The Water Budget in West Bank - Palestine

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الملخص

الموازنة المائية هي أحد أهم عناصر الدورة المائية في منظومة غلاف الأرض الجوي، ويمكن تطبيقها على أي منطقة من مناطق سطح الأرض. وتزودنا تقنية الموازنة المائية بمعلومات نافعة عن التبخر الحقيقي ومقدار الفائض والعجز المائي ، وعن تغيرات مخزون المياه في التربة أو الرطوبة المتوفرة في التربة. كما أن هذه الموازنة تُقدم المعرفة عن حجم المياه الداخلة والخارجة. وطُبقت في هذا البحث الموازنة المائية بصورتها البسيطة على منطقة الضفة الغربية في فلسطين. واستخدمت فيها القيم والبيانات المناخية الشهرية والسنوية مثل الأمطار ودرجة الحرارة والتبخر – نتح ومعامل الحرارة ، بالإضافة إلى بعض المتغيرات الأخرى مثل درجة العرض وطول فترة النهار. ويُبرز هذا البحث نتائج الموازنة المائية في الضفة الغربية لفترة 22 عاماً 1975-1997 ، وتبدو أنها متمشية مع مظاهر المناخ المعروف لهذه المنطقة في تلك الفترة .

Abstract

Water budget is one of the most important components of hydrological cycle within earth atmosphere system. It can be applied to any part of Earth's surface. Water budget technique can provide us with useful information about actual evapotranspiration, water surplus, deficit and changes in soil water storage or availability of soil moisture. This budget gives knowledge of the volume of input and output of water. In this paper a simple water budget is applied to the land area of West_Bank-Palestine. It makes use of monthly and yearly values of meteorological data, as well as variables like precipitation, temperature, evapotranspiration and heat index, along with values of latitude and daylight. The paper also presents results of the twenty-two years period, 1975-1997. It seems that these results conform to the known climate features of the period in this area.

Keywords and phrases: water budget, precipitation, evapotranspiration, surplus, deficit, field capacity, wilting point.

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1. Introduction

Water budget can be established for any area of Earth's surface by calculating the inputs and outputs of water. The pioneer geographer Charles Warren Thornthwaite (1899-1963) was the first who used water budget concept in the climatological studies in 1948 to develop a new climatic classification system. (Thornthwaite, C. W., 1948) He worked with his team to develop a water-budget approach for water resource analysis. He and his team related the water-budget concepts to various geographical problems, especially to assess water needs for irrigation and timing. (Thornthwaite, C. W., 1955) Thornthwaite also developed methods for estimating evaporation and transpiration from a variety of groundcovers and surfaces, and he identified the relationship between a given supply of water and the local demand as an important climatic element. (Christopherson, Robert W., 1992) Water budget may be undertaken on a range of time steps including annual, monthly or daily. (Martens, Daniel M., 2001) Soil moisture can be estimated using climatological data and simple water budget applet or model based on rainfall data and estimated evapotranspiration (PE). (Heine, R. W., 1984; Jense, M. E., 1990) Measurments of soil moisture content availability is very useful for providing detailed temporal of moisture availability at a range of time scales. However, a considerable number of measurements are needed for this data to be useful in differentiating spatial patterns of moisture availability at the local or regional scale. (Barringer, J. and Lilburne, L., 1999)

2. Purposes and Scope

The purposes and scopes of the present study are as follows: (a) to describe the various ways in which water supply is expended; (b) to present the long-term average water supply and demand conditions for some areas in West Bank: Jenin, Tulkarm, Nablus, Jerusalem, Jericho and Hebron; (c) to estimate monthly and annual soil water surplus and deficit using the Thornthwaite water budget methodology and calculating applet (Sabaev, M., 1997) for each area; (d) to show the interaction of various components of water-budget.

The research presented here is based upon a general water budget that has been derived for the purpose of estimating and calculating spatial variations in the monthly values for each component of the water budget. Given the extensive research completed on precipitation (P), this paper concentrates primarily on evapotranspiration and changes in soil moisture storage over the period 1975-1997.

3. Description of Study Area

The study unit includes Jenin, Tulkarm, Nablus, Jeruasalem, Jericho and Hebron (Fig. 1), all of which are areas in West Bank-Palestine.

