POTENTIAL UTILIZATION OF WATER AND LAND IN JORDAN

BY

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ABSTRACT

The knowledge of potential water requirements for agricultural development on the national level is becoming more important in arid and semi arid regions of the world. Realizing this fact , this work was planned to achieve the following objectives:-

1) To study, compare and evaluate five common methods of estimating crop water requirements using available data from Jordan.
2) To establish an agroclimatological zoning for Jordan based on soil, topography and climate.
3) To estimate the potential water requirements(WRP) for different agroclimatological zones.
4) To identify an optimal land and water use priorities for agricultural development.

As a results of dividing the land according to land slope, annual rainfall and soil parent material, 35 agroclimate subunits were established to represent the East Bank of Jordan lands. Comparing the different methods for ETP estimation, the monthly values of ETP obtained by Hargreaves and Jensen-Haise methods are very closely related to ETP measured by class A pan at most of the subunits established.

About 62.7% of the total country area is recommended for range land and 25.6% could be used for cereals , fruit trees and vegetables. Where 8.5% could not be used for agriculture.

The results show that about 12855 million cubic meters (MCM) of water are required for irrigation to reach the optimal land use.

(91 Pages)

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I. INTRODUCTION

The knowledge of potential water requirements for agricultural development on the national level is becoming more important in arid and semi arid regions of the world.

The studies of water requirements for agricultural purposes, when linked to potential land use and available water resources, would help in the establishment of national plans for optimal water resources allocation and agricultural development. Such studies are important in countries like Jordan where water is limited and its optimal use is vital for a sound agricultural development. The availability of such studies in Jordan is limited and falls short of providing sufficient bases for optimal national development.

Realizing the importance of such studies, this work was planned to achieve the following objectives:-

1) To study, compare and evaluate five common methods of estimating crop water requirements using available data from Jordan.
2) To establish an agroclimatological zoning of the east bank of Jordan based on topography and climate.
3) To estimate the potential water requirements for the established agroclimatological zones.
4) To identify the optimal land and water use priorities for agricultural development in the east bank of Jordan.

II. LITERATURE REVIEW

AGROCLIMATOLOGY:

Soil and climate are the two major factors that affect agriculture. The climate of Jordan ranges from mediterranean to desert. It is characterized by a hot dry summer and cold winter. Two main seasons are recognized: Summer, from May to October and Winter, from November to April (National Water Master Plan,1977; Ionides,1939; Natur,1984; and El-Kawasma,1983).

The climate of Jordan could be classified according to Long (1957), Bagnouls and Gaussen (1957), Koppen (1936) and Thornthwaite (1948) classification methods as follows:

According to Long (1957) Jordan falls within the Mediterranean bioclimate region (Mediterranean sub-humid and Mediterranean semi-arid bioclimates). According to Bagnouls and Gaussen (1957) classification, three types of climate are identified, the Hot desertic, Hot sub-desertic and Xertheric. According to Koppen (1936) classification, two main types of climates occur, B and C climates moreover, six subdivisions of the climate have been defined in Jordan, these are: Bwh (warmer hot desert, Bwk (cool desert), Bsh (warm or hot steppe), Bsk (cool steppe), Csa (Mediterranean: dry warm or hot summer and rainy winter) and Csb (Mediterranean: dry cool summer and rainy winter). And according to Thornthwaite (1948) classification, five classes of climate are identified, these are CBs2a (dry subhumid mesothermal climate with large winter water surplus), CBsa (dry subhumid mesothermal climate with moderate winter water surplus), DBda (the semi arid mesothermal climate of little or no winter water surplus), EBda (the arid mesothermal climate (Badia)), and EBda (the arid megathermal climate (Jordan Valley)).

RAINFALL:

Agriculture in Jordan depends mainly on rainfall. About 91% of Jordan receives less than 200mm of rain annualy. About 6% of the total area receives 200-350mm, and less than 2% receives 350-500mm where only about 1% receives more than 500mm (Jordan Ministry of Agriculture,1974; Arar,1978; Natur,1984; and El-Kawasma,1983).

In the Jordan Valley, mean annual rainfall varies from more than 366mm in the North (Baqura) to 65mm in the South (Ghor El-Safi). The hilly regions, receives from 400-600mm (Ras Munief) to 300-350mm in the South (Tafila). With respect to steppe and steppe desert regions rainfall decreases gradually from West to East and Southeast dropping to a very low value of 18mm. Rainfa East and Southeast dropping to a very low value of 18mm. Rainfall distribution over the country seems to be closely related to topography and distance from the coast (El-Kawasma, 1983).

SOIL AND TOPOGRAPHY:

Soil and Topography of Jordan have been studied by several authours (Ionides, 1939; Hunting, 1956; and Moormann, 1959).

According to Ionides (1939), Jordan can be divided into three main topographic units, notably:

1) The Jordan Valley:- This area is a part of the Great Rift which extends some 400 Km from the north to the head of the Gulf of Aqaba and then further to the Red Sea and the African Rift. The altitude ranges from 197 meter below mean sea level in the north to about 392 meter below mean sea level near the Dead Sea.

2) The Hilly Region:- In this region, altitude increase from west to east to about 1200 meter in the north and to about more than 1500 meter above mean sea level in the south.

3) The Steppe and Steppe Desert:- This Region lies in the east and south east of the country and is the largest area. It is rather level with altitude between 600 to 800 meter above mean sea level, with some isolated mountaines up to 1754 meter in the southwest. In the southern part altitudes decrease from about 900 meter to about 600 meter.

Reports of the Jordan Ministry of Agriculture (1974) and El-Kawasma (1983) indicated that about 88% of the total country area have slope gradient 0~8%, soils with medium slope (9~25%) cover only 8% and the last 4% have rather high slopes (more than 25%).

SOIL PARENT ROCKS:

The geologic map of Jordan shows three main types of soil bed rock formations, namely; Limestone, Sandstone, and Basalt. (Bender and Flathe, 1964).

The soils of the desert land zone are formed from the Basalt and Limestone bed rocks in northern and eastern parts of the country and from Sandstone and Granite in the southern part. (Hunting, 1956 and Mitchell and Howard, 1978). The Granite rocks are only found in the desertic and semi desertic south-western area of Jordan (Moormann, 1959).

The soils of the hilly country are largely derived from the insoluble residue after the Limestone has been dissolved by the action of carbonated rain water. While the soils of the Jordan Valley can be divided into the slopes of the upper Jordan terrace and the flood area of the present Jordan River (Ionides, 1939). Un-consolidated material are present also in the soils of the Jordan Valley. The soils of the steppe land zone are formed from Limestone, Sandstone, Un-consolidated material and Basalt parent material (Mitchell and Howard, 1978).

POTENTIAL CROP WATER REQUIREMENTS:

Consumptive use of water or evapotranspiration (ET)is one of the important elements of the hydrological cycle from the moment water falls as precipitation until it reaches the ocean or is returned to the atmosphere (Collins et al, 1973). Evapotranspiration is essential for estimating irrigation water requirement and is necessary in planning, designing, operating and managing water related projects (Collins at al, 1973; Shih et al, 1983 and Abdin et al, 1984) . Relative humidity, wind movement and solar radiation along with air temperature combine to cause ET(Harrold, 1955) .

Several studies have been conducted on ET and water requirements in Jordan. Hanbali et al (1977) and Abu Khayt (1978) studied consumptive use and water reqirements at fifteen meteorological stations for Jordan by using Blaney-Criddle and Penman methods. The authors also estimated crop factor (Kc) from different crops. Actual consumptive use was also estimated in four different regions.

Actual measurements of consumptive use (ET) under each of the various physical and climatic conditions of any large area are time-consuming and expensive. Formulas have been developed relating ET and climatological data (Collins et al,1973). Each formula uses one or more of the climatic parameters to estimate ETP. Penman, Blaney-Criddle, Hargreaves, and Jensen-Haise formulas are some of the commonley used.

Blaney and Criddle developed a simplified formula using temperature and day time hours for the arid western portion of the United State (Hanson et al, 1979) . This formula was developed to estimate a refrence or potential crop evapotranspiration (ETP) in areas where only measured air temperature is available (Doorenboss and Pruitt, 1975).Sohi (1970) showed that Blaney-Criddle formula can successfully be used in most arid zones of the world . Hanbali et al (1977) and Abu-Khayt (1978) found that, on a seasonal basis, the ratio between ETP measured for alfalfa crop and ETP estimated by modified Blaney-Criddle formula, was approximately around one for the desert and Jordan Valley . That ratio is very evident in winter crops which have good yield . However, this formula tends to under estimate ETP during summer months by 20% for the desert and Jordan Valley . (Hanbali et al, 1977 and Abu Khayt, 1978).

For areas where available climatic data include measured air temperature and sun shine , cloudiness or radiation, the latter is suggested to predict the effect of climate on crop water requirements (Doorenboss and Pruitt,1975) Hargreaves and Jensen-Haise formulas are mainly based on temperature and solar radiation. Jensen-Haise formula utilizes vapour pressure and coefficients related to elevation for estimating ETP, its performance is quite reliable for semi arid and arid conditions. Hargreaves method is similar in concept to Jensen-Haise and is subject to similar limitations, it has been used extensively in Latin America (Hansen et al, (1979) .

Fardous (1983) indicated that in the central region of the Jordan Valley (University of Jordan Research Station) both Jensen-Haise and Hargreaves methods gave good estimation of ETP . The two methods were superior to Blaney-Criddle when compared to ETP measured by lysimeter in that region.

The Penman method is suggested for calculating ETP when measured climatic data include air temperature, wind speed and humidity . Original Penmam equation (1984) calculated the loss of water by evaporation from free water surface . The limitation of Penman is related to availablitiy of data and its complex computations . Hence the choice of method in many instances depends on the availability of climatological data for the given location (EL- Kawasma, 1983). Another fact to remember concerning the use of Penman equation is that the coefficients used in the equation should be calibrated for the specific location to better fit the relative importance of advective and solar energy in determining consumptive use (Hansen et al, 1979) . Hanbali et al (1977) and Abu Khayt (1978) stated that the original Penman equation with a constant of 0.35 in its aerodynamic expression was applicable during winter season for the desert and Jordan Valley. However a constant of 0.7 is recommended to replace the 0.35 in the aerodynamic term.

Several authors recommended Pan Evaporation measurements to estimate ETP (Harrold, 1955; Stanhill, 1961; Loams, 1964; and Pruitt, 1966). Class A United State Weather Bureau Evaporation Pan is widely used throughout the world to provide evaporation data related to ET. (Hill et al, 1983).

The open water evaporation measured in standard evaporation pans represents the best method for estimating ETP when compared to other methods in which other climatic parameters are involved (Stanhill,1961). According to Harrold (1955) pan evaporation data may be useful in developing soil moisture procedures for farm use in scheduling time and amount of irrigation.

Abdin et al (1984) found that under extremely arid conditions the Jensen-Halse method has given best estimate of ETP followed by class A pan , Hargreaves, Modified Penman and Blaney-Criddle methods respectively.

WATER RESOURCES OF JORDAN:

Water in Jordan is very limited; it is the major limiting factor for agricultural development . About 50% of the available water resources for irrigation is located for the Jordan Valley where only 5% of the population live (Shatanawi and Herzallah, 1984) . It has been estimated by the water Authority that the available annual surface water and ground water of the Kingdom total 1100 million cubic meters (MCM) (Sahouri, 1986).

Obvious water accumulation should not be considered as the only potential source of water . There are other source which can be made by the using appropriate technology which should be examined in detail in accordance with water requirements for developmental needs in Jordan (Salameh,1983) .

Data on surface water resources, except in certain relatively well studied areas like Jordan Valley,are limited and some times inconsistant . It has been estimated that 60% of the catchment area is ungaged (National Water Master Plan, 1977 and Natur, 1984).

The distribution of the available water resources over the country is given by Shatanawi and Herzallah,(1984)and Water Authority, (1987) . By the year 2000 it is projected that the water demand will rise to about 1100 MCM, about 800 MCM being utilized for agricultural purposes and 300 MCM for domestic and industrial purposes (Nasser, 1986).

on the basis of average annual rainfall conditions, the East Bank catchments (including the Syrian area of the Yarmouk River Basin) would receive a rainfall volume of about 8065 MCM . About 75% (or 6000 MCM) of this annual rainfall can be related to Jordanian territory. On the average, from the total amount of annual ground water reacharge in East Jordan of about 580 MCM, some 220 MCM seemed to be available as annual ground water resources, in addition to the stream flow and the stored ground water (National Water Master Plan, 1977).

III. MATERIALS AND METHODS

STUDY AREA:

The study covers the East bank of Jordan .

AGROCLIMATOLOGICAL ZONING:

Agroclimatological zoning of East Jordan was established using land slope gradient, annual rainfall and soil parent material .

Topography maps with scale 1:50000 were used to classify land into three slope gradient zones:-

[S1] represents 0-8% slope zone .

[S2] represents 8-15% slope zone .

[S3] represents more than 15% slope zone .

Boundary of each zone was determined by contour lines . The area of each zone was measured by the planimeter . The smallest area measured was about 1.0 Km^2 . To improve the accuracy of measurement, isolated areas with different slope within each zone were also measured (ie. slope more than 8% inside 0-8% zone, and slope more than 15% inside 8-15%) .

According to annual rainfall (Jordan Meteorology Department 1977) the country was classified into the following zones:-

[R1] represents 0-100mm annual rainfall zone.
[R2] represents 100-200mm annual rainfall zone.
[R3] represents 200-300mm annual rainfall zone.
[R4] represents 300-400mm annual rainfall zone.
[R5] represents 400-500mm annual rainfall zone.
[R6] represents more than 500mm annual rainfall zone.

The area of each zone was measured and overimposed on land slope zones

Geological map (scale 1:500000) constructed by Bender (1964) was used to classify the soil parent material of Jordan into the following:-

[L] represents Limestone area .

[B] represents Basalt area .

[S] represents Sandstone area .

Granite parent material was ignored and treated as Sandstone parent material due to sandy texture of soil on the surface .Un-consalidated material was ignored also and treated as limestone because it is culloviam originated by limestone . The boundaries of each zone were identified and the area was measured and overimposed on land slope and annual rainfall zones .

Each area is described in terms of parent material, slope and rainfall, thus the code LS2R6 indicate that the parent material is Limestone and the dominant slope is 8-15% and it receives more than 500mm annual rainfall .

ESTIMATING POTENTIAL EVAPOTRANSPIRATION (ETP)

Potential evapotranspiration (ETP) was estimated by four methods which are: Penman, Blaney-Criddle, Jensen-Haise and Hargreaves .

ETP was calculated at the following agrometeorological stations;-

1) El-Rabba.

2) Deir Alla .

3) Irbid .

4) Wadi Dhuliel .

5) El-Baqura .

6) Ghor El-Safi .

7) El-Shoubak .

8) Wad El-Yabis .

