60	0.02	0.98	-0.02	0.02	-4.09	4.09	3.17	0.90	0.03	0.16	0.52	1.88
13	1985	1.56	1.46	0.10	0.009	65	0.02	0.98	-0.02	0.02	-4.17	4.17	3.24	0.90	0.03	0.16	0.53	1.90
14	1986	1.46	1.44	0.08	0.006	70	0.01	0.99	-0.01	0.01	-4.24	4.24	3.30	0.90	0.03	0.16	0.54	1.91
15	1987	1.56	1.41	0.05	0.003	75	0.01	0.99	-0.01	0.01	-4.31	4.31	3.37	0.90	0.03	0.16	0.55	1.91
16	1988	1.36	1.41	0.05	0.002	80	0.01	0.99	-0.01	0.01	-4.38	4.38	3.42	0.90	0.03	0.16	0.56	1.93
17	1989	1.08	1.39	0.03	0.001	85	0.01	0.99	-0.01	0.01	-4.44	4.44	3.48	0.90	0.03	0.16	0.57	1.94
18	1990	1.26	1.36	0.00	0.000	90	0.01	0.99	-0.01	0.01	-4.49	4.49	3.53	0.90	0.03	0.16	0.58	1.94
19	1991	1.14	1.34	-0.02	0.001	95	0.01	0.99	-0.01	0.01	-4.55	4.55	3.58	0.90	0.03	0.16	0.59	1.95
20	1992	1.02	1.33	-0.03	0.001	100	0.01	0.99	-0.01	0.01	-4.60	4.60	3.63	0.90	0.03	0.16	0.60	1.95
21	1993	1.30	1.32	-0.04	0.001	105	0.01	0.99	-0.01	0.01	-4.65	4.65	3.67	0.90	0.03	0.16	0.60	1.97
22	1994	1.59	1.32	-0.04	0.001	110	0.01	0.99	-0.01	0.01	-4.70	4.70	3.71	0.90	0.03	0.16	0.61	1.97
23	1995	1.59	1.32	-0.04	0.002	115	0.01	0.99	-0.01	0.01	-4.74	4.74	3.75	0.90	0.03	0.16	0.62	1.98
24	1996	1.41	1.31	-0.05	0.002	120	0.01	0.99	-0.01	0.01	-4.78	4.78	3.79	0.90	0.03	0.16	0.62	1.99
25	1997	1.46	1.30	-0.07	0.005	125	0.01	0.99	-0.01	0.01	-4.82	4.82	3.83	0.90	0.03	0.16	0.63	1.99
26	1998	1.23	1.27	-0.09	0.008	130	0.01	0.99	-0.01	0.01	-4.86	4.86	3.86	0.90	0.03	0.16	0.64	2.00
27	1999	1.62	1.26	-0.10	0.010	135	0.01	0.99	-0.01	0.01	-4.90	4.90	3.89	0.90	0.03	0.16	0.64	2.00
28	2000	1.32	1.23	-0.13	0.018	140	0.01	0.99	-0.01	0.01	-4.94	4.94	3.93	0.90	0.03	0.16	0.65	2.01
29	2001	1.47	1.19	-0.18	0.031	145	0.01	0.99	-0.01	0.01	-4.97	4.97	3.96	0.90	0.03	0.16	0.65	2.01
30	2002	1.31	1.14	-0.22	0.049	150	0.01	0.99	-0.01	0.01	-5.01	5.01	3.99	0.90	0.03	0.16	0.66	2.02
31	2003	1.47	1.08	-0.28	0.079	155	0.01	0.99	-0.01	0.01	-5.04	5.04	4.02	0.90	0.03	0.16	0.66	2.02
32	2004	1.47	1.06	-0.30	0.092	160	0.01	0.99	-0.01	0.01	-5.07	5.07	4.05	0.90	0.03	0.16	0.67	2.03
33	2005	1.39	1.04	-0.33	0.106	165	0.01	0.99	-0.01	0.01	-5.10	5.10	4.07	0.90	0.03	0.16	0.67	2.03
34	2006	1.32	1.02	-0.34	0.115	170	0.01	0.99	-0.01	0.01	-5.13	5.13	4.10	0.90	0.03	0.16	0.68	2.04