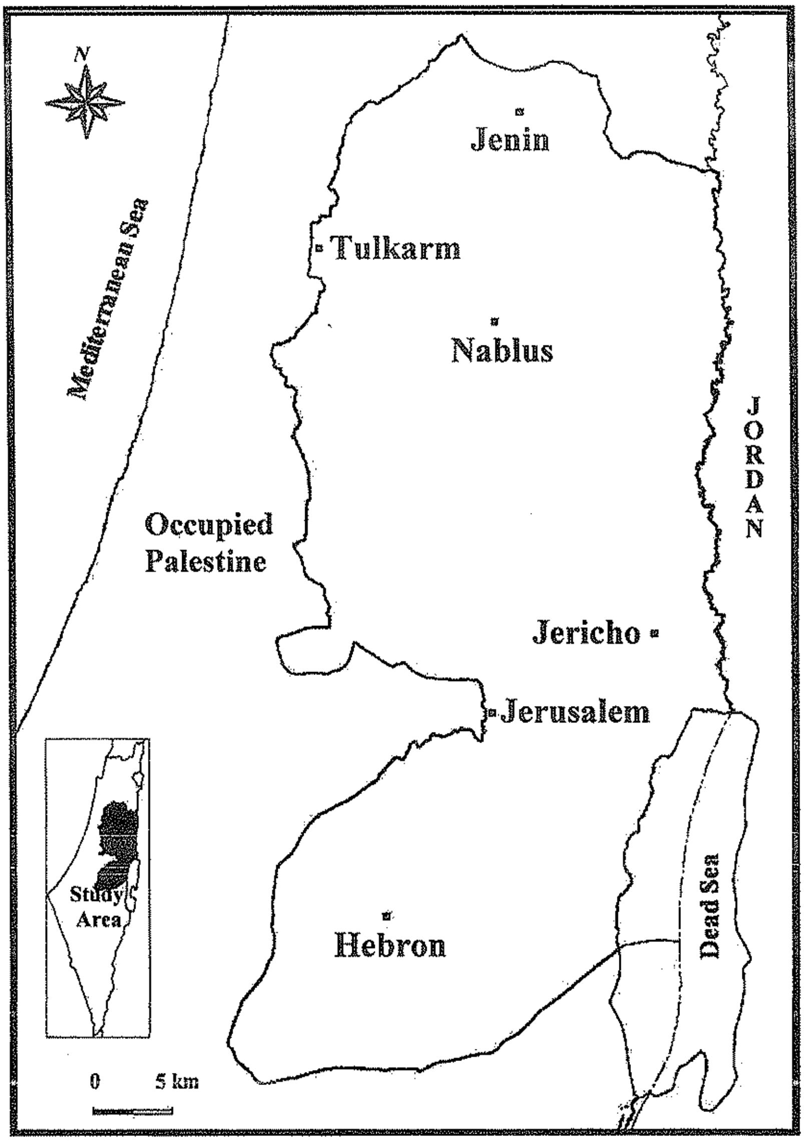

Fig. (1) West Bank (Study Area).

West Bank, territory lies in southwestern Asia, bounded on the north, west, and south by occupied Palestine and on the east by Jordan. It is located on the western bank of the Jordan River in the northeast, and on a portion of the Dead Sea in the southeast. The West Bank covers about 5860 sq km. (Microsoft Encarta, Encyclopedia, 2000) Landscape of the study area is hilly. The steppe gradually rises from west to east to form a mountainous upland area with an average altitude of 600 meters (m) and having several peaks higher than 1000 m. The transition to the Jordan Rift Valley, east of the uplands is sharp, with land altitude falling from 600 m above sea level to 200 to 400 m below sea level over a distance of about 15 km. The climate of much of the area is typically Mediterranean, with mild rainy winters and hot, dry summer; the eastern and southern parts are much drier. (U.S. National Academy of Science, 1999) Rain falls in the study area from October to April. Most of the study area receives in average about 520 millimeters (mm) of rainfall per year. The study area's highest rainfall - those of more than 600 mm falls in an area of highlands in the middle of the study area. The lowest rainfall falls in the eastern part of the study area especially in Jericho, 156 mm, which locates in the Jordan Rift Valley. Soils in the study area tend to be shallow and stony, especially in the upland limestone areas, and suitable for pasture and non-mechanized farming. Alluvial soils in the larger valleys are more suitable for agriculture. (U.S. National Academy of Science, 1999) The study area has approximately 2 million inhabitants, with varying proportions in urban centers and practicing a variety of activities.