These stations are the only agrometeorological stations in Jordan. Location coordinates and record duration and elevation for the eight stations are shown in Table (1). The following meteorological parameters are collected:-
parameters are collected:-

1) Temperature in degrees celsius (C°).

2) Solar radiation (langley/day).

3) Relative humidity (%) .

4) Wind speed (Km/day) at (2)meter hight above soil surface.

5) Class A pan evaporation (mm/day) .

6) ETP estimated by original Penman method (mm/day) .

Table 1: Location, Elevation and Record Duration of Agrometeorological Stations Used in the Study .

Station	Latitude North	Longitude East	Elevation meter	Record Duration
El-Rabba	31°16′	35°45′	+ 920	1974-1984
Deir Alla	32°13′	35°37′	- 224	1972-1984
Irbid	32°33′	35°51′	+ 616	1972-1984
Wadi Dhuleil	32°09′	36°17′	+ 580	1972-1984
El-Baqura	32°38′	35°37′	- 170	1972-1084
Ghor El-Safi	31°02′	35°28′	- 350	1974-1984
El-Shoubak	30°31′	35°32′	+1365	1974-1984
Wad El-Yabis	32°24′	35°35′	- 200	1973-1977

Cited from Jordan Meteorology Department, 1971.

These climatic parameters are issued every 10 days by the jordan meteorology department .

Class A pan evaporation was used to determine ETP at five stations located in the desert to represent the deserts zones . These stations are:-

1) Um El-Jemal.

2) Qa Disi .

3) Azraq .

4) Rueishid (H-4).

5) Bayir .

Location coordinates and duration of obtained records and elevation for the desert stations are shown in Table 2.

Table 2: Location, Elevation and Record Duration of the Desert Satations Used in the Study .

Station	Latitude North	Longitude East	Elevation meter	Record Duration
Um El-Jemal	32°18′	36°20′	+ 675	1966-1972
Qa Disi	29°39′	35°31′	+ 810	1966-1972
Azraq	31°51′	36°49′	+ 533	1960-1976
Rueishid	32°30′	38°12′	+ 686	1960-1976
Bayir	30°46′	36°41′	+ 900	1964-1973

Cited from National Water Master Plan of Jordan, Volume III.

METHODS OF ESTIMATING ETP:-

Penman

The original Penman equation (1948) predicted evaporation losses from an open water surface. Penman combined energy balance and aerodynamic equation into what is commonly known as "combination equation" which is now used extensively throughout the world (Collins et al, 1973). The equation may be written as follow (Chang, 1968).

$$E_o = \frac{\Delta Rn + \gamma Ea}{\Delta + \gamma}$$

Where:

E_o = Evapotranspiration in mm/day .

Δ = Slope of saturation vapor pressure vs temperature curve (de_a/dT) in mb/°C .

e_a = Saturation vapor pressure in mm Hg at temperature (T).

T = Temperature in °K .

R_n = Net radiation expressed in evaporation unit .

$R_n = (1-r)\, R_a\, (0.18+0.55n/N) - \sigma T^4 (0.56-0.092\sqrt{ed})(0.1+0.9n/N)$.

r = Reflection coefficient (for mean annual values , Penman used 0.05 for open water, 0.10 for wet, bare soil, 0.20 for fresh, green vegetation)(r is taken 0.25 for ETP) .

R_a = The theoritical maximum extra terrestrial radiation that would reach the earth in the absence of an atmosphere in mm .

n/N = Ratio between actual and possible hours of sun shine

σ = The Stefan-Boltzman constant . (cal/cm² day K^4).

e_d = Saturation vapor pressure in mm of Hg at the dew point temperature .

γ = The Psychrometric constant, or the ratio of specific heat of air to the latent heat of evaporation of water.

E_a = An aerodynamic component .

= $0.35\ (e_d - e_a)(1 + U_2/100)$.

U_2 = Wind speed in miles per day at height of two meters .

Blaney-Criddle

Blaney and Morin (1942) first developed an emperical equation relating evapotranspiration to mean air temperature, average relative humidity and mean percentage of day time hours. This equation was later modified by Blaney and Criddle (1945, 1962) and Blaney et al (1952). The equation can be written in SI units as follow:

$$U = KP\ \frac{45.7t + 813}{100}$$

Where:

U = Consumptive use of crop in mm/month .

K = Emperical coefficient.

t = Mean monthly temperature (°C).

P = Percentage of day light hours of the year occuring during a particular month.

The Soil Conservation Service of the United States Technical Release No. 21 presents a modified Blaney-Criddle equation for computing monthly consumptive use. The modification is made on the monthly K as:

$$K = KcKt$$

Where:

Kc = Monthly growth stage coefficient .

Kt = Climatic coefficient calculated as follow:

Kt = 0.03114t+0.24 subject to K>0.30.

Jensen-Haise

Jensen and Haise (1963) used observation of consumptive use from the western United State to develope a linear relationship for estimating ETP (Hansen et al, 1979). The equation is as follows:-

$$ETP = C_t(T_a - T_x)R_s \times 10/\lambda$$

Where:

ETP = Potential evapotranspiration in mm/day,

C_t = An empirical coefficient .

T_a = Temperature in °C .

T_x = The intercept on temperature axis .

R_s = Incident solar radiation in langley/day .

λ = 595-0.51T .

The values of C_t and T_x were determined as:

$C_t = 1/(C_1 + C_2 C_H)$.

Where

$C_H = 50\ mb/(e_2 - e_1)$.

$C_1 = 38-(2°C \times EL(M)/305)$.

$C_2 = 7.6°C$.

e2, e1 are saturation vapour pressure(e_s) of water at mean maximum and mean minumum temperature respectively for the warmest month of the year in a given area.

$e_s = 1.3329\ exp[21.07-(5336.0/(T+273.1)]$.

T= Mean temperature in °C.

$T_x = 2.5-0.14(e_2-e_1)EL/550$

EL= Elevation in m .

Hargreaves

Hargreaves (1977) based his work on data from grass lysimeter. The method is similar in concept to Jensen-Haise and is subject to similar limitations. It has been used extensively in Latin America to estimate crop water requirements (Hansen et, al, 1979). The equation may be written as follows:-

The equation is

$$Etg=0.135(T+17.78)Rs/\lambda$$

Where

Etg= reference crop consumptive use, well watered grass in mm/day,

T= average daily temperature in C^{o}.

R_s= incident solar radiation in langleys/day .

λ= latent heat of water in cal/g .

= 595-0.51T .

Class A Pan Evaporation

Evaporation pans use the integrated effect of radiation, temperature, wind and humidity to measure evaporation from a specific open water surface (Doorenboss and Pruitt, 1975). Many studies over several decades have suggested the use of pan evaporation data to estimate ETP using a simple proportional relationship:-

$$ETP = K_p E_p$$

where

ETP= potential evapotranspiration in mm/day .

Ep = class A pan evaporation in mm/day and represents the mean daily value of the period considered.

Kp = pan coefficient, effected by wind speed, relative humidity and green cover of the surroundings.

For determining pan coefficients the information regarding the surroundings of the agrometeorological stations and desert the green cover of the surroundings of the agrometeorological stations and desert stations used in the study and through the obtained records, were un available.

The assumption that the class A pan is surrounded by short green crop, with 100 meter up wind distance of green crop in all months through the year, was used for determining pan coefficient for agrometeorological stations . This assumption was adapted because the agrometeorological stations are actually located in agricultural lands . This also means that the surrouding land for at least 100 meter is coverd by green crop through most of the year .

The assumption that the class A pan is surrounded by fallow land with 1000 meter up wind distance and light wind speed and moderate relative humidity in all month of the year, was used for determining pan coefficient for desert stations. This assumption was adapted because these stations are actually located in desert. This means that the surrounding land for at least 1000 meter is fallow land, also the wind speed is light and relative humidity are moderate through most months of the year .

The pan coeficient data which developed by Doorenboss and Pruitt (1975) was used to determine Kp in this study.

IV. RESULTS AND DISCUSSION

AGROCLIMATOLOGICAL ZONING

Zoning according to land slope gradient

Lands slope gradient was classified into three classes, slope [S1]<8%, slope [S2]8~15% and slope [S3]>15%. Total areas measured within each class is given in Table 3. Figure 1 shows the distribution of the different slopes on the east bank of Jordan lands. Measurement of different areas indicates that the majority of the land 86.9% (73626 Km^2) has a slope of less than 8%. About 2% (1484 Km^2) of this class however, include lands with a slope of more than 8%. lands with a slope of 8~15% cover onlyl 1.9% (1636 Km^2). About 6.3% (102 Km^2) of this zone lands with a slope of more than 15%. Steep lands with slope of more than 15% covers the remaining 11.2% (9502 Km^2) of east bank of Jordan lands.

Zoning according to annual rainfall

Areas of different annual rainfall classes are shown in fig. 2. Table 4 shows that 90.8% (76964 Km^2) of the total country area receives an average annual rainfall of less than 200mm, about 7.4% (6250 Km^2) receives between 200~400mm and 1.8% (1550 Km^2) of the land receives over 400mm Of annual rainfall.

Zoning according to soil parent material

Soil developed from different parent materials and falling within established zones are shown in Fig. 3. Table 5 gives the total areas of different parent materials zones in Km^2 and the percent of the each zone to the total area. Limestone parent

Table 3 : Areas of East Bank of Jordan Land Slope gradient Zones .

Slope Interval	Area		Inclusion*	
	km^2	%	km^2	%
S1 (< 8%)	73626	86.9	1484	2.0
S2 (8~15%)	1636	1.9	102	6.3
S3 (>15%)	9502	11.2	—	—
Total	84764	100.0	—	—

* Area having slope gradient greater than prespective interval.

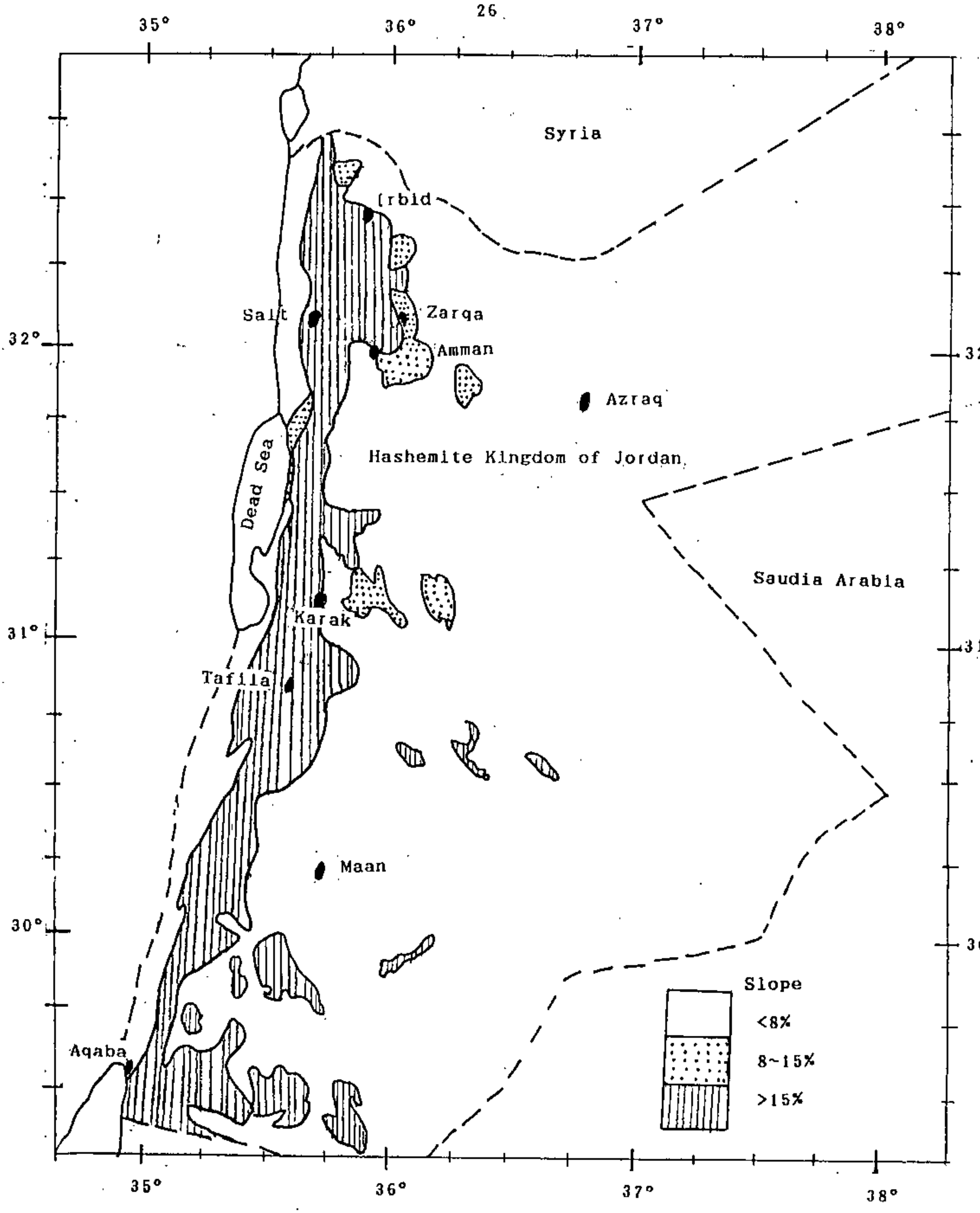

Fig. 1 : East Bank of Jordan Land Slope Gradient Zones.