ETO_{mean}	1.36

Table no. (8)

Average ETo values by Blany Criddle & Hargraeves method based on Gumbel distribution for 25,50,75,100,125 And 150 years return period							
Month	***Ave. ET0 (mm/days) values for Return periods***						
	Current time	***25***	***50***	***75***	***100***	***125***	***150***
Jan.	***1.36***	***1.75***	***1.86***	***1.91***	***1.95***	***1.99***	***2.01***
Fb.	***2.18***	***2.76***	***2.91***	***3.00***	***3.06***	***3.11***	***3.15***
Mar.	***3.01***	***3.60***	***3.75***	***3.84***	***3.91***	***3.95***	***3.99***
Apr.	***4.19***	***5.10***	***5.34***	***5.48***	***5.58***	***5.65***	***5.72***
May	***5.47***	***6.13***	***6.31***	***6.41***	***6.48***	***6.54***	***6.58***
Jun	***6.63***	***7.30***	***7.48***	***7.58***	***7.65***	***7.71***	***7.75***
Jully	***7.14***	***7.85***	***8.04***	***8.15***	***8.23***	***8.29***	***8.39***
Aug.	***6.65***	***7.04***	***7.15***	***7.21***	***7.25***	***7.28***	***7.31***
Sep.	***5.39***	***6.60***	***6.92***	***7.11***	***7.24***	***7.34***	***7.43***
Oct.	***3.89***	***4.31***	***4.43***	***4.49***	***4.54***	***4.57***	***4.60***
Nov.	***2.52***	***3.00***	***3.12***	***3.20***	***3.25***	***3.29***	***3.32***
Des.	***1.84***	***2.26***	***2.37***	***2.44***	***2.48***	***2.52***	***2.55***
Annual sum	***50.28***	***57.70***	***59.68***	***60.82***	***61.62***	***62.24***	***62.80***

Table no. (9)

Average monthly rainfall in Sulaimnyia from 1973 to 2006

S.N	Average total monthly rainfall data (mm)																																			Average Rainfall for current time (mm)
	Year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
1	January	132	135	63	99	113	98	187	81	175	164	113	17	114	34	38	152	35	121	87	159	80	189	69	230	104	274	88	147	83	208	127	272	110	142	124.73
2	February	94	163	224	143	78	99	55	106	158	91	104	41	155	170	68	205	53	96	64	23	68	96	112	108	46	92	98	46	84	65	174	103	123	276	108.23
3	March	67	42	68	140	106	125	117	115	142	106	64	127	83	59	168	147	166	91	102	157	82	104	139	177	192	143	19	38	82	134	132	13	145	3	105.63
4	April	95	96	81	157	141	34	27	57	72	16	44	117	85	101	19	134	1	67	55	85	223	96	198	89	69	70	17	33	35	132	66	74	56	123	81.21
5	may	67	4	25	94	23	23	27	7	26	68	60	53	39	70	66	1	1	19	23	75	90	8	71	22	44	36	0	14	13	27	19	96	24	117	39.67
6	Jon	0	0	0	0	0	8	0	0	4	0	0	0	0	0	0	6	0	0	6	6	0	0	19	0	0	4	0	0	0	0	0	0	0	0	1.56
7	July	0	0	0	0	0	Az	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0.16
8	August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
9	September	0	0	0	0	0	0	0	1	0	7	0	0	0	0	0	0	0	0	4	0	0	7	12	0	0	0	0	3	4	0	0	0	0	0	1.10
10	October	3	0	0	37	20	8	67	13	49	146	0	41	5	33	103	23	11	15	57	0	56	70	0	0	52	0	7	28	22	57	2	13	1	0	27.49
11	November	42	64	37	17	38	21	49	109	99	168	35	232	101	201	18	63	145	25	36	160	196	264	13	0	161	4	51	31	43	58	131	116	36	12	81.71
12	December	77	114	155	57	127	285	155	79	58	65	64	82	138	62	270	181	86	83	364	157	80	118	40	112	147	4	59	165	148	248	161	65	50	44	120.56
Total		576	617	652	745	645	701	684	566	782	831	484	710	721	729	749	911	498	517	800	821	874	953	672	738	813	629	339	505	513	930	811	752	545	716	