4. Data and Methodology

The water budget is implemented using meteorological data (precipitation and temperatures) for the period from January 1975 to December 1997. These data for the period used to comprise all the months of the year whether rainy or dry for some areas in West Bank. The Palestine Climate Data Handbook and World Weather Information Service (WWIS) (only for Jerusalem) amply provides precipitation and temperature data in six selected stations located in: Jenin, Tulkarm, Nablus, Jerusalem, Jericho and Hebron. (Palestinian National Authority, 1998; WWIS, 2003)

Research on evapotranspiration (PE) in many parts of the world has attempted to extend spatially PE measurements by employing estimation methods that rely on generally available data for meteorological variables that are correlated with PE. Typically, these variables include temperature, daylight duration, solar insolation, wind speed and relative humidity. In this article, evapotranspiration (PE) was calculated using a form of Thornthwaite's equation, which considers air temperature, heat index and daylight. Based on these variables, PE was calculated. The formulas of PE, are expressed as: (Huang, J. and others, 1996)

$$PE_i = \left(\frac{10T_i}{I} \right)^a \qquad (1)$$

where T is mean surface air temperature per month i (°C) and I is the heat index defined in Equation (2) below. The exponent a in Equation (1) is a function of the heat index (I).

$$I = \sum_{i=1}^{N} (T_i / 5)^{1.514} \qquad (2)$$

$$a = 6.7 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2} I + 0.49 \qquad (3)$$

Monthly estimates of potential evapotranspiration calculated with Equation (1) need to be adjusted for day length because 30-day a month and 12-hour per day were assumed when this relationship was developed. The adjusted potential evaporation accounting for month length and daylight duration is given by:

$$APE_i = PE_i [(d/30)(h/12)] \qquad (4)$$

Where APE is in (mm/month), d is length of the month in days, and h is the duration of daylight in hours on the fifteenth day of the month. C++ programs, created by Eng. Hassan Akram Al – Hallaq , have been used to compute PE (according to Thornthwaite's equation) and duration of daylight.

5. Components and Concepts of the Water Budget Equation

The purpose of the water budget is to describe the various ways in which the water supply is expended. To understand Thornthwaite's water budget methodology, concept and accounting procedures, which is still a very useful technique to understand roughly the water affairs, (Te Kung, H, 2003), we need to know the various components, terms and concepts in the simple water budget equation, (5): (Christopherson, Robert W., 1992)

$$P = (PE - D) + S \pm \Delta ST \qquad (5)$$

$$\text{Supply} = \underbrace{(\text{Demand} - \text{Shortage})}_{\text{AE (Actual evapotranspiration)}} + \text{Oversupply} \pm \text{Soil moisture or recharge}$$

Where:

- **P** means precipitation in the form of rain makes up the primarily supply of water to the soil. "*The moisture supply*"
- **PE** is the potential evapotranspiration. It is the amount that would be withdrawn from the soil water and vegetation if the moisture were available, (Broner, I., 2001) and return to the atmosphere. Evapotranspiration is the sum of evaporation and transpiration. "*The moisture demand*" (Wanielista, M. P., 1990)
- **D** is the deficit. A soil moisture deficit occurs when the demand for water exceed that which is actually available. In other words, deficits occur when PE exceeds actual evapotranspiration (AE) and soil is being depleted. "*The moisture shortage*"(Critchfield, J. Howard, 1974)
- **S** is the surplus. Surplus occurs when P exceeds PE and the soil is at its field capacity (saturated). "*The moisture oversupply*" Surplus, also, is precipitation or water, which does not evaporate or remain in soil storage and includes both surface and sub-surface runoff._(Maidment, David R. and others, 1997; Reed, Seann M., 1997)
- **Δ ST** is the change in soil moisture storage (ST). ST means the amount of water held in the soil at any particular time. Thornthwaite assumed soil moisture has storage capacity of 100 mm (4 inches) of water. When P>PE, moisture fill up in soil first then excess water gets into surplus. When PE>P, soil starts dry out first. (Te Kung, H, 2003) The Change in soil moisture storage is the amount of water that is being recharged to or utilized from what is stored. "*The moisture saving*"
- **AE** is the actual evapotranspiration. It is the amount of water delivered to the air from evaporation and transpiration. It is derived from PE – D. "*The actual satisfied demand*" Actual evapotranspiration_(AE) is not directly measured but is usually calculated from measurements of PE, P and estimates of the maximum useful quantity of water stored in the soil.

6. Results and Discussion:

Using all of these concepts, we can apply the water budget equation to specific stations in West Bank.