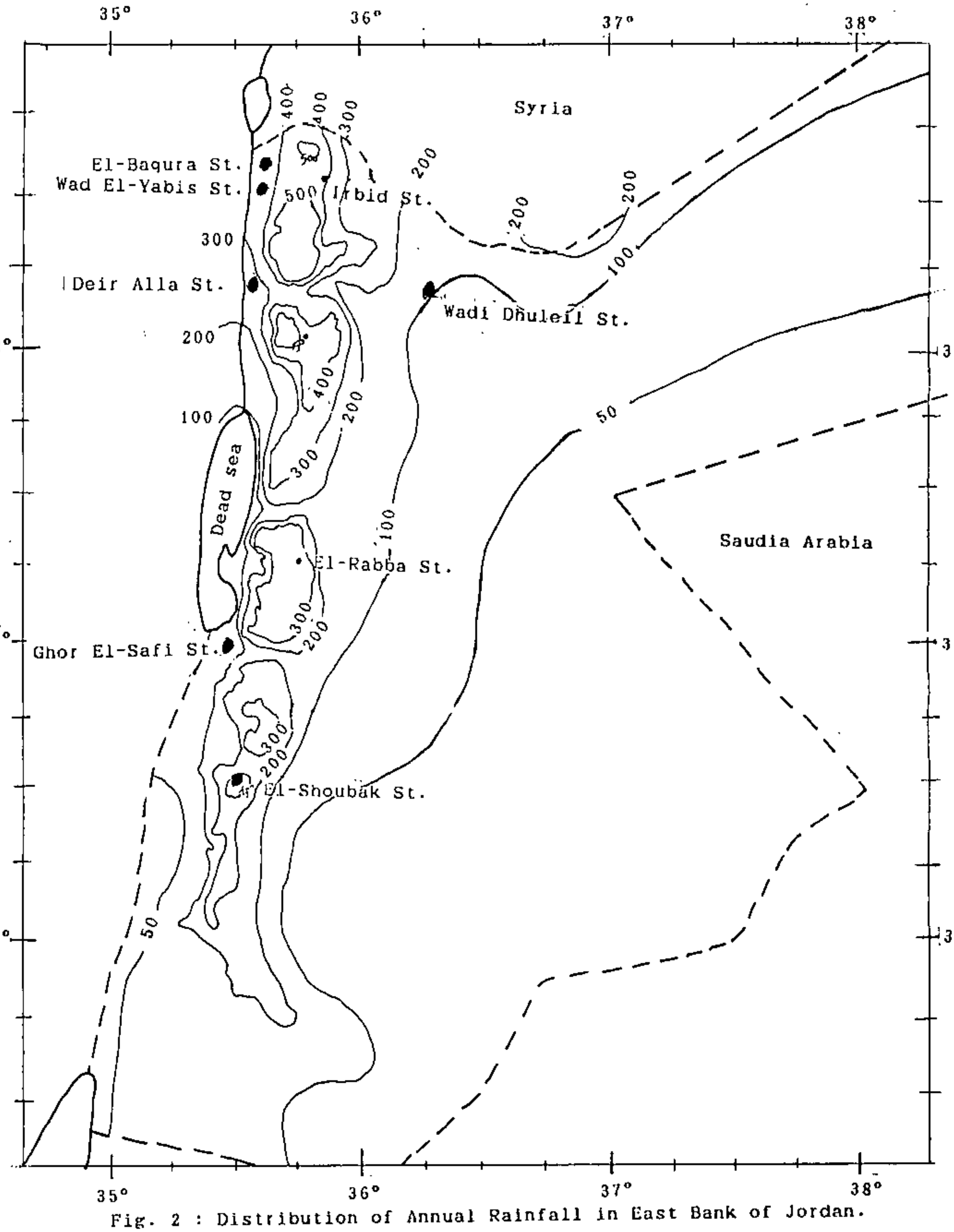

Fig. 2 : Distribution of Annual Rainfall in East Bank of Jordan.

Cited from Jordan Climate Atlas, 1971.

Table 4 : Areas of East Bank of Jordan Annual Rainfall Zones.

Annual Rainfall (mm)	Area km²	Area %
R1 (0~100)	65808	77.6
R2 (100~200)	33101	13.2
R3 (200~300)	3636	4.3
R4 (300~400)	2614	3.1
R5 (400~500)	1017	1.2
R6 (>500)	353	0.6
Total	84764	100.0

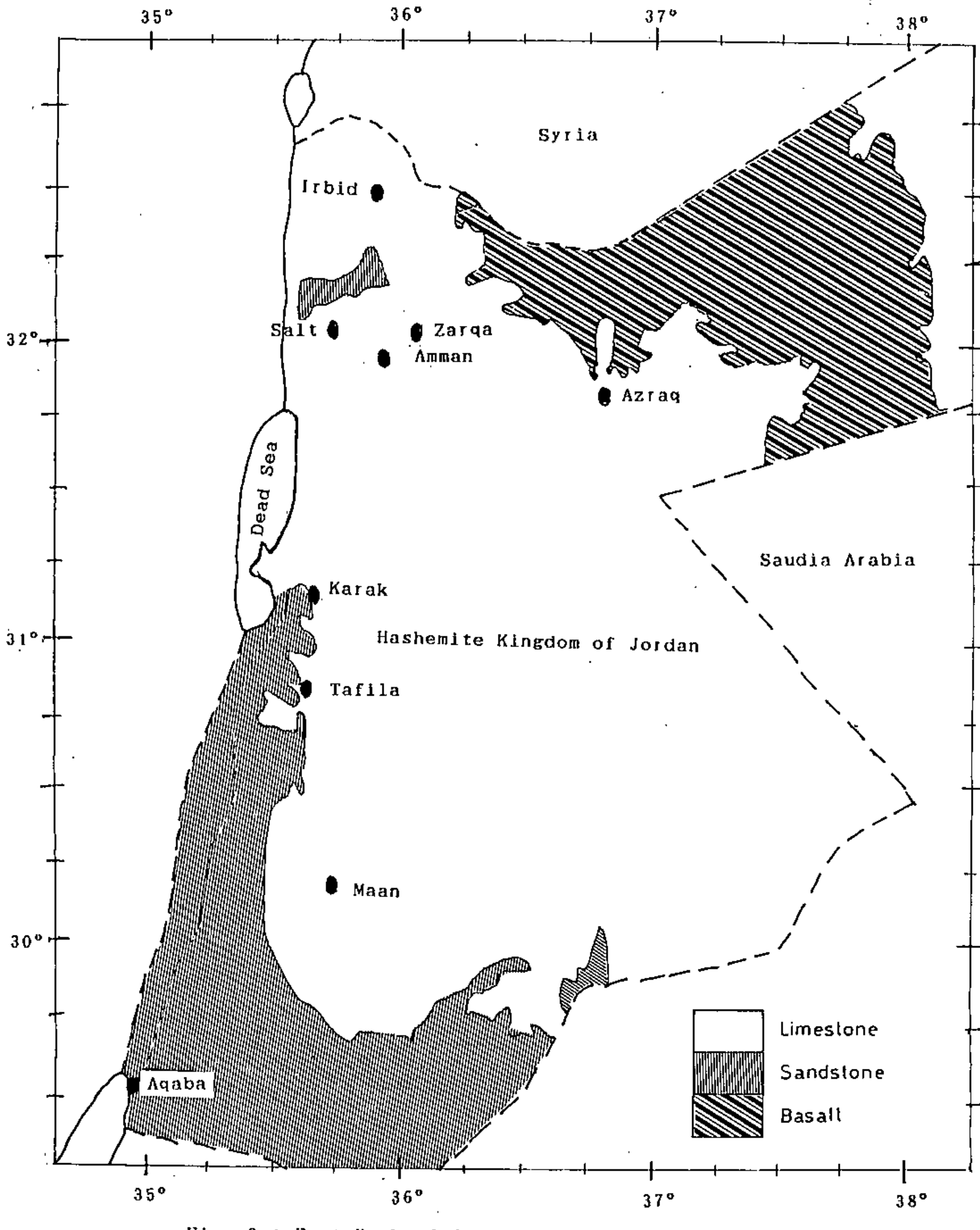

Fig. 3 : East Bank of Jordan Soil Parent Material Zones.

Table 5 : Areas of East Jordan Soils Parent Material Zones.

Soil Parent Material	Area	
	km^2	%
L (Limestone)	61233	72.2
B (Basalt)	10594	12.5
S (Sandstone)	12937	15.3
Total	84764	100.0

material occupies 72.2% (61233 Km^2) of the total areas. Basalt parent material occupies 12.5% (10594 Km^2), while Sandstone parent material occupies 15.3% (12937 Km^2).

<u>Combined zoning according to slope, annual rainfall and soil parent material</u>

The three agroclimatology parameters (slope, parent material and annual rainfall) are combined to produce a 35 distinguished agroclimate subunits representing the east bank of Jordan lands. Each of these subunit was given a code that includes the three parameters their classes, ie [LS1R2] is the code of a subunit which has a Limestone parent material (L) and a land slope of less than 8% (S1) and an average annual rainfall of 200~300mm (R3). Fig.4 shows a map of the distribution of these subunit over the east bank of Jordan lands. The total area in (Km^2) which each of the 35 subunits occupy is shown in Table 6. This classification will be the basis for studying land use and potential water requirements in Jordan . The characteristics of these agroclimatological subunits can be summarized as follows:-

[LS1R1] subunit :- This subunit has an extremely low value for agriculture. Its natural potential land use is for limited grazing only. This is mainly due in part to its shallowness for slope gradient more than 5% or to salinity of the soil and low rainfall with high carbonate content. Reclamation and leaching of soil is highly needed for any agricultural development. Less than 5% deep soils are found, sometimes it could be calcareous soil or having gypsum.

Table 6 : Areas of East Bank of Jordan Zones (Km^2) According to Slope Gradient, Mean Annual Rainfall and Soil Parent Material.

Parent Material Classes	L			B			S		
Slope Classes / Rainfall Classes	S1	S2	S3	S1	S2	S3	S1	S2	S3
	Km^2								
R1	45953	432	643	8010	0.0	0.0	7549	18	3203
R2	5949	483	1199	2470	0.0	0.0	302	17	736
R3	1553	326	1023	114	0.0	0.0	255	31	334
R4	1095	151	933	0.0	0.0	0.0	32	42	361
R5	336	88	536	0.0	0.0	0.0	0.0	2	55
R6	8	46	479	0.0	0.0	0.0	0.0	0.0	0.0

[LS1R2] subunit:- This subunit receives low level of effective rainfall due to high runoff. The soil is less problematic than the previous subunit, but are calcareous in deep areas. Beside water, the problem of desertification prevails. Pasture use in this subunit is of a major importance.

[LS1R3] subunit:- The pasture use in this area is of great importance. Soils of this subunit are deep with some rock out crops. Soil is not saline, not higly calcareous as LS1R2, proper management in addition to water greatly improve the soil productivity.

[LS1R4], [LS1R5] and [LS1R6] subunits:- These subunits are different in average annual rainfall receives. The soils of these subunits have a smooth relief and uniform soil conditions with an excellent water storage. Therefor, soils of these units are suitable for agriculture. Wheat is planted as dominant crop in these subunits.

[LS2R1] and [LS2R2] subunits:- These subunits are different in the average annual rainfall receives. Soils of these subunits are usually shallow, gravelly, light in texture and calcareous. They have little agriculture value. The vegetation, if present, is of low quality for grazing.

[LS2R3], [LS2R4], [LS2R5] and [LS2R6] subunits:- The soils of these subunits are usually shallow due to high slope, while soil may be deep in pockets. The major land use of these subunits are suitable for pasture and forests.

[LS3R1], [LS3R2], [LS3R3], [LS3R4], [LS3R5] and [LS3R6] subunits:- In general, the soils of these subunits are not suitable for cultivation due to its shallowness and steep slope.

[BS1R1], [BS1R2] and [BS1R3] subunits:- Soils of these subunits are deep, saline and stoney. Shallowness problem may be present where slope is more than 5%. Reclamation and leaching of the soil is highly needed for any agricultural development.

[SS1R1] and [SS1R2] subunits:- The lands of these subunits is used for grazing. The soils are suitable for any agricultural development if the water for irrigation is provided.

[SS1R3] and [SS1R4] subunits:- The soils of these subunits are limestone affected by sandstone. The sandy texture is mainly present at these subunits. The lands of these subunits are suitable for any agricultural development.

[SS2R1], [SS2R2] and [SS2R3] subunits:- The soils of these subunits are not suitable for agriculture due to its shallowness and rockiness. No cultivation is found on these subunits.

[SS2R4] and [SS2R5] subunits:- The soils of these subunits are limestone affected by sandstone. The sandy texture is dominant at these subunits. These lands are not suitable for agriculture due to the shallowness, gravels and rockiness of the soil. These subunits are under pasture use.

[SS3R1], [SS3R2] and [SS3R3] subunits:- Soils of these subunits are very shallow and rocky, therefor these subunits are not suitable for agriculture.

[SS3R4] and [SS3R5] subunits:- The soils of these subunits are limestone affected by sandstone. The sandy texture are present at these subunits. These soils are very shallow and rocky and are used as range.

POTENTIAL WATER REQUIREMENTS

Estimating Potential Evapotranspiration(ETP):

Penman, Blaney-Criddle, Jensen-Haise and Hargreaves methods were utilized in computing monthly values of ETP from corresponding climatic records observed at eight stations.

Reference ETP was developed from pan evaporation data at each station. Pan coefficients were determined and applied to pan evaporation records to get pan ETP .

The estimated pan coefficient (Kp) for the different station are found in Table 7. Pan coefficient (Kp) of 0.8 is used for Deir Alla, Wadi Dhuliel. El-Baqura, Ghor El-Safi, El-Shoubak and Wad El-Yabis stations, 0.75 for El-Rabba and Irbid stations and 0.6 for all desert stations.

Figures 5 through 12 show the estimated ETP by the Penman, Blaney-Criddle, Jensen-Haise and Hargreaves methods. On the same figures Pan ETP was plotted for comparison. ETP tables 1 through 8 that may be found in the appendix is used in plotting the figures.

Table 7 : Pan coefficient (Kp) for class A pan evaporation at different stations and months of the year.

Station / Month	El-Rabba	Deir Alla	Irbid	Wadi Dhuleil	El-Baqura	Ghor El-Safi	El-Shoubak	Wadi El-Yabis	Desert Stations
Jan.	0.75	0.75	0.85	0.80	0.75	0.80	0.85	0.80	0.60
Feb.	0.75	0.80	0.75	0.80	0.80	0.80	0.80	0.80	0.60
Mar.	0.75	0.80	0.75	0.80	0.80	0.80	0.80	0.80	0.60
Apr.	0.75	0.80	0.75	0.80	0.80	0.80	0.80	0.80	0.60
May.	0.75	0.80	0.75	0.80	0.80	0.80	0.80	0.80	0.60
June	0.75	0.80	0.75	0.80	0.80	0.80	0.80	0.80	0.60
July	0.75	0.80	0.75	0.80	0.80	0.80	0.80	0.80	0.60
Aug.	0.75	0.80	0.75	0.80	0.80	0.80	0.80	0.80	0.60
Sep.	0.75	0.80	0.75	0.80	0.80	0.80	0.80	0.80	0.60
Oct.	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.60
Nov.	0.75	0.80	0.75	0.80	0.80	0.80	0.80	0.80	0.60
Dec.	0.75	0.75	0.75	0.85	0.80	0.80	0.80	0.80	0.60

Comparison and Evaluation of ETP Estimation Methods:

Evaporation pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on evaporation from an open water surface . It is the only direct method used in this investigation for measuring ETP . Class A pan evporation is used as a refernce to compare, evaluate and rank the suitability of Penman, Blaney-Criddle, Jensen-Haise and Hargreaves methods, for estimating ETP at the eight different agrometeorological stations . Monthly and annual deviation of ETP estimated using emperical methods from class A pan evaporation, have been computed and are shown in Tables 8 through 16. The percentage of deviation is computed as follows:

$$\% \text{ of deviation} = \frac{\text{ETP (class A pan)} - \text{ETP (method)}}{\text{ETP (class A pan)}} \times 100$$

The smaller the deviation the closer the methods estimation of ETP to pan ETP. Negative and positive values however, indicate under or over estimation of ETP respectively.