Table no. (10)

Frequency distribution analysis for rainfall using Gumbel Method

Average monthly rainfall for Sulaimnyia center form 1973 to 2006 (mm)/ Month - January

S.N	Year	Ave. Rainfall (P) (mm)	(P) in desending order	(P) desending - (P) mean	(P desending - P mean) ^{2}	Assumed (T)	Yt = - ln (-ln(1-1/T))						K = (Yt - Yn) / Ysn	$\sigma = \sqrt{\sum (ETO - ETO_{mean})^2 / N-1}$			σ * K	Pt= Pmean + σk
							1/T	1-1/T	ln(1-1/T))	-ln(1-1/T))	$Y_t^{/}$ = ln (-ln(1-1/T))	Y_t = - ln (-ln(1-1/T))		∑ (P - P mean)2	∑ (P - P mean)2 /N-1	$\sigma = \sqrt{\sum (P - P_{mean})^2 / N-1}$		
1	1973	132	274	148.87	22162.452	5	0.20	0.80	-0.22	0.22	-1.50	1.50	0.86	129877.89	3935.69	62.74	53.77	178
2	1974	135	272	147.27	21688.626	10	0.10	0.90	-0.11	0.11	-2.25	2.25	1.53	129877.89	3935.69	62.74	95.80	221
3	1975	63	230	104.77	10976.876	15	0.07	0.93	-0.07	0.07	-2.67	2.67	1.91	129877.89	3935.69	62.74	119.52	244
4	1976	99	208	83.67	7000.767	20	0.05	0.95	-0.05	0.05	-2.97	2.97	2.17	129877.89	3935.69	62.74	136.12	261
5	1977	113	189	64.37	4143.573	25	0.04	0.96	-0.04	0.04	-3.20	3.20	2.37	129877.89	3935.69	62.74	148.91	274
6	1978	98	187	62.57	3915.079	30	0.03	0.97	-0.03	0.03	-3.38	3.38	2.54	129877.89	3935.69	62.74	159.32	284
7	1979	187	175	49.77	2477.111	35	0.03	0.97	-0.03	0.03	-3.54	3.54	2.68	129877.89	3935.69	62.74	168.09	293
8	1980	81	164	39.47	1557.927	40	0.03	0.98	-0.03	0.03	-3.68	3.68	2.80	129877.89	3935.69	62.74	175.67	300
9	1981	175	159	34.27	1174.473	45	0.02	0.98	-0.02	0.02	-3.80	3.80	2.91	129877.89	3935.69	62.74	182.35	307
10	1982	164	152	27.37	749.149	50	0.02	0.98	-0.02	0.02	-3.90	3.90	3.00	129877.89	3935.69	62.74	188.31	313
11	1983	113	147	22.47	504.927	55	0.02	0.98	-0.02	0.02	-4.00	4.00	3.09	129877.89	3935.69	62.74	193.70	318
12	1984	17	142	16.87	284.617	60	0.02	0.98	-0.02	0.02	-4.09	4.09	3.17	129877.89	3935.69	62.74	198.62	323
13	1985	114	135	9.97	99.413	65	0.02	0.98	-0.02	0.02	-4.17	4.17	3.24	129877.89	3935.69	62.74	203.14	328
14	1986	34	132	7.57	57.314	70	0.01	0.99	-0.01	0.01	-4.24	4.24	3.30	129877.89	3935.69	62.74	207.32	332
15	1987	38	127	2.47	6.104	75	0.01	0.99	-0.01	0.01	-4.31	4.31	3.37	129877.89	3935.69	62.74	211.21	336