6.1 Jenin:

Table (1) presents the long-term average water supply and demand conditions for the area of Jenin in north of West Bank. Jenin port is at 32° 28' N, 35° 18' E, with an elevation of 138 m, and has maintained weather records for 22 years. The monthly values in Table (1) assume that precipitation (P) and potential evapotranspiration (PE) are evenly distributed throughout each month, smoothing out actual daily and hourly conditions.

By comparing P with PE on a per-month basis to determine whether there is a net supply (+) or net demand (-) for water, we can see that Jenin experiences a net supply from January through March and from November to December. However, the warm days and months from April through October result in net demand for water. Assuming a soil moisture storage capacity of 100 mm, those months of net demand for moisture are satisfied through soil moisture utilization.

Table (1) P – PE for Jenin. (mm)*

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	101	100	71	14	2	1	0	0	0	14	58	107
PE	20	22	39	74	110	140	163	168	137	97	51	26
Net Supply (+) Or Demand (-)	81	78	32	-60	-108	-139	-163	-168	-137	-83	7	81

* Source: by author.

Table (2) presents the annual water budget for Jenin, and Figure (2) graphs the water budget components of these same monthly averages. The following discussion elaborates on both this table and graph.

Table (2) shows that soil moisture estimates are at field capacity (FC) through March, with the excess supply-crediting surplus (S) each month. In April the net demand is – 60 mm, most of which is withdrawn from soil moisture storage, bringing soil moisture capacity down to 40 mm at the end of April. In May the net demand is -108 mm and the soil moisture capacity down to 0 mm at the end of May. The other 68 mm of net demand appears as deficit (D); that amount remains in the soil, reflecting the increasing inefficiency as soil moisture drops below field capacity.

From May through October, the actual evapotranspiration (AE) is progressively less than the optimum PE, and high deficits continue to be recorded. By the end of May shallow-rooted soil moisture is near the wilting point. (WP)

Table (2) Water budget for Jenin. (mm)*

Mon.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	101	100	71	14	2	1	0	0	0	14	58	107	**468**
PE	20	22	39	74	110	140	163	168	137	97	51	26	**1047**
P-PE	81	78	32	-60	-108	-139	-163	-168	-137	-83	7	81	-
P+ST	201	200	171	114	42	1	0	0	0	14	58	114	-
Δ ST	0	0	0	-60	-40	0	0	0	0	0	7	81	**-12**
ST	100	100	100	40	0	0	0	0	0	0	7	88	-
AE	20	22	39	74	42	1	0	0	0	14	51	26	**289**
D	0	0	0	0	68	139	163	168	137	83	0	0	**758**
S	81	78	32	0	0	0	0	0	0	0	0	0	**191**

* Source: by author.

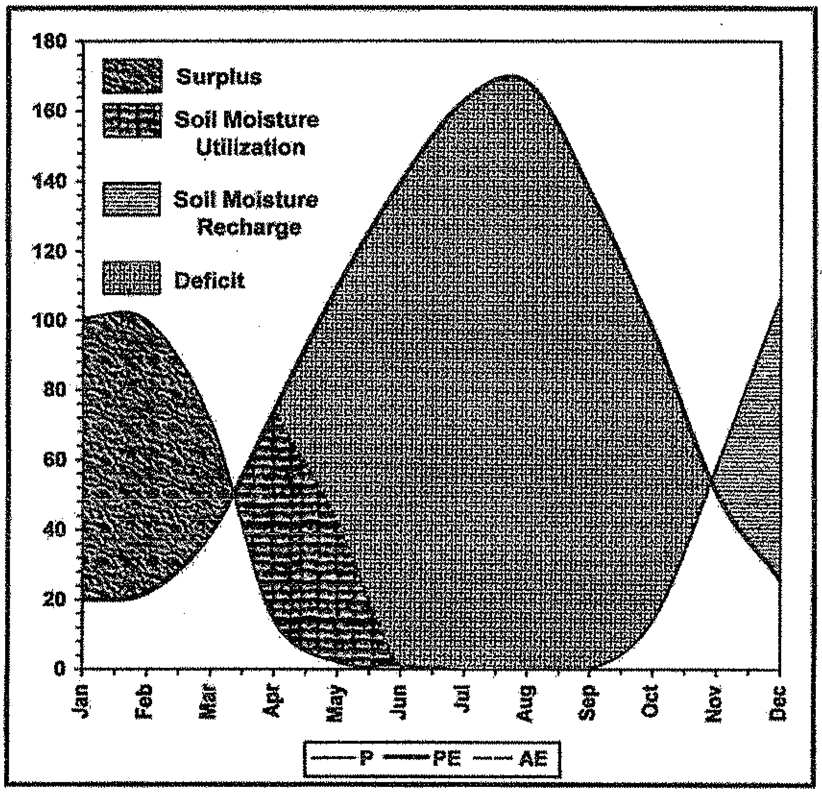

Fig. (2) Average monthly water budget for Jenin. (mm)