Following, is a comparison and evaluation of each of the methods at the different agrometeorological stations considered:-

El-Rabba Station: Figure 5 shows the mean monthly ETP estimated by different methods and determined by class A pan method at El-Rabba station . Deviation of ETP estimates, using emperical methods from that of class A pan at El-Rabba station are shown in Table 8.

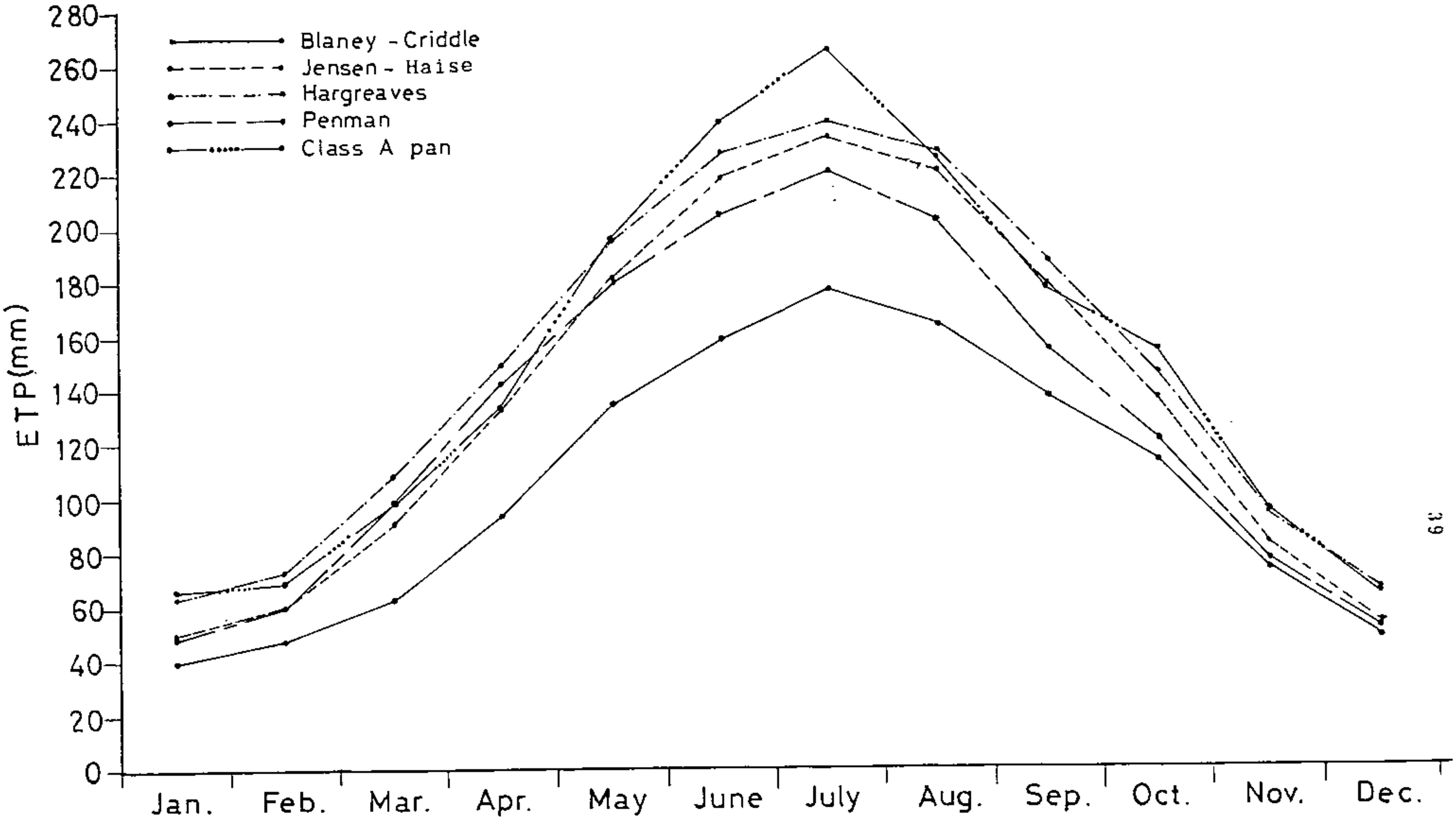

Fig. 5 : Mean Monthly Potential Evapotranspiration (ETP) Estimated by Emperical Methods and that Determined by Class A Pan at El-Rabba Station.

Table 8 :Deviations of Estimated ETP Using Emporical Methods from that of Class A pan at El-Rabba station.

Month	Class A pan	Penman	Blaney-Crddile	Jensen-Haise	Harg-reaves
	(mm)	----------	----------	(%) ----------	----------
Jan.	66	-27.3	-39.4	-25.8	- 4.5
Feb.	68	-11.8	-30.9	-11.8	+ 7.4
Mar.	98	+ 1.0	-35.7	- 7.1	+10.2
Apr.	134	+ 6.7	-29.9	- 0.8	+11.2
May	195	- 7.2	-30.8	- 6.7	- 0.5
June	238	-13.9	-33.2	- 8.4	- 4.6
July	256	-17.0	-33.2	-12.5	- 9.8
Aug.	225	-10.2	-27.1	- 2.2	+ 0.9
Sep.	177	-13.0	-23.2	+ 1.1	+ 5.7
Oct.	154	-21.4	-26.6	-11.7	- 5.8
Nov.	94	-18.1	-22.3	-12.8	- 1.1
Dec.	65	-21.5	-24.6	-16.9	0.0
Annual	1779	-12.3	-29.7	- 8.0	- 0.5

The monthly values of ETP obtained by Hargreaves, Jensen-Haise and Penman methods are very close to that of class A pan from August through May. All methods under estimate ETP, but still Hargreaves and Jensen-Haise are the best.

Blaney-Criddle method under estimates ETP over all months of the year by an average of 30% . The domination of temperature term in the equation under relatively low temperature in that area and the ignorance of the other climatic factors may be the reason.

The Penman method gave lower values of ETP during summer months, however the deviation from class A pan is much less than that for Blaney-Criddle.

The difference of Jensen-Haise and Hargreaves estimates from that of pan evaporation is so narrow and can not be significant over all months of the year .

Based on annual trends in deviation of ETP,estimated by emperical methods from that of class A pan, it can be concluded that Hargreaves and Jensen-Haise methode can gave good estimate of ETP in El-Rabba station and may be recommended for use at this station and representative areas.

Deir Alla Station: Figure 6 shows the mean monthly ETP estimated by different methods and class A pan evaporation at Deir Alla station. Deviation, of ETP estimates, using emperical methods from that of class A pan, at Deir Alla station are shown in Table 9.

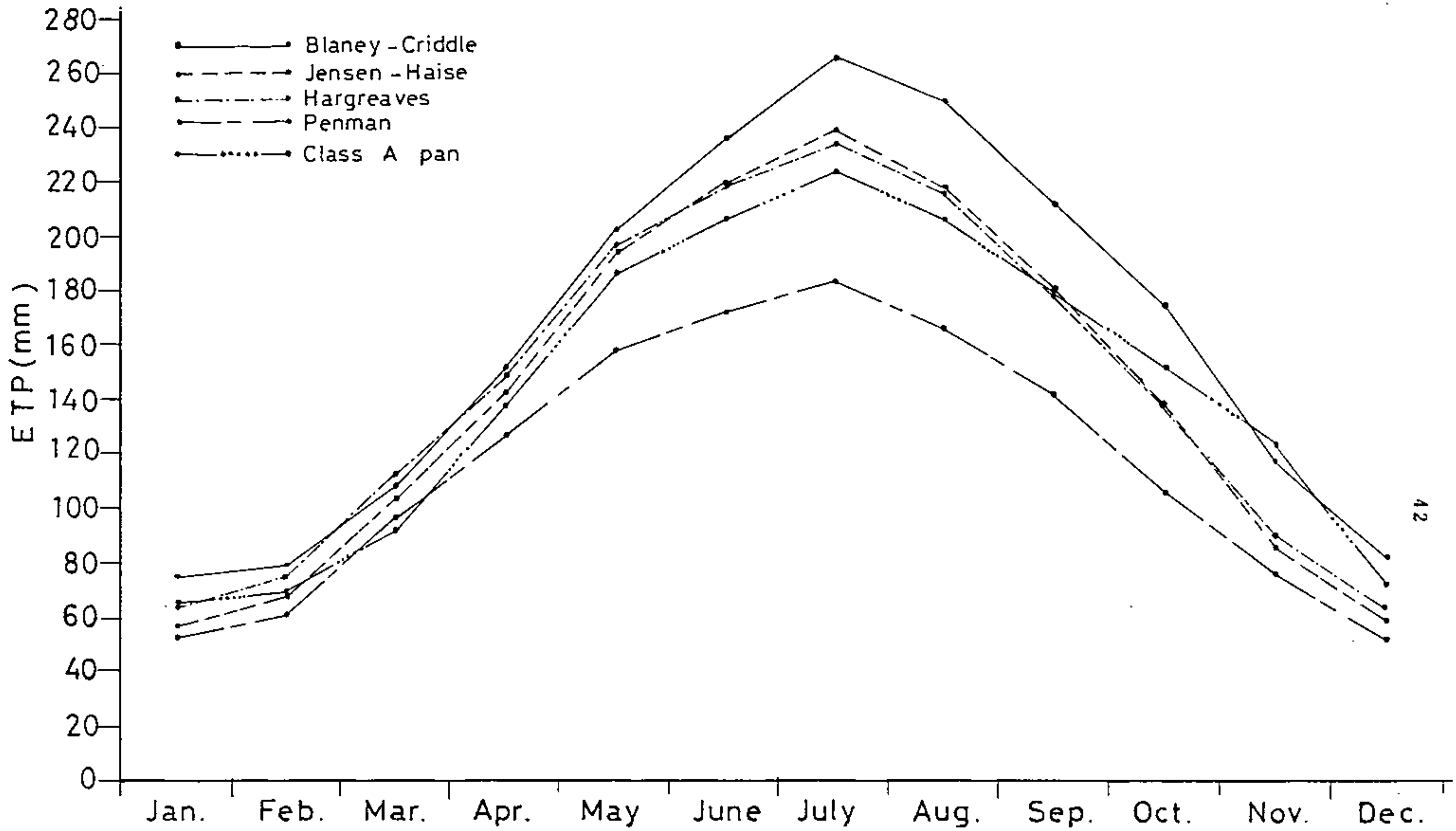

Fig. 6 : Mean Monthly Potential Evapotranspiration (ETP) Estimated by Emperical Methods and that Determined by Class A Pan at Deir Alla Station.

Table 9 :Deviations of Estimated ETP Using Emperical Methods from that of Class A pan at Deir Alla station.

Month	Class A pan	Penman	Blaney-Crddile	Jensen-Haise	Harg-reaves
	(mm)	------------------	(%)	------------------	
Jan.	66	-19.7	+13.6	-13.6	- 3.0
Feb.	69	-11.6	+14.5	- 0.2	+ 8.7
Mar.	92	+ 4.3	+17.4	+13.0	+22.8
Apr.	138	- 8.0	+10.1	+ 3.6	+ 7.2
May	187	-15.5	+ 8.6	+ 4.3	+ 5.3
June	206	-16.5	+15.0	+ 0.8	+ 6.3
July	224	-17.9	+19.2	+ 7.1	+ 4.9
Aug.	207	-19.3	+21.3	+ 5.3	+ 4.3
Sep.	180	-20.6	+18.3	+ 0.6	- 0.6
Oct.	152	-30.3	+15.8	- 9.2	- 9.2
Nov.	124	-38.6	- 4.8	-30.6	-27.4
Dec.	73	-28.8	+13.7	-19.2	-12.3
Annual	1718	-18.8	+14.2	- 0.5	+ 1.2

The monthly values of ETP obtained by Hargreaves and Jensen-Haise equations, are in good agreement with class A pan values over the entire year.

Blaney-Criddle method over estimated ETP through the year by an average of 14.2% . Over estimation was maximum during summer months where the dominant parameter (temperature) in the equation is high . On the other hand, Penman method under estimated ETP by an average of 18.8% distributed over most of the year .

Based on annual trends of ETP deviation, estimated by emperical methods from class A pan, the Jensen-Haise and Hargreaves methods gave best estimate of the ETP at this station. Therefore, it recommended that Jensen-Haise or Hargreaves methods be used to estimate ETP at this station and similar areas.

Irbid Station: Figure 7 shows the mean monthly ETP estimated by different methods, and class A pan at Irbid station. Deviation of ETP estimates, using emperical methods from that of class A pan at Irbid station are shown in Table 10.

The Jensen-Haise and Hargreaves methods gave a good estimates of ETP over most of the year . However Hargreaves showed better agreement during the second half of the year where Jensen-Haise were close to class A pan values in the first half of the year .

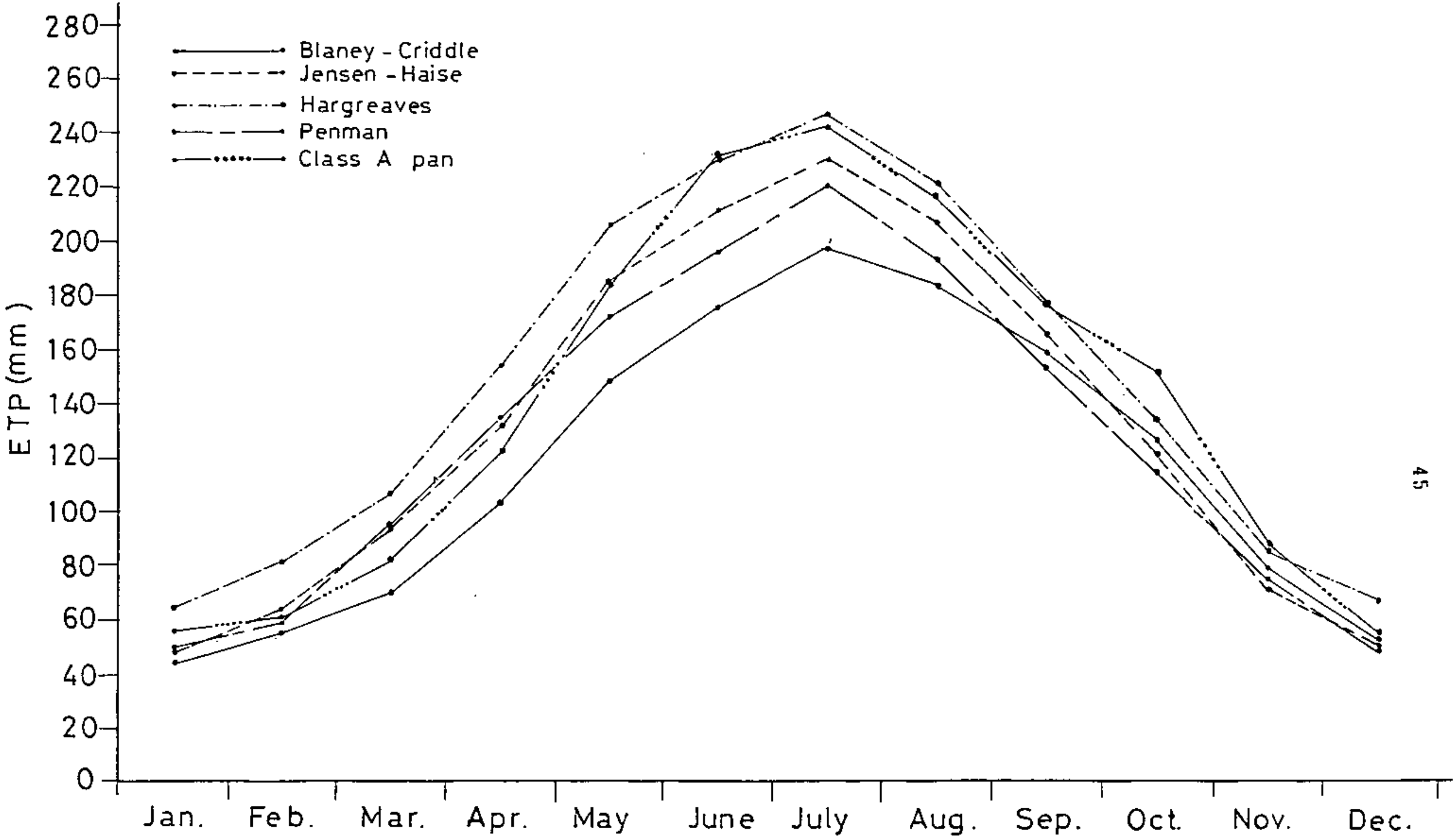

Fig. 7 : Mean Monthly Potential Evapotranspiration (ETP) Estimated by Emperical Methods and that Determined by Class A Pan at Irbid Station.