16	1988	152	121	-3.73	13.909	80	0.01	0.99	-0.01	0.01	-4.38	4.38	3.42	129877.89	3935.69	62.74	214.85	340
17	1989	35	114	-10.63	112.984	85	0.01	0.99	-0.01	0.01	-4.44	4.44	3.48	129877.89	3935.69	62.74	218.27	343
18	1990	121	113	-11.33	128.356	90	0.01	0.99	-0.01	0.01	-4.49	4.49	3.53	129877.89	3935.69	62.74	221.49	346
19	1991	87	113	-11.73	137.579	95	0.01	0.99	-0.01	0.01	-4.55	4.55	3.58	129877.89	3935.69	62.74	224.54	349
20	1992	159	110	-14.43	208.208	100	0.01	0.99	-0.01	0.01	-4.60	4.60	3.63	129877.89	3935.69	62.74	227.42	352
21	1993	80	104	-20.83	433.864	105	0.01	0.99	-0.01	0.01	-4.65	4.65	3.67	129877.89	3935.69	62.74	230.17	355
22	1994	189	99	-25.43	646.655	110	0.01	0.99	-0.01	0.01	-4.70	4.70	3.71	129877.89	3935.69	62.74	232.79	358
23	1995	69	98	-26.53	703.810	115	0.01	0.99	-0.01	0.01	-4.74	4.74	3.75	129877.89	3935.69	62.74	235.29	360
24	1996	230	88	-36.83	1356.406	120	0.01	0.99	-0.01	0.01	-4.78	4.78	3.79	129877.89	3935.69	62.74	237.68	362
25	1997	104	87	-37.73	1423.509	125	0.01	0.99	-0.01	0.01	-4.82	4.82	3.83	129877.89	3935.69	62.74	239.98	365
26	1998	274	83	-42.13	1774.887	130	0.01	0.99	-0.01	0.01	-4.86	4.86	3.86	129877.89	3935.69	62.74	242.18	367
27	1999	88	81	-43.73	1912.261	135	0.01	0.99	-0.01	0.01	-4.90	4.90	3.89	129877.89	3935.69	62.74	244.31	369
28	2000	147	80	-44.83	2009.676	140	0.01	0.99	-0.01	0.01	-4.94	4.94	3.93	129877.89	3935.69	62.74	246.35	371
29	2001	83	69	-55.63	3094.631	145	0.01	0.99	-0.01	0.01	-4.97	4.97	3.96	129877.89	3935.69	62.74	248.32	373
30	2002	208	63	-62.13	3860.064	150	0.01	0.99	-0.01	0.01	-5.01	5.01	3.99	129877.89	3935.69	62.74	250.23	375
31	2003	127	38	-86.33	7452.767	155	0.01	0.99	-0.01	0.01	-5.04	5.04	4.02	129877.89	3935.69	62.74	252.07	377
32	2004	272	35	-89.53	8015.516	160	0.01	0.99	-0.01	0.01	-5.07	5.07	4.05	129877.89	3935.69	62.74	253.86	379
33	2005	110	34	-90.73	8231.826	165	0.01	0.99	-0.01	0.01	-5.10	5.10	4.07	129877.89	3935.69	62.74	255.58	380
34	2006	142	17	-107.53	11562.574	170	0.01	0.99	-0.01	0.01	-5.13	5.13	4.10	129877.89	3935.69	62.74	257.26	382
Pmean			125															

Table no. (11)

Average monthly effective rainfall (Pe) mm, based on Gumbels distribution analysis for average monthly rain fall for T = (25,50,75,100,125 and 150) years return period