From June through October shallow-rooted moisture is at wilting point. During November, however, 7 mm of net supply is generated and is credited as soil moisture recharge. Recharge occurs again in December, bringing the soil moisture near the field capacity by the end of the year, with no surplus. In January the soil moisture back up to field capacity, with a surplus of 81 mm estimated for this month. The Jenin water budget equation for the year and for the months is isolated in Table (3) to show the interaction of these various components. (Compare with Table 2)

Table (3) Annual and Monthly water budgets for Jenin. (mm)*

	P	**=**	**(PE**	**-**	**D)**	**+**	**S**	**±**	**Δ ST**
Annual	**468**	**=**	**(1047**	**-**	**758)**	**+**	**191**	**-**	**12**
Jan	101	=	(20	-	0)	+	81	±	0
Feb	100	=	(22	-	0)	+	78	±	0
Mar	71	=	(39	-	0)	+	32	±	0
Apr	14	=	(74	-	0)	+	0	-	60
May	2	=	(110	-	68)	+	0	-	40
Jun	1	=	(140	-	139)	+	0	±	0
Jul	0	=	(163	-	163)	+	0	±	0
Aug	0	=	(168	-	168)	+	0	±	0
Sep	0	=	(137	-	137)	+	0	±	0
Oct	14	=	(97	-	83)	+	0	±	0
Nov	58	=	(51	-	0)	+	0	+	7
Dec	107	=	(26	-	0)	+	0	+	81

* Source: by author.

6.2 Tulkarm:

Tulkarm lies in the north-west of West Bank, close to the Green Line, (32° 20' N 34° 51' E), with an elevation of 65 m. Table (4) shows the long-term average water supply and demand conditions for the area of Tulkarm. Like Jenin, it is clear that Tulkarm experiences a net supply from January through March and from November to December. The warm periods from April to October result in net demands for water.

Table (5) presents the annual water budget for Tulkarm, and Figure (3) graphs the water budget components of these same monthly averages. The following discussion explains in both this table and graph.

Table (4) P – PE for Tulkarm. (mm)*

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	111	104	87	18	4	0	0	0	1	26	90	162
PE	19	21	36	63	91	122	145	148	118	97	50	28
Net Supply (+) Or Demand (-)	**92**	**83**	**51**	**-45**	**-87**	**-122**	**-145**	**-148**	**-117**	**-71**	**40**	**134**

* Source: by author.

Table (5) Water budget for Tulkarm. (mm)*

Mon.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	111	104	87	18	4	0	0	0	1	26	90	162	**603**
PE	19	21	36	63	91	122	145	148	118	97	50	28	**938**
P-PE	92	83	51	-45	-87	-122	-145	-148	-117	-71	40	134	-
P+ST	211	204	187	118	59	0	0	0	1	26	90	202	-
Δ ST	0	0	0	-45	-55	0	0	0	0	0	40	60	**± 0**
ST	100	100	100	55	0	0	0	0	0	0	40	100	-
AE	19	21	36	63	59	0	0	0	1	26	50	28	**303**
D	0	0	0	0	32	122	145	148	117	71	0	0	**635**
S	92	83	51	0	0	0	0	0	0	0	0	74	**300**

* Source: by author.

We shall budgeting procedure at the end of a dry season when soil moisture storage is at its lowest, and the P begins to replenish the soil moisture, called soil moisture recharge, in November. At the beginning of the month, the soil is considered dry, as the storage in October is equal zero.

During November 90 mm of rainfall on the earth surface, as P. PE requires 50 mm. P therefore satisfies the need for water with 40 mm of water left over. The excess 40 mm of water is put into storage (Δ ST = 40) bringing the amount in storage to 40 mm. AE is equal to PE, as November is a wet month. There is no D during this month as the soil now has some water in it and no S, as it has not reached its water FC.

During December, P far exceeds PE. All of the excess water is added to the existing soil moisture. ST becomes 100 mm and the soil moisture reaches to FC in December. Any excess water that falls on the surface will likely generate S.