Table 10: Deviations of Estimated ETP Using Emperical Methods from that of Class A Pan at Irbid station.

Month	Class A pan	Penman	Blaney-Crddile	Jensen-Haise	Harg-reaves
	(mm)	(%)			
Jan.	56	-12.5	-21.4	-14.3	+14.3
Feb.	60	- 1.7	- 8.3	+ 6.7	+35.0
Mar.	83	+14.5	-16.9	+12.0	+39.8
Apr.	112	+ 9.8	-15.6	+ 7.4	+26.2
May	184	- 6.0	-19.6	+ 0.5	+12.0
June	230	-14.8	-23.9	- 8.3	- 0.4
July	242	- 9.1	-18.6	- 5.0	+ 1.2
Aug.	216	-10.6	-15.3	- 4.6	+ 1.9
Sep.	177	-13.6	-10.2	- 6.8	0.0
Oct.	151	-23.8	-16.6	-19.9	-11.3
Nov.	86	-12.8	- 9.3	-18.6	- 2.3
Dec.	54	-11.1	- 3.7	- 5.6	+22.2
Annual	1661	- 9.1	-16.4	- 5.2	+ 6.9

Blaney-Criddle method under estimates ETP through the year by an average of 16.4%. Where penman method showed relatively reasonable estimates except during summer months where it under estimated ETP .

Based on annual trends in deviation of ETP, estimated by emperical methods from that of class A pan the Jensen-Haise and Hargreaves methods has the best estimates of ETP at this station. On the other hand, Blaney-Criddle method was the poorest in the estimation of ETP.

The Jensen-Haise or Hargreaves methods may be recommended for estimating ETP at this station and other similar areas .

Wadi Dhuliel Station: Figure 8 shows the mean monthly ETP estimated by different methods and class A pan at Wadi Dhuliel station. Deviation of ETP estimates using emperical methods from that of class A pan are shown in Table 11.

Hargreaves method estimated ETP during all month of the year with a very close agreement with pan ETP. Penman and Blaney-Criddle methods have significantly under estimated ETP over most of the year with an overall average of 20.2% and 17.6%, respectively . On the other hand, Jensen-Haise method over estimate ETP for all months of the year, by an average of 12.9%. That was particularly clear during the summer months .

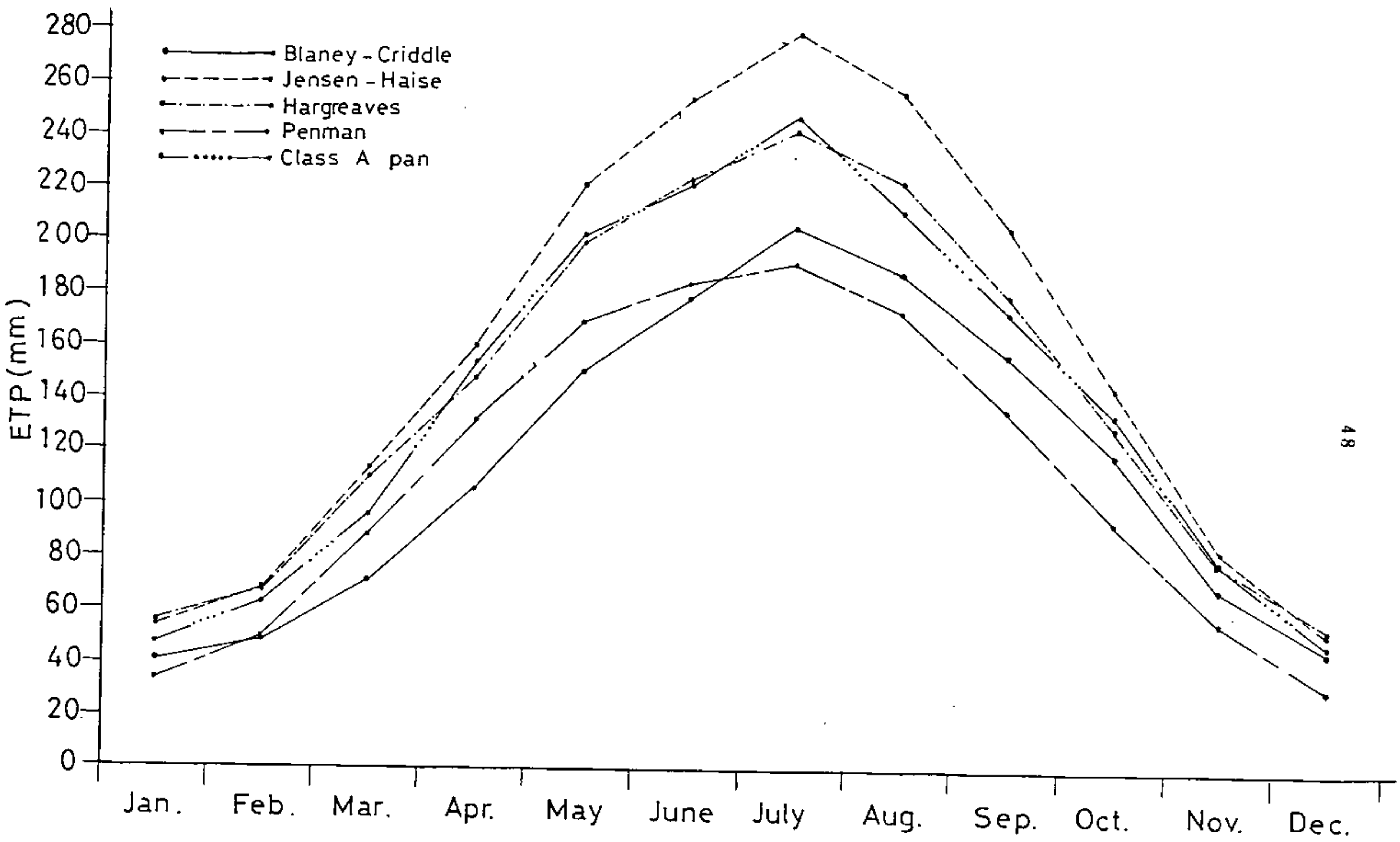

Fig. 8 : Mean Monthly Potential Evapotranspiration (ETP) Estimated by Emperical Methods and that Determined by Class A Pan at Wadi Dhuleil Station.

Table 11 :Deviations of Estimated ETP Using Emperical Methods from that of Class A pan at Wadi Dhuleil station.

Month	Class A pan	Penman	Blaney-Crddile	Jensen-Haise	Harg-reaves
	(mm)	--------	--------	(%) --------	--------
Jan.	47	-29.8	-12.8	+14.9	-19.1
Feb.	62	-22.6	-22.6	+ 9.7	+ 9.7
Mar.	95	- 7.4	-25.3	+20.0	+16.8
Apr.	154	-14.3	-31.2	+ 3.9	- 3.9
May	202	-16.3	-25.2	+ 9.9	- 1.0
June	222	-16.7	-19.4	+14.4	+ 0.9
July	247	-22.3	-16.6	+13.0	- 1.6
Aug.	213	-18.3	-11.3	+20.7	+ 5.2
Sep.	174	-21.3	- 9.2	+17.8	+ 3.4
Oct.	135	-29.6	-11.1	+ 7.4	+ 3.7
Nov.	80	-30.0	-13.8	+ 5.0	0.0
Dec.	48	-35.4	- 6.3	+10.4	+12.5
Annual	1679	-20.2	-17.6	+12.9	+ 2.3

Based on annual trends in deviation of ETP, estimated by emperical methods from that of class A pan, the Hargreaves method can strongly be recommended for ETP estimation at this station and representative areas.

El-Baqura Station: Figure 9 shows the mean monthly ETP estimated by different methods and class A pan at El-Baqura station. Deviation of ETP estimates, using emperical methods from class A pan evaporation, at El-Baqura station are shown in Table 12.

It can be seen that both Jensen-Haise and Hargreaves methods gave good estimates of ETP during all months of the year. Blaney-Criddle and Penman methods have over and under estimated ETP through the year by an average of 16.7% and 18.5% respectively. Based on annual trends in deviation of ETP, estimated by emperical methods from that of class A pan, the Jensen-Haise method has the best estimated ETP at this station, followed by Hargreaves method. Both methods are recommended for use in estimating ETP at this station and representative areas.

Ghor El-Safi station: Figure 10 shows the mean monthly ETP estimated by different methods and class A pan at Ghor El-Safi stations. Deviations of ETP estimates using emperical methods from class A pan at Ghor El-Safi station are shown in Table 13.

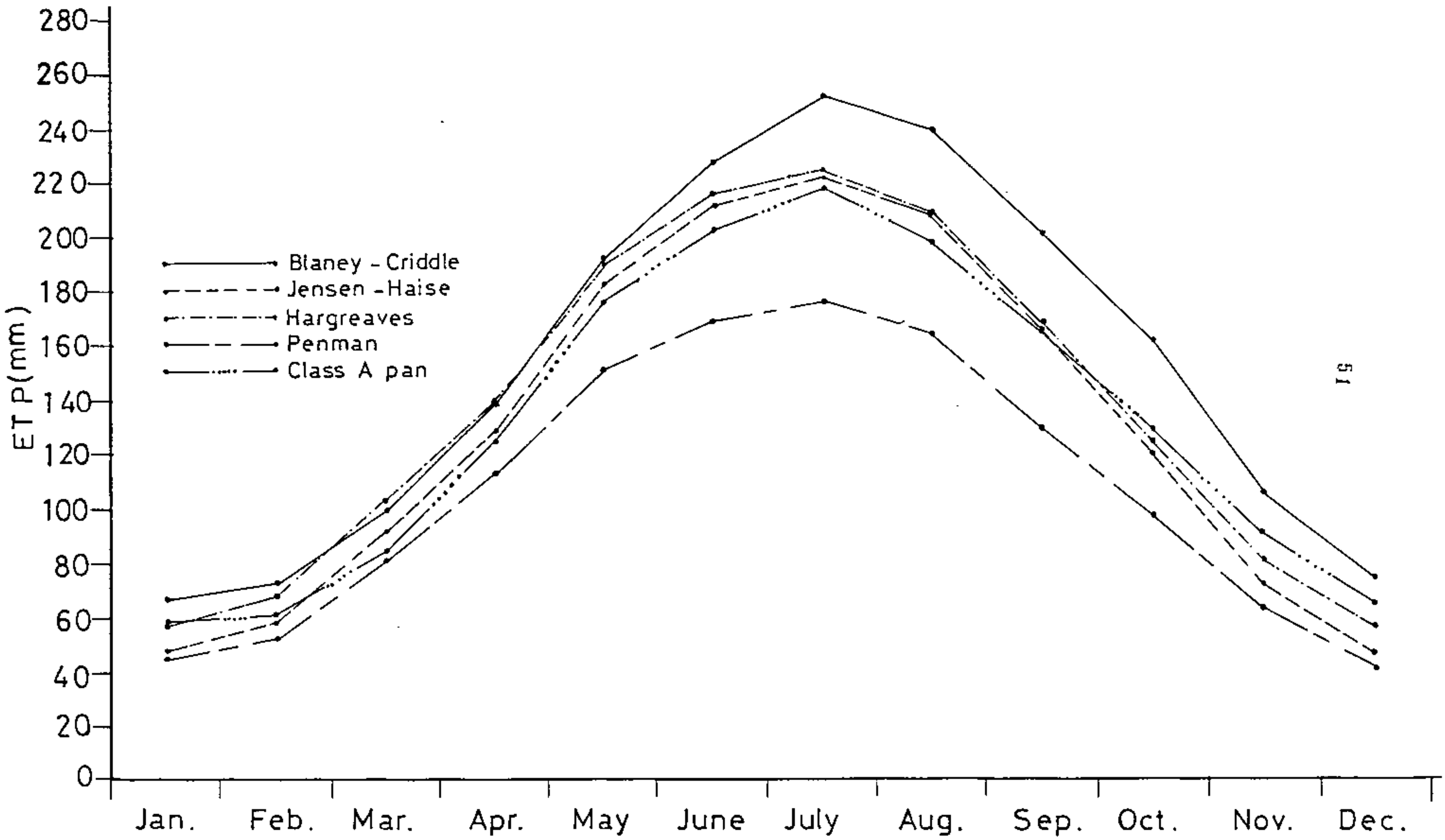

Fig. 9 : Mean Monthly Potential Evapotranspiration (ETP) Estimated by Emperical Methods and that Determined by Class A Pan at El-Baqura Station.

Table 12 :Deviations of Estimated ETP Using Emperical Methods from that of Class A pan at El-Baqura station.