Return periods (T)	***Rainfall ((P) and effective rainfall (mm)***	***Month***											
		Jan.	***Feb..***	***Mar.***	***Apr.***	***May***	***Jun***	***July***	***Aug.***	***Sep.***	***Oct.***	***Nov.***	***Des.***
Current time	***Average monthly rainfall P (mm/month)***	***124.73***	***108.23***	***105.63***	***81.21***	***39.67***	***1.56***	***0.16***	***0.00***	***1.10***	***27.49***	***81.71***	***120.56***
	Average monthly effective rainfall Pe (mm/month)	***74.78***	***61.58***	***59.51***	***39.97***	***13.80***	***-9.06***	***-9.91***	***-10.00***	***-9.34***	***6.49***	***40.36***	***71.44***
		74.78	***61.58***	***59.51***	***39.97***	***13.80***	***0.00***	***0.00***	***0.00***	***0.00***	***6.49***	***40.36***	***71.44***
25	***Average monthly rainfall P (mm/month)***	***274.00***	***241.00***	***221.00***	***202.00***	***115.00***	***10.00***	***2.00***	***0.00***	***7.00***	***107.00***	***252.00***	***307.00***
	Average monthly effective rainfall Pe (mm/month)	***194.20***	***167.80***	***151.80***	***136.60***	***67.00***	***-4.00***	***-8.80***	***-10.00***	***-5.80***	***60.60***	***176.60***	***220.60***
		194.20	***167.80***	***151.80***	***136.60***	***67.00***	***0.00***	***0.00***	***0.00***	***0.00***	***60.60***	***176.60***	***220.60***
50	***Average monthly rainfall P (mm/month)***	***313.00***	***277.00***	***251.00***	***234.00***	***134.00***	***13.00***	***2.00***	***0.00***	***9.00***	***128.00***	***296.00***	***356.00***
	Average monthly effective rainfall Pe (mm/month)	***225.40***	***196.60***	***175.80***	***162.20***	***82.20***	***-2.20***	***-8.80***	***-10.00***	***-4.60***	***77.40***	***211.80***	***259.80***
		225.40	***196.60***	***175.80***	***162.20***	***82.20***	***0.00***	***0.00***	***0.00***	***0.00***	***77.40***	***211.80***	***259.80***
75	***Average monthly rainfall P (mm/month)***	***336.00***	***297.00***	***269.00***	***252.00***	***146.00***	***14.00***	***2.00***	***0.00***	***10.00***	***141.00***	***323.00***	***385.00***
	Average monthly effective rainfall Pe (mm/month)	***243.80***	***212.60***	***190.20***	***176.60***	***91.80***	***-1.60***	***-8.80***	***-10.00***	***-4.00***	***87.80***	***233.40***	***283.00***
		243.80	***212.60***	***190.20***	***176.60***	***91.80***	***0.00***	***0.00***	***0.00***	***0.00***	***87.80***	***233.40***	***283.00***
100	***Average monthly rainfall P (mm/month)***	***352.00***	***311.00***	***281.00***	***265.00***	***154.00***	***15.00***	***2.00***	***0.00***	***11.00***	***149.00***	***341.00***	***405.00***
	Average monthly effective rainfall Pe (mm/month)	***256.60***	***223.80***	***199.80***	***187.00***	***98.20***	***-1.00***	***-8.80***	***-10.00***	***-3.40***	***94.20***	***247.80***	***299.00***
		256.60	***223.80***	***199.80***	***187.00***	***98.20***	***0.00***	***0.00***	***0.00***	***0.00***	***94.20***	***247.80***	***299.00***
125	***Average monthly rainfall P (mm/month)***	***365.00***	***323.00***	***291.00***	***275.00***	***160.00***	***16.00***	***3.00***	***0.00***	***11.00***	***156.00***	***355.00***	***420.00***
	Average monthly effective rainfall Pe (mm/month)	***267.00***	***233.40***	***207.80***	***195.00***	***103.00***	***-0.40***	***-8.20***	***-10.00***	***-3.40***	***99.80***	***259.00***	***311.00***
		267.00	***233.40***	***207.80***	***195.00***	***103.00***	***0.00***	***0.00***	***0.00***	***0.00***	***99.80***	***259.00***	***311.00***
150	***Average monthly rainfall P (mm/month)***	***375.00***	***332.00***	***299.00***	***284.00***	***165.00***	***17.00***	***3.00***	***0.00***	***12.00***	***161.00***	***367.00***	***433.00***
	Average monthly effective rainfall Pe (mm/month)	***275.00***	***240.60***	***214.20***	***202.20***	***107.00***	***0.20***	***-8.20***	***-10.00***	***-2.80***	***103.80***	***268.60***	***321.40***
		275.00	***240.60***	***214.20***	***202.20***	***107.00***	***0.20***	***0.00***	***0.00***	***0.00***	***103.80***	***268.60***	***321.40***