Month	Class A pan	Penman	Blaney-Crddile	Jensen-Haise	Harg-reaves
	(mm)	------------------(%)------------------			
Jan.	58	-22.4	+15.5	-17.2	- 1.7
Feb.	60	-13.3	+21.7	- 1.7	+11.7
Mar.	84	- 3.6	+19.0	+ 9.5	+22.6
Apr.	125	- 9.6	+10.4	+ 3.2	+10.4
May	176	-14.2	+ 9.2	+ 4.0	+ 8.0
June	203	-16.7	+12.3	+ 4.4	+ 6.4
July	218	-19.3	+15.6	+ 1.8	+ 2.8
Aug.	199	-17.1	+20.1	+ 4.0	+ 5.0
Sep.	166	-21.7	+21.7	- 0.6	+ 1.2
Oct.	129	-24.0	+26.4	- 7.0	- 3.1
Nov.	91	-30.8	+16.5	-20.9	-11.0
Dec.	65	-38.5	+15.4	-29.2	-13.8
Annual	1574	-18.5	+16.6	- 1.2	+ 3.8

Blaney-Criddle equation showed good estimate of ETP as compared with pan ETP over most of the year. On the other hand Penman was poorest since it under estimated ETP over all months of the year by an average of 19.5%. Hargreaves and Jensen-Haise methods gave reasonable estimates but not as good as Blaney-Criddle. Based on annual trends in the deviations of ETP estimated by emperical methods from class A pan evaporation, the Blaney-Criddle method has best estimated ETP at this station. It is recommended that this method be used for this station and representative areas.

El-Shoubak station: Figures 11 shows the mean monthly ETP estimated by different methods from class A pan at El-Shoubak station. Deviations of ETP estimates, using emperical methods from class A pan at El-Shoubak station are shown in Table 14.

Penman method shows the best agreement with pan ETP during all months of the year . Jensen-Haise and Hargreaves methods over estimated ETP for all months of the year by an average of 16.1% and 18.3% respectively . On the other hand, Blaney-Criddle method under estimated ETP over all months of the year by an average of 33.4% .

Based on annual trends in the deviations of ETP estimated by emperical methods from class A pan evaporation, the Penman method has best estimated the ETP at this station, followed by Jensen-Haise method . On the other hand, Blaney- Criddle method

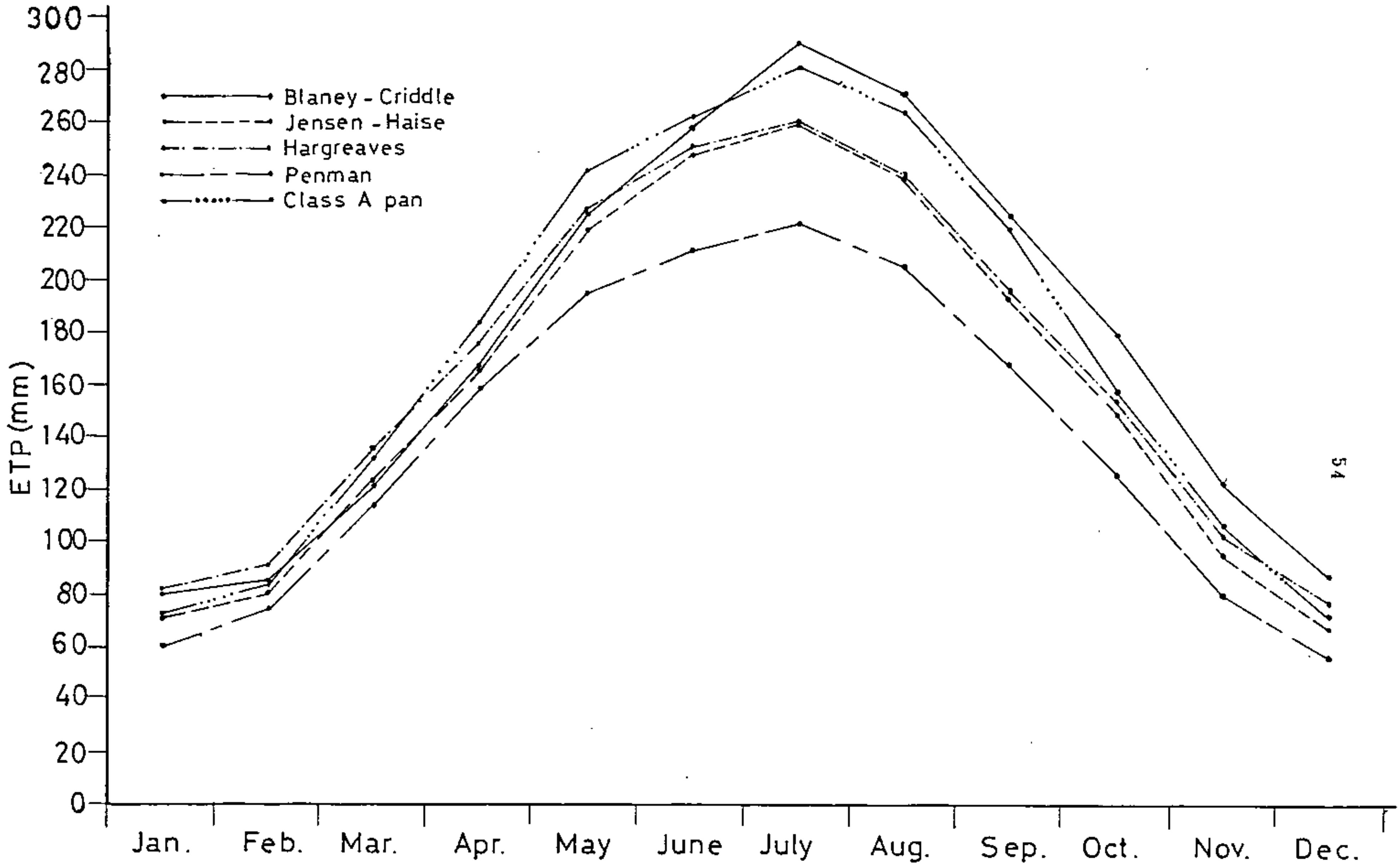

Fig. 10: Mean Monthly Potential Evapotranspiration (ETP) Estimated by Emperical Methods and that Determined by Class A Pan at Ghor El-Safi Station.

Table 13 :Deviations of Estimated ETP Using Emperical Methods from that of Class A pan at Ghor El-Safi station.

Month	Class A pan	Penman	Blaney-Crddile	Jensen-Haise	Harg-reaves
	(mm)	-----------------	(%)	-----------------	
Jan.	72	-16.7	+11.1	- 1.4	+13.9
Feb.	83	-10.8	+ 2.4	- 3.6	+ 9.6
Mar.	132	-13.6	- 7.6	- 6.8	+ 3.0
Apr.	184	-14.1	- 9.2	- 9.8	- 4.3
May	242	-1.94	- 6.6	- 9.5	- 6.2
June	262	-19.1	- 1.1	- 5.3	- 3.8
July	282	-20.9	+ 3.2	- 7.8	- 7.4
Aug.	265	-22.3	+ 2.3	- 9.8	- 9.1
Sep.	220	-23.2	+ 2.7	_12.3	-11.4
Oct.	158	-20.2	+14.2	- 5.7	- 2.5
Nov.	106	-23.6	+16.0	- 9.4	- 2.8
Dec.	73	-23.3	+20.5	- 6.8	+ 5.5
Annual	2079	-19.5	+ 1.9	- 8.0	- 4.0

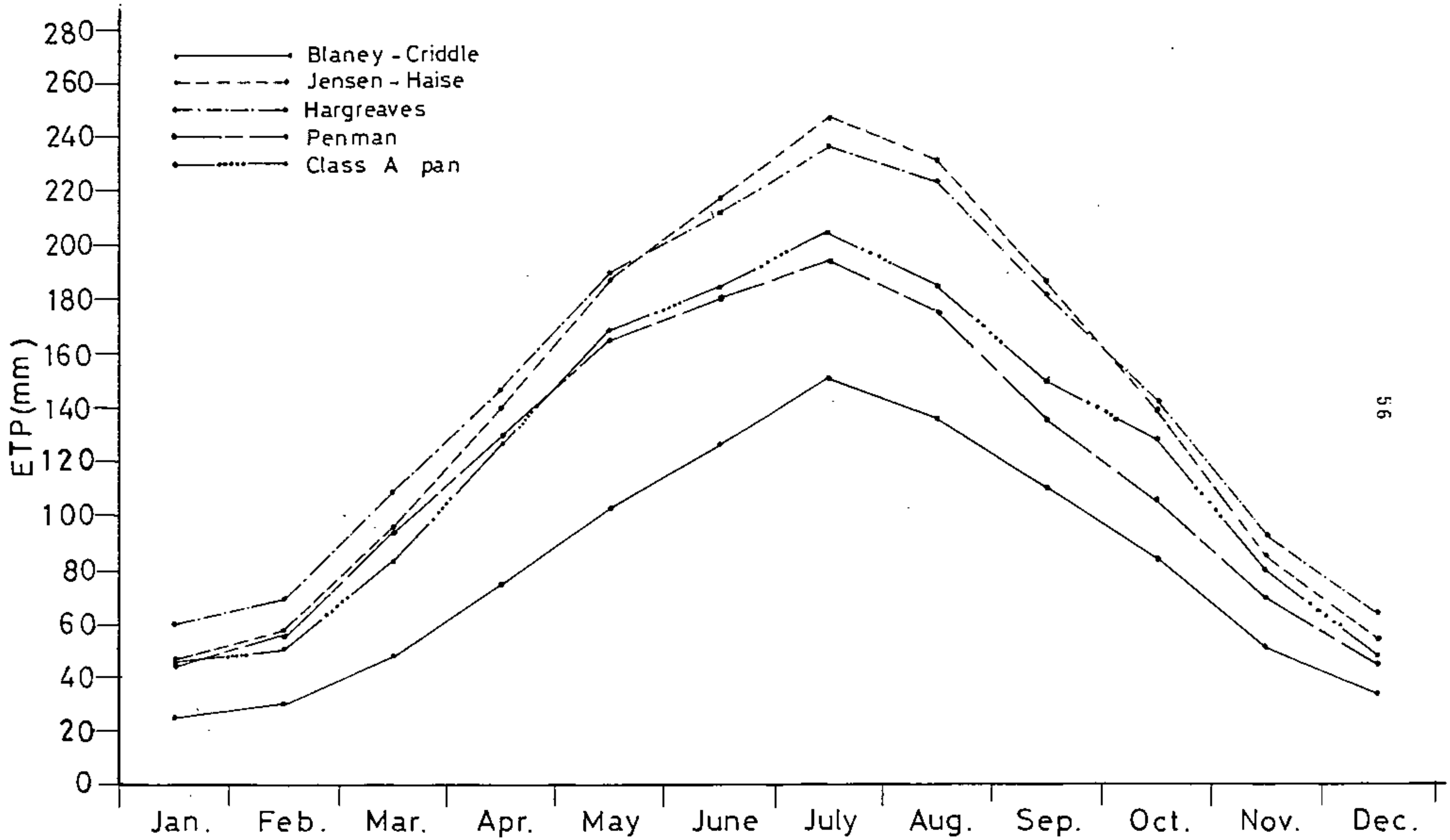

Fig. 11: Mean Monthly Potential Evapotranspiration (ETP) Estimated by Emperical Methods and that Determined by Class A Pan at El-Shoubak Station.

Table 14 :Deviations of Estimated ETP Using Emperical Methods from that of Class A pan at El-Shoubak station.

Month	Class A pan	Penman	Blaney-Crddile	Jensen-Haise	Harg-reaves
	(mm)	------------	------------	(%) ------------	------------
Jan.	46	- 2.2	-43.5	+ 2.2	+28.3
Feb.	51	+ 7.8	-41.2	+11.8	+35.3
Mar.	83	+13.2	-43.4	+14.5	+31.3
Apr.	127	+ 2.4	-41.7	+10.2	+15.0
May	168	- 1.8	-38.7	+11.9	+12.5
June	185	- 2.2	-31.9	+17.3	+14.6
July	205	- 5.4	-26.3	+21.0	+15.1
Aug.	185	- 5.4	-26.5	+26.5	+20.5
Sep.	149	- 8.0	-26.8	+25.5	+21.5
Oct.	128	-17.2	-34.4	+ 9.4	+10.2
Nov.	80	-13.8	-37.5	+ 5.0	+15.0
Dec.	48	- 8.3	-31.2	+12.5	+33.3
Annual	1455	- 4.1	-33.4	+16.1	+18.3

is the poorest in the estimation of ETP . The penman method is recommended for use in estimating ETP at this station and the representing areas

Wad El-Yabis station: Figure 12 shows the mean monthly ETP estimated by different methods and pan ETP at Wad El-Yabis station. Deviations of ETP estimates using emperical methods from class A pan evaporation at Wad El-Yabis station is shown in Table 15.

The monthly values obtained by Jensen-Haise and Hargreaves methods are in good agreement with that of class A pan during July to December . The Penman methods gave good estimate of ETP from February to June and under estimates ETP from July to December. On the other hand Blaney-Criddle method over estimated ETP for all months of the year by an average of 9.4%.

Based on annual trends in the deviations of ETP estimated by emperical methods from that of class A pan, the Jensen-Haise Hargreaves method. Jensen-Haise method is recommended for use in estimating ETP at this station and representative areas.

Desert Stations: ETP determined from class A pan evaporation data at the desert stations Um El-Jemal, Qa Disi, Azraq, Rueished (H-4) and Bayir stations are shown in Table 16.