Table no. (12)

Monthly effective rainfall according to crop types with their growing periods for different return periods

Item descriptions	Crop type	Month											
		January	February	March	April	may	Jun	July	August	September	October	November	December
Grown period for crops	Rice					■	■	■	■	■			
	Wheat and Barley	■	■	■	■							■	■
	Cucumber							■	■				
	Sunflower					■	■	■	■				
	Celery				■	■	■						
	Onion				■	■	■						
	Tomatoes				■	■	■	■	■				
	Peppers				■	■	■	■					
	Egg plant				■	■	■	■					
	Radish								■	■	■		
	Sweet melons					■	■	■	■				
	Cowpeas					■	■	■	■				
T = Current time	Average monthly effective rainfall (Pe) -mm	74.78	61.58	59.51	39.97	13.80	0.00	0.00	0.00	0.00	6.49	40.36	71.44
T =25		194.20	167.80	151.80	136.60	67.00	0.00	0.00	0.00	0.00	60.60	176.60	220.60
T =50		225.40	196.60	175.80	162.20	82.20	0.00	0.00	0.00	0.00	77.40	211.80	259.80
T =75		243.80	212.60	190.20	176.60	91.80	0.00	0.00	0.00	0.00	87.80	233.40	283.00
T = 100		256.60	223.80	199.80	187.00	98.20	0.00	0.00	0.00	0.00	94.20	247.80	299.00
T = 125		267.00	233.40	207.80	195.00	103.00	0.00	0.00	0.00	0.00	99.80	259.00	311.00
T = 150		275.00	240.60	214.20	202.20	107.00	0.20	0.00	0.00	0.00	103.80	268.60	321.40

Table (4.1) - Comparison table for calculated ETcrop for different return period with approximate range of ETcrop

S.N	*Crops Type*	*Calculated ETcrop values (mm/growing seasons) on the basis of current time*	*Approximate ETcrop range values*	*Calculated ETcrop values comply with approximate ETcrop*
1	*Rice*	*803*	*500 - 950*	*Yes*
2	*Wheat and Barley*	*317*	*300 - 450*	*Yes*
3	*Cucumber/vegetables*	*310*	*250 -500*	*Yes*
4	*Sunflower/Oil seeds*	*466*	*300 - 600*	*Yes*
5	*Celery/vegetables*	*250*	*252 -500*	*Yes*
6	*Onion/small vegetables*	*362*	*350 - 600*	*Yes*
7	*Tomato's/vegetables*	*498*	*300 - 600*	*Yes*
8	*Peppers/vegetables*	*381*	*250 -500*	*Yes*
9	*Egg plant/vegetables*	*413*	*250 –500*	*Yes*
10	*Radish vegetables*	*396*	*250 -500*	*Yes*
11	*Sweet melons vegetables*	*416*	*250 -500*	*Yes*
12	*Cowpeas/legumes*	*440*	*250 - 500*	*Yes*

In this study, and according to the above table, the calculated seasonal (ETcrop) values for all the type of crops with different return period comply with the standard approximate range of the seasonal (ETcrop).

4.3.2 Checking the calculated average ETO by Hargreaves and Blaney Criddle with modified Penman method:

The calculated ETo by Hargreaves and Blaney Criddle method using equations (2.7 and 2.12) with their average values are compared with the modified Penman method using equation (2.1) as shown in the annexes table (5 and 6).

In this study, this comparison was done only from years 2001 up to 2006 because for this period only full metrological was available and the modified Penman method could be used only when such full data available.

Based on this comparison the mean average ETo values of the two methods are more close to the ETo values by the Penman method rather than the ETo values by each method singly and the following points are detected.

- ✓ Using ETo values by Hargreaves method instead of mean average values of the two method gives small values for the required crop water volume and this means unsafe conditions from design view.
- ✓ Using ETo values by Blaney Criddle method instead of mean average values of the two method gives large values for the required crop water volume and this means over safety conditions from design view and consequently uneconomical case.
- ✓ Using the mean ETo values of the two methods Blaney Criddle and Hargreaves gives the most suitable values for the required crop water volume and this means safe conditions from design view and consequently economical case. Therefore, depending on this fact the mean average ETo is used as a standard for ETcrop calculation and consequently the required water volume as shown in the annexes table (14, 15. and 16).

CHAPTER FIVE

CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions:

According to the sequence of the work procedures, and depending on the obtained results by Hargreaves and Blaney Criddle methods for the study area located in Bakrajo area with an area of (324) hectare which composed of different crop types with same cropping intensity as previously demonstrated in table no. (3.2), the following conclusions and recommendations were attained.

5.1.1) The obtained results for estimating the reference evapotraspiration (ETo) using equations which require limited climatological data (Hargreaves and Blaney Criddle equations), showed good accuracy after comparing the mean average ETo values with a standard basic method using modified Penman method (1977).

5.1.2) Carrying out the frequency distribution analysis by Gumbel method on the basis of different return periods (5, 10, 15, 20 and 25) years for reference evapotraspiration, rainfall and effective rainfall to obtain the crop water requirements will reduce and diminish the risk level for any mistake occurred through the work through expect their future values.

5.1.3) Both of the two methods Hargreaves and Blaney Criddle method for calculating reference evapotraspiration (ETo), have showed the same behavior for estimating the crop evapotraspiration, since both of the methods contain mean daily air temperatures.

5.1.4) When the mean daily air temperature gets high value, especially from June to September, the estimated values of crop evapotraspiration by the aforementioned two method show that their values will be more close to each other, and this closeness in their values is due to that both method contains mean daily air temperature in their equation as one of the main parameters inputs.

5.2 Recommendations for future research:

5.2.1) Carrying out detailed surveys of all the natural water resources in the around area in order to prepare contour maps, soil maps, vegetative maps and land use maps as a data base before initiating such research program in other locations and places.

5.2.2) Full knowledge with computer usage is so important before initiating such type of thesis because it facilitates calculation, other wise it is too difficult if one uses other tools as manual calculator and usually it consumes time.

5.2.3) In the future, detailed investigation and experiments should be carried out for the studied area to determine the ground water contribution under field conditions.

5.2.4) When sufficiently long climatic records are available (10) years or more and as the climatological data vary from year to year the frequency distribution analyses are highly recommended because it protects the designer from any risk since the selected magnitude is not based on the average values but on the likely range of conditions and on an assessment of tolerable risk of not meeting crop water requirements.

Irrigated land photos

Rice crop in the planted in BAKRAJO land area

Irrigated land photos (Fig. 4)

Tomato crop in the planted in BAKRAJO land area

Irrigated land photos (Fig. 5)

Irrigated land photos, continued

Egg plant crop in the planted in BAKRAJO land

Irrigated land photos (Fig.6)

Sweet melons crop in the planted in BAKRAJO

Irrigated land photos (Fig. 7)