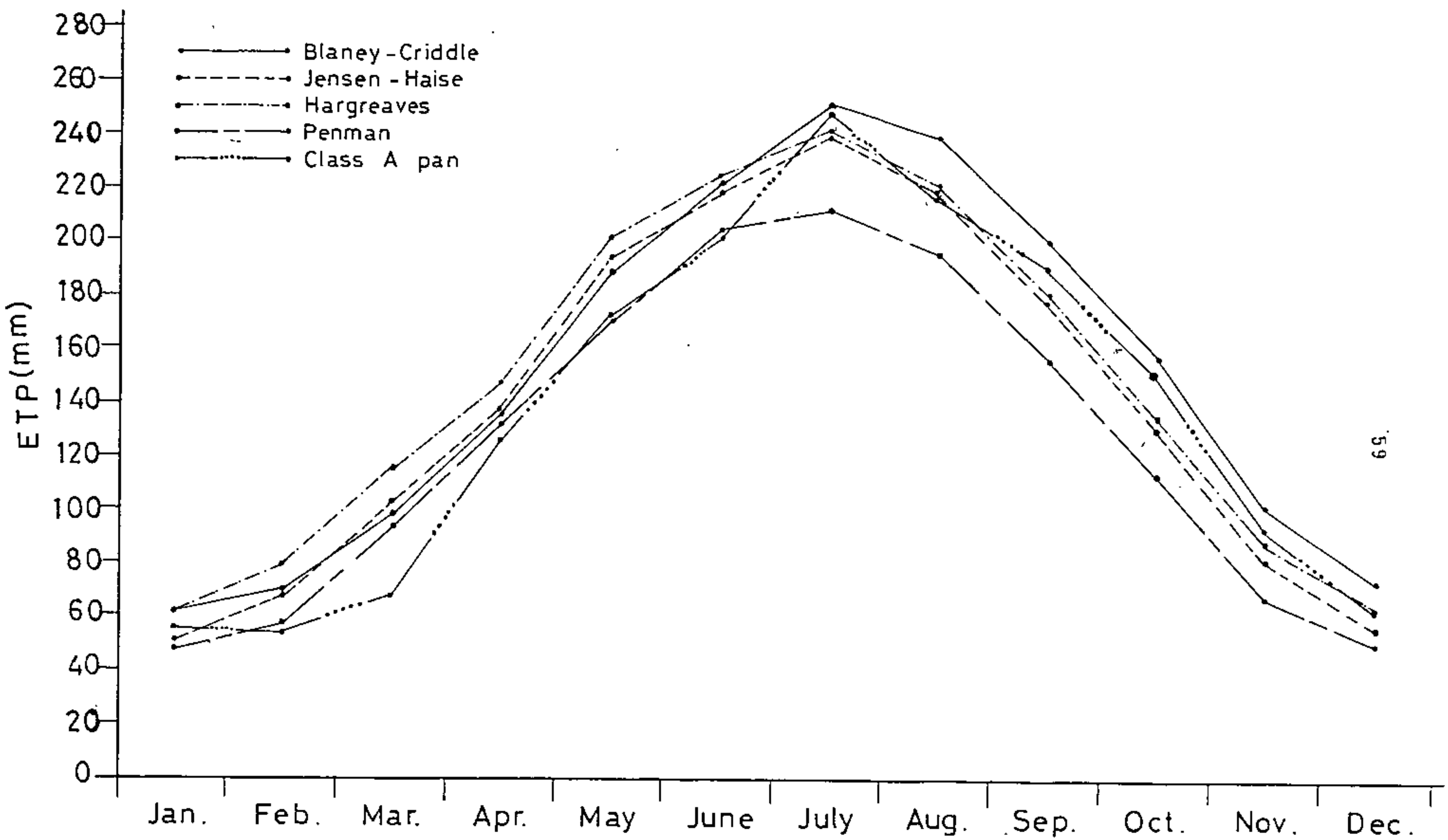

Fig. 12: Mean Monthly Potential Evapotranspiration (ETP) Estimated by Emperical Methods and that Determined by Class A Pan at Wad El-Yabis Station.

Table 15 :Deviations of Estimated ETP Using Emperical Methods from that of Class A pan at Wad El-Yabis station.

Month	Class A pan	Penman	Blaney-Crddile	Jensen-Haise	Harg-reaves
	(mm)	-------------------	(%)	-------------------	
Jan.	55	-10.9	+14.5	- 7.3	+12.7
Feb.	53	+ 7.5	+32.1	+28.3	+50.9
Mar.	68	+38.2	+42.6	+51.5	+70.6
Apr.	126	+ 4.8	+ 7.9	+ 8.7	+16.7
May	183	- 1.1	+ 3.3	+ 5.5	+ 9.8
June	203	+ 1.0	+ 8.9	+ 7.9	+10.3
July	249	-14.9	+ 1.2	- 3.6	- 3.2
Aug.	218	- 9.6	+ 9.6	+ 0.5	+ 0.9
Sep.	191	-17.8	+ 4.7	- 7.3	- 5.8
Oct.	151	-24.5	+ 4.0	-13.9	-11.3
Nov.	93	-28.0	+ 8.6	-12.9	- 4.3
Dec.	55	- 9.1	+34.5	+ 1.8	+18.2
Annual	1645	- 7.9	+ 9.4	+ 1.8	+ 6.9

Azraq station shows the highest value of annual ETP, followed by Bayir station, while Um El-Jemal station shows the lowest value. These values of ETP will be used for estimating water requirements at the corresponding subunits.

Table 16: Mean Monthly Potential Evapotranspiration (ETP) Determined from Class A Pan Evaporation Data at Five Desert Stations.

Month	Um El-Jemal	Qa-Disi	Azraq	H-4	Bayir
Jan.	60	73	63	57	78
Feb.	71	95	89	88	105
March	110	147	152	143	150
April	149	181	202	185	176
May	209	251	290	236	256
June	253	295	351	278	307
July	268	307	366	295	320
Aug.	254	278	341	273	295
Sep.	208	232	262	221	245
Oct.	146	166	187	167	175
Nov.	97	110	98	94	101
Dec.	61	81	66	69	83
Total	1886	2216	2467	2106	2291

Cited from National Water Master Plan of Jordan, Volume III.

Potential Water Requirements:

The annual potential water requirement (WRP) for different established subunits were computed according to differences between the annual potential evapotranspiration(ETP), determined by class A pan evaporation method and the potential annual rainfall (RP).

$$WRP = ETP - RP$$

The resulted values of (WRP) presented in Table 17. It can be observed that subunits [LS1R1], [LS2R1], [LS3R1], [LS3R2], [BS1R1], [SS1R1], [SS1R2], [SS2R1], [SS2R2], [SS3R1] and [SS3R2] were located in areas of high water requirements (more than 2.000 MCM/Km^2) due to having low rainfall (less than 200 mm/annual) and high ETP. Areas represent at these subunits are Bayir, Azraq, Qa Disi, H-4 and Ghor El-Safi. The water requirements estimated for subunits [LS1R5], [LS1R6], [LS2R5], [LS2R6], [LS3R5], [LS3R6], [SS2R5] and [SS3R5] range from 1.111 to 1.211 MCM/Km^2 . These subunits have the lowest values of (WRP) due to relatively high rainfall (more than 400 mm/annual) and low ETP.

The remaining subunits showed moderate water requirements due to rainfall which ranges from 200 mm/annual to 400 mm/annual and also due to ETP determined at the stations representing these subunits.

Table 17: Annual Potential Water Requirements for Established Subunits.

Subunit	Representative Stations	Potential Water Requirement MCM/Km²
LS1R1	Bayir	2.241
	Azraq	2.417
LS1R2	Deir Alla	1.568
	Wadi Dhuliel	1.529
LS1R3	Deir Alla	1.468
	Wadi Dhuliel	1.429
LS1R4	Irbid	1.311
	El-Baqura	1.224
	Wad El-Yabis	1.295
LS1R5	Irbid	1.211
LS1R6	Irbid	1.111
LS2R1	Azraq	2.417
LS2R2	Wadi Dhuliel	1.529
LS2R3	Wadi Dhuliel	1.429
LS2R4	Irbid	1.311
LS2R5	Irbid	1.211
LS2R6	Irbid	1.111
LS3R1	Bayir	2.066
LS2R2	Qa Disi	2.066

cont .

Continue Table 17.

Subunit	Representative Station	Potential Water Requirement MCM/Km²
LS3R3	El-Shoubak	1.205
	EL-Rabba	1.529
LS3R4	Irbid	1.311
	El-Shoubak	1.105
	El-Rabba	1.429
LS3R5	Irbid	1.211
LS3R6	Irbid	1.111
BS1R1	H-4	2.056
BS1R2	Um El-Jemal	1.736
BS1R3	Um El-Jemal	1.636
SS1R1	Qa Disi	2.166
	Ghor El-Safi	2.029
SS1R2	Qa Disi	2.066
SS1R3	Deir Alla	1.468
SS1R4	Deir Alla	1.368
SS2R1	Qa Disi	2.166
SS2R2	Qa Disi	2.066
SS2R3	El-Shoubak	1.205
	El-Rabba	1.529
SS2R4	El-Shoubak	1.105

cont .

Continue Table 17.

Subunit	Representative Station	Potential Water Requirement MCM/Km²
	El-Rabba	1.429
SS2R5	Irbid	1.211
SS3R1	Qa Disi	2.166
SS3R2	Qa Disi	2.066
SS3R3	El-Shoubak	1.205
	El-Rabba	1.529
SS3R4	El-Shoubak	1.105
	El-Rabba	1.429
SS3R5	Irbid	1.211

WATER RESOURCES AND OPTIMAL LAND USE PRIORITIES FOR AGRICULTURAL DEVELOPMENT

Water resources

The water resources in Jordan are very limited. Fig. 13 shows the basins of water resources available in Jordan. Table 18 shows the volume of water available for surface and ground basins. The Yarmouk river basin represents about 40% (480 MCM) of the total water resources of Jordan.

Shatanawi and Harzalla (1985) classified Jordan, according to the availability of its water resources, into the following three groups:-

Group 1: Areas where the availability of water resources is sufficient, such as Yarmouk river basin, Wadi Dhuleil, Hilly region beside Dead Sea, Hilly region beside Wadi Araba, Jafar basin and Qa Disi basin.

Group 2: Areas where the availability of water resources is not sufficient, such as Jordan Valley, Amman region and south Ghor area.

Group 3: Areas where the water resources are not available such as Irbid and Aqaba region.

It is projected that by the year 2000, the water demand will rise to about 1100 MCM, about 800 MCM being utilized for agricultural purposes. Due to this facts nearly all the potential water resources of Jordan will be exhausted. New sources of water are needed for irrigation. The reuse of sewage waste water for irrigation may be one of these new sources.

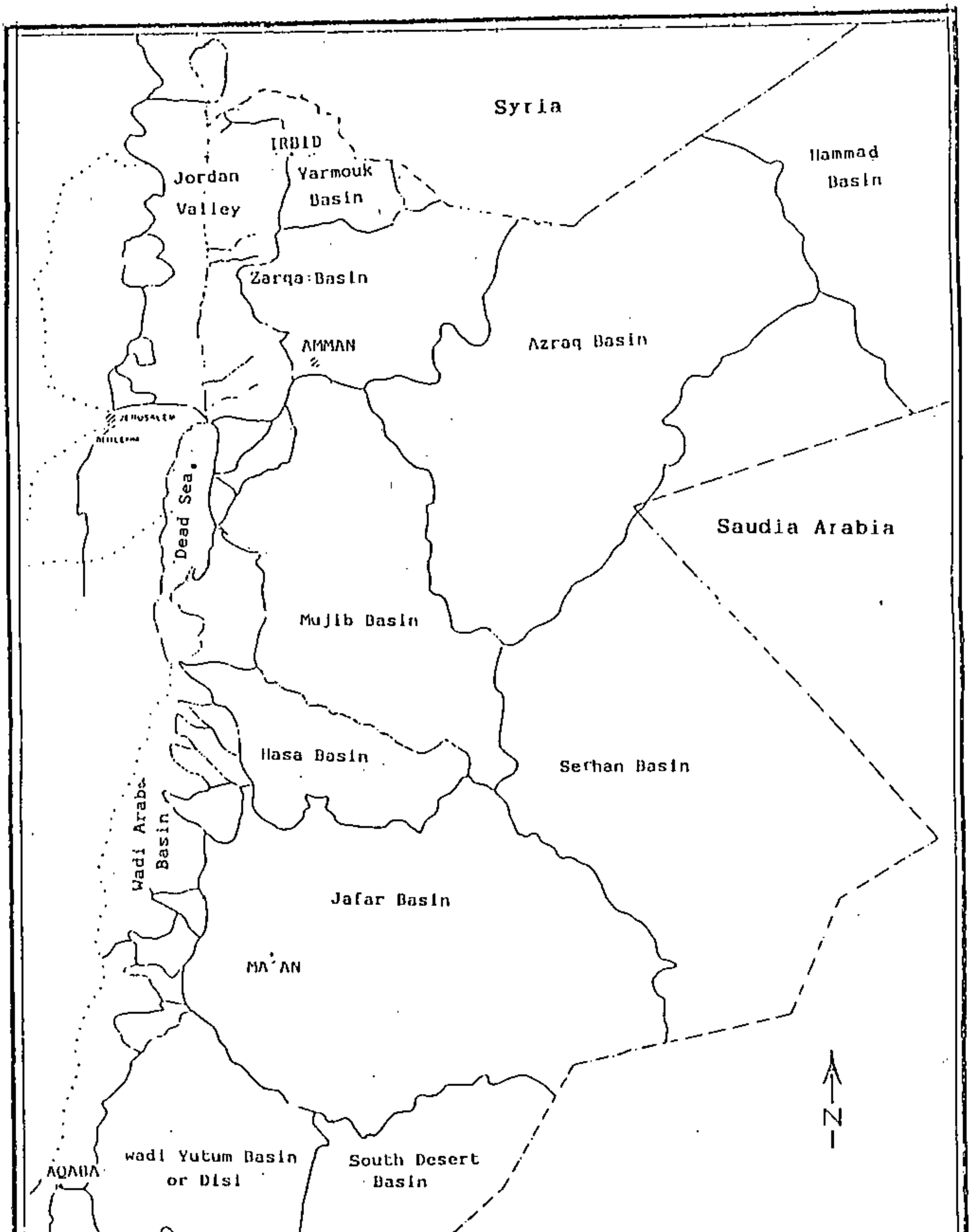

Fig. 13 : The Water Resources Basins of Jordan.

Produced by the Water Authority of Jordan (1983).

Table 18 : Available Water Resources in Jordan.

Basin	Ground Water MCM	Surface Water MCM	Total MCM
Yarmouk River Basin	80.0	400.0	480
Jordan Valley Basin	12.0	——	12.0
Jordan River North Side Wadies	8.0	82.0	90.0
Jordan River South Side Wadies	10.0	37.0	47.0
Amman-Zarka-Dhuliel Basin	56.0	91.0	149.0
Dead Sea Small Side Wadies	9.0	71.3	80.3
Mujib Basin	6.0	78.5	84.5
Hasa Basin	10.0	41.2	51.2
Wadi Arab Basin	13.0	32.5	45.5
South Desert Basin(Qa Disi-Muduara)	100 *	——	100.0
Jafar Basin	15.0	15.0	30.0
Serhan Basin	5.0	——	5.0
Azraq Basin	23.0	27.6	50.6
Hammad Basin	5.0	——	5.0
Total	352.0	878.2	1230.2

Cited from Shatanawi and Harzalla, 1985; and Water Authority, 1987.

* under investigation.

Potential Land and Water Use Priorities for Agricultural Development

Water and water demand in Jordan are dominantly resulting from the requirements of domestic and industrial water supply, and from irrigated agriculture (National Water Master Plan, 1977). Water use for agriculture has the third priority in the water plan of Jordan after the domestic and industrial water use.

Realizing the optimal water and land use for agricultural development in Jordan, the following recommendation may be considered in optimal land use for established subunits:-

[LS1R1] and [LS1R2] subunits:- These subunits needs water for reclamation, leaching and irrigation. It also needs full irrigation to produce economic crop. If the water resources are available, these areas are recommended to be used for irrigated crops. Due to the high water requirements these subunits are recommended to be used for range land purposes.

[LS1R3] subunit:- Water for leaching and irrigation is needed for this subunit. Some barley and wheat can produced without irrigation. Supplemental irrigation is needed for optimal production. It is recommended to be used for cereals or vegetables .

[LS1R4], [LS1R5] and [LS1R6] subunits:- These subunits need water for summer irrigation only. Good winter crops can be produced without irrigation. To maximize the production supplemental irrigation is needed. It is recommended to be used for cereals, vegetables and fruit trees.

[LS2R1], [LS2R2] and [LS2R3] subunits:- Due to high water requirements, slope and low rainfall, these subunits are recommended to be used for pasture.

[LS2R4], [LS2R5] and [LS2R6] subunits:- In areas were some soil pockets exist, orchards can be grown, aslo forestry may be used at these lands.

[LS3R1], [LS3R2] and [LS3R3] subunits:- The lands of these subunits are not suitable for agricultural purposes due to land slope and soil problems.

[LS3R4], [LS3R5] and [LS3R6] subunits:- These subunits are recommended to be used for forests due to high rainfall.

[BS1R1], [BS1R2] and [BS1R3] subunits:- These subunits needs water for leaching and irrigation. If water resources are available, it is recommended for cereals or vegetables under full irrigation.

[SS1R1] and [SS1R2] subunits:- These subunits needs watr for irrigation and leaching. Full irrigation are needed at these subunits for good production. These subunits are very suitable for vegtables and cereals.

[SS1R3] and [SS1R4] subunits:- Full irrigation is needed for these subunits to maximize the production. Cereals can be produced under supplemental irrigation. These lands are recommended for vegetables production.

[SS2R1], [SS2R2] and [SS2R3] subunits:- These subunits are not recommended to be used for agricultural purposes due to soil problems.

[SS2R4] and [SS2R5] subunits:- Due to terrain problems and high rainfall, these subunits are recommended to use for forests.

[SS3R1], [SS3R2] and [SS3R3] subunits:- These subunits are not suitable for agricultural purposes due to soil problems.

[SS3R4] and [SS3R5] subunits:- Forests are recommended at these subunits due to high rainfall.

The total areas that may be alocated for different types of agricultural development at established subunits are presented in Table 19.

Table 19: Areas in Km^2 and its recommended land use.

recommended use	Subunit	Area Km^2	Area %
Cerals and vegetables	LS1R3, LS1R4, LS1R5, LS1R6, BS1R1, BS1R2, BS1R3, SS1R1, SS1R2, SS1R3, SS1R4	21724	25.6
Orchards	LS2R4, LS2R5, LS2R6	285	0.4
Pasture	LS1R1, LS1R2, LS2R1, LS2R2, LS2R3	53143	62.7
Forests	LS3R4, LS3R5, LS3R6, SS2R4, SS2R5, SS3R4, SS3R5	2408	2.8
Not recommended for agriculture use	LS3R1, LS3R2, LS3R3, SS2R1, SS2R2, SS2R3, SS3R1, SS3R2, SS3R3	7204	8.5

Net water requirements:

The actual water requirements (WRA) was estimated for the subunits recommended for cereals, vegetables and orchards only. These three types of crops were considered for the determination of these crop coefficients (Kc). Orchards, vegetables (irrigated crops) and cereals average crop coefficient for the growing season was estimated under general agricultural practices for each of the three types of croping. Overall crop coefficient of 0.5 was considered for orchards plantations. For Vegetables and Cereals an overall crop coefficients of 0.8 and 0.65 was considered respectively. The length of the irrigation period (Ip) was considered as 6, 4 and 6 months for Orchards, Irrigated crops and Cereals respectively. The actual water requirements (WRA) was estimated as follow:-

$$WRA = WRP \times Kc \times Ip$$

Net water requirements for each of subunits established are presented in Table (20). For utilizing all suitable lands in Jordan, about 12855 MCM of water is needed for irrigation. about 1684 MCM of water is available from existing water resources. Therefore, deficit is about 11171 MCM. Most of this deficit is concentrated in subunits [BS1R1], [BS1R2], [BS1R3], [SS1R1] and [SS1R2].

Table 20 : Estimated water requirements and annual rainfall at different subunits.

Subunit**	Area Km²	Recommended crop	Region	Actual water requirement MCM/Km²	Actual water requirement MCM	Annual rainfall MCM/area	Deficit MCM/area
LS1R3	1553	Vegetables	Deir Alla	0.39			
			Wadi Dhuleil	0.38	598*	388	210
LS1R4	1095	Vegetables	Irbid	0.35			
			El-Baqura	0.33	—	—	—
			Wad El-Yabis	0.35			
LS1R5	336	Cereals	Irbid	0.39	—	—	—
LS1R6	8	Cereals	Irbid	0.36	—	—	—
BS1R1	8010	Cereals	H-4	0.67	5367	400	4967
BS1R2	2470	Cereals	Um El-Jemal	0.56	1383	370	1013
BS1R3	114	Cereals	Um El-Jemal	0.53	60	29	31
SS1R1	7549	Cereals	Qa Disi	0.70			
			Ghor El-Safi	0.66	5133*	377	4756
SS1R2	302	Cereals	Qa Disi	0.67	202	45	157
SS1R3	255	Vegetables	Deir Alla	0.39	100	64	36
SS1R4	32	Vegetables	Deir Alla	0.36	12	11	1
LS2R4	151	Orchards	Irbid	0.33	—	—	—
LS2R5	88	Orchards	Irbid	0.30	—	—	—
LS2R6	46	Orchards	Irbid	0.28	—	—	—
Total					12855	1684	11171

* Average value.

** LS1R1, LS1R2, LS2R1, LS2R2, LS2R3, LS3R1, LS3R2, LS3R3, LS3R4, LS3R5, LS3R6, SS2R1, SS2R2, SS2R3, SS2R4, SS2R5, SS3R1, SS3R2, SS3R3, SS3R4 and SS3R5 subunits are not included in this table due to un suitable for vegetables, cereals and orchards. Total area = 62755 Km².

__ Rainfed.

VI. SUMMARY AND CONCLUSIONS

This study Covers the East Bank of Jordan territory to achieve four objectives, these are:

1) To study, compare and evaluate five common methods of estimating crop water requirements
2) To establish an agroclimatological zoning for Jordan based on soil, topography and climate.
3) To estimate the potential water requirements (WRP) for different agroclimatological zones.
4) To identify an optimal land and water use priorities for agricultural development.

Agroclimatological zoning of the east bank of Jordan was established based on land slope gradient, annual rainfall and soil parent material . Potential evapotranspiration (ETP) was estimated at each zone by four methods, namely; Penman; Blaney-Criddle; Jensen-Haise and Hargreaves. The study covered eight agrometeorological stations. Class A pan evaporation data was used to determine ETP at five stations located in desert areas to represent the study of agroclimatological zones. The water requirement was estimated at each established subunit.

The following conclusions can be obtained from the results of this study :-

1) There exist a 35 distinguishe agroclimatic subunit with using characteristics represent the east bank of Jordan.
2) Hargreaves and Jensen-Haise methods are recommended to use for estimating ETP at most established subunits.

3) About 25.6% of the total country area can be used to produce cereals and vegetables, 62.7% are recommended for range land, 3.2% are recommended for orchards and fruit trees and 8.5% can not be used for agricultural purposes.

4) The results show that about 12855 MCM of water are required for irrigation to fullfill the recommended land use.

الخلاصـــــــه

الاستخدام الممكن لاراضي وميـــاه الاردن

اجريت هذه الدراسه على الضفة الشرقية من الاردن لتحقيق الاهداف التالية :-

(١) دراسة ومقارنة وتقييم خمس طرق تجريبيه شائعه لتقدير المتطلبات المائيـــه للزراعه في الاردن باستخدام المعلومات المناخيه المتوفره .

(٢) تقسيم الاردن الى مناطق زراعيه مناخيه متميزه بالاعتماد على عوامل التربه ، الطبوغرافيه والمناخ .

(٣) تحديد المتطلبات المائيه للاستغلال الامثل لهذه المناطق .

(٤) تحديد اولويات استخدام المياه والاراضي من النواحي الزراعيه .

تم تقسيم الاردن الى مناطق زراعيه مناخيه متميزه بالاعتماد على ماده اصـــل التربـــه ، ميل الاراضي ، ومعدل الامطار السنويه . قدرت المتطلبات المائيه فـــي هذه المناطق بواسطة خمس طرق هي بنمان ، بلاني وكريدل ، جنسن وهيز ، هارجريفـــز ، وحوض التبخر لتغطي ثماني محطات زراعيه مناخيه . جمعت نتائج حوض التبخر في خمـــس محطات اخرى واقعه في المناطق الصحراويه لتمثيلها . وقد تم التوصل الى النتائـــج والتوصيات التاليه :-

١) امكن تقسيم الاردن الى خمس وثلاثين منطقة زراعيه مناخيه متميزه .

٢) بينت الدراسه ان طريقتي هارجريفز وجنسن هيز لتقدير المتطلبات المائيـــه تعطي افضل النتائج في معظم هذه المناطق الزراعيه المناخيه .

٣) اكدت الدراسه بان الافضل استخدام لحوالي ٠٫٦٢/٠ من المساحه الكليه لـــلاردن هي للمراعي الطبيعيه و ٠٫٢٦/٠ لزراعة الحبوب والخضراوات و ٠٫٠٣/٠ لزراعـــة الاشجار المثمره والغابات بينما ٠٫٠٨/٠ لا تصلح للاغراض الزراعيه .

٤) اشارت النتائج الى ان كمية المياه اللازمه لتحقيق هذه التوصيات تقـــدر بحوالي ١٢٨٥٥ مليون متر مكعب سنويا يتوفر منها ١٦٨٤ مليون متر مكعبا والنقص يقدر بحوالي ١١١٧١ مليون متر مكعب .

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APPENDIX

Table 1 :Mean Monthly Potential Evapotranspiration (ETP) Estimated by Different Methods at EL-Rabba Station.

Month	Class A pan	Penman	Blaney-Criddle	Jensen-Haise	Harg-reaves
	(mm)				
Jan.	66	48	40	49	63
Feb.	68	60	47	60	73
Mar.	98	99	63	91	108
Apr.	134	143	94	133	149
May	192	181	135	182	194
June	238	205	159	218	227
July	265	220	177	232	239
Aug.	225	202	146	220	227
Sep.	177	154	136	179	187
Oct.	154	121	113	136	145
Nov.	94	77	73	82	93
Dec.	65	51	49	54	65
Annual	1779	1561	1250	1636	1770

Table 2 :Mean Monthly Potential Evapotranspiration (ETP) Estimated by Different Methods at Deir Alla Station.

Month	Class A pan	Penman	Blaney-Criddle	Jensen-Haise	Harg-reaves
	(mm)				
Jan.	66	53	75	57	64
Feb.	69	61	79	68	75
Mar.	92	96	108	104	113
Apr.	138	127	152	143	148
May	187	158	203	195	197
June	206	172	237	220	219
July	224	184	267	240	235
Aug.	207	167	251	218	216
Sep.	180	143	213	181	179
Oct.	152	106	176	138	138
Nov.	124	76	118	86	90
Dec.	73	52	83	59	64
Annual	1718	1395	1962	1709	1738

Table 3 :Mean Monthly Potential Evapotranspiration (ETP) Estimated by Different Methods at Irbid Station.

Month	Class A pan	Penman	Blaney-Criddle	Jensen-Haise	Harg-reaves
	(mm)				
Jan.	56	49	44	48	64
Feb.	60	59	55	64	81
Mar.	83	95	69	93	116
Apr.	122	134	103	131	154
May	184	173	148	185	206
June	230	196	175	211	229
July	242	220	197	230	245
Aug.	216	193	183	206	220
Sep.	177	153	159	165	177
Oct.	151	115	126	121	134
Nov.	86	75	78	70	84
Dec.	54	48	52	51	66
Annual	1661	1510	1389	1575	1776

Table 4 :Mean Monthly Potential Evapotranspiration (ETP) Estimated by Different Methods at Wadi Dhuleil Station.

Month	Class A pan	Penman	Blaney-Criddle	Jensen-Haise	Hargreaves
	(mm)				
Jan.	47	33	41	54	56
Feb.	62	48	48	68	68
Mar.	95	88	71	114	111
Apr.	154	132	106	160	148
May	202	169	151	222	200
June	222	185	179	254	224
July	247	192	206	279	243
Aug.	213	174	189	257	224
Sep.	174	137	158	205	180
Oct.	135	95	120	145	130
Nov.	80	56	69	84	80
Dec.	48	31	45	53	54
Annual	1679	1340	1383	1895	1718

Table 5 :Mean Monthly Potential Evapotranspiration (ETP) Estimated by Different Methods at El-Baqura station.

Month	Class A pan	Penman	Blaney-Criddle	Jensen-Haise	Harg-reaves
	(mm)				
Jan.	58	45	67	48	57
Feb.	60	52	73	59	67
Mar.	84	81	100	92	103
Apr.	125	113	138	129	138
May	176	151	193	183	190
June	203	169	228	212	216
July	218	176	252	222	224
Aug.	199	165	239	207	209
Sep.	166	130	202	165	168
Oct.	129	98	163	120	125
Nov.	91	63	106	72	81
Dec.	65	40	75	46	56
Annual	1574	1283	1836	1555	1634

Table 6 :Mean Monthly Potential Evapotranspiration (ETP) Estimated by Different Methods at Ghor El-Safi Station.

Month	Class A pan	Penman	Blaney-Criddle	Jensen-Haise	Harg-reaves
	(mm)				
Jan.	72	60	80	71	82
Feb.	83	74	85	80	91
Mar.	132	114	122	123	136
Apr.	184	158	167	166	176
May	242	195	226	219	227
June	262	212	259	248	252
July	282	223	291	260	261
Aug.	265	206	271	239	241
Sep.	220	169	226	193	195
Oct.	158	126	180	149	154
Nov.	106	81	123	96	103
Dec.	73	56	88	68	77
Annual	2079	1674	2118	1912	1995

Table 7 :Mean Monthly Potential Evapotranspiration (ETP) Estimated by Different Methods at El-Shoubak Station.

Month	Class A pan	Penman	Blaney-Criddle	Jensen-Haise	Harg-reaves
	(mm)				
Jan.	46	45	26	47	59
Feb.	51	55	30	57	69
Mar.	83	94	47	95	109
Apr.	127	130	74	140	146
May	168	165	103	188	189
June	185	181	126	217	212
July	205	194	151	248	236
Aug.	185	175	136	232	223
Sep.	149	137	109	187	181
Oct.	128	106	84	140	141
Nov.	80	69	50	84	92
Dec.	48	44	33	54	64
Annual	1455	1395	969	1689	1721

Table 8 :Mean Monthly Potential Evapotranspiration (ETP) Estimated by Different Methods at Wad El-Yabis Station.

Month	Class A pan	Penman	Blaney-Criddle	Jensen-Haise	Harg-reaves
	(mm)				
Jan.	55	49	63	51	62
Feb.	53	57	70	68	80
Mar.	68	94	97	103	116
Apr.	126	132	136	137	147
May	183	181	189	193	201
June	203	205	221	219	224
July	249	212	252	240	241
Aug.	218	197	239	219	220
Sep.	191	157	200	177	180
Oct.	151	114	157	130	134
Nov.	93	67	101	81	89
Dec.	55	50	74	56	65
Annual	1645	1515	1799	1674	1759