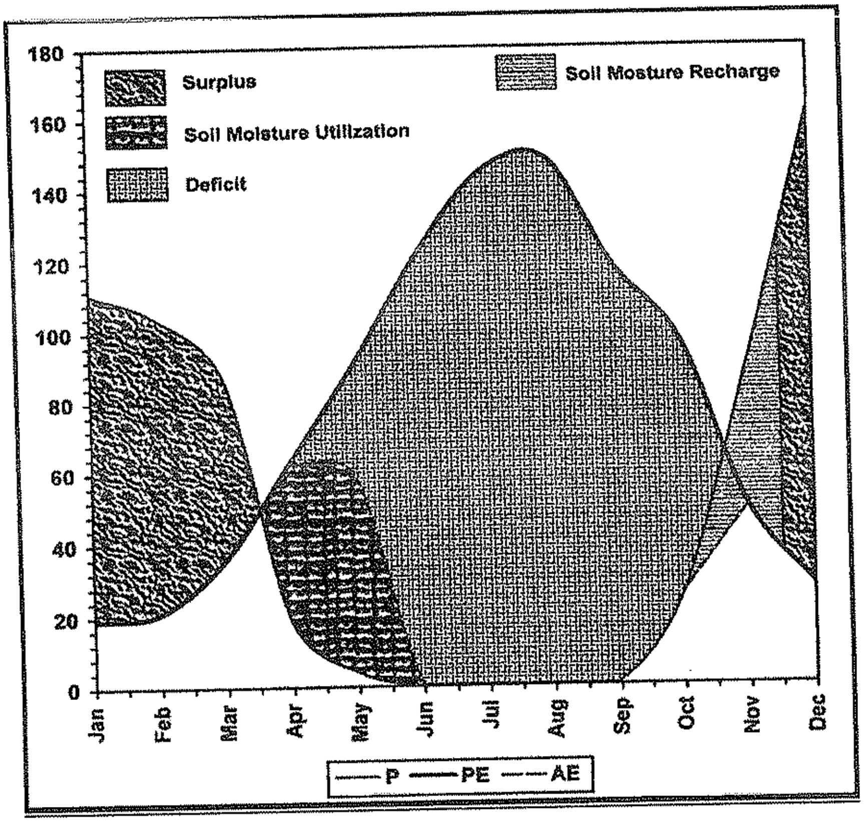

Fig. (3) Average monthly water budget for Tulkarm. (mm)

Similar conditions occur for the months of January, February and March. All of these months are wet, and the soil remains at its FC so; all excess water becomes S water.

In April, temperatures have increased to the point where evaporation is proceeding quite rapidly and plants are requiring more water to keep them healthy. As a result, PE is approaching its maximum value. P, however, is falling off in value. During April P-PE is –45 mm. This means that P no longer is able to meet the demand of PE. In order to meet the needs for water, plants must extract some of the water that is stored in the soil from the previous months. The 45 mm is taken out of storage reducing its value to 55 mm.

The month of April is considered dry (P<PE) and so AE is now equal to P plus the absolute value of Δ ST and AE is equal to PE. This means that P and what was extracted from storage was able to meet the needs demanded

by PE during the month April. As a result of this scenario, no surplus can be observed in this month. Furthermore, the soil moisture storage has dropped below its FC. There is still no D as water remains in storage.

By the time May ends, water held in storage is down to 0 mm and the soil moisture reached to WP. This condition is continuous from June through October. These months are dry. PE still exceeds P and the differences are –87, -122, -145, -148, -117, and –71 mm respectively. In these months, there has not been enough water from P and what is in storage to meet the demands of PE. The amounts in storage fall to 0 mm and the soil is dried out. The unmet need for water shows up as soil moisture deficit.

The Tulkarm water budget equation for the year and for the months is isolated in Table (6) to show the interaction of the various components. It is apparent that 300 mm of the total of P (49.8%) forms a surplus. This means that about a half of P is lost by AE.

Table (6) Annual and Monthly water budgets for Tulkarm. (mm)*

	P	=	(PE	-	D)	+	S	±	Δ ST
Annual	**603**	=	**(938**	-	**635)**	+	**300**	±	**0**
Jan	111	=	(19	-	0)	+	92	±	0
Feb	104	=	(21	-	0)	+	83	±	0
Mar	87	=	(36	-	0)	+	51	±	0
Apr	18	=	(63	-	0)	+	0	-	45
May	4	=	(91	-	32)	+	0	-	55
Jun	0	=	(122	-	122)	+	0	±	0
Jul	0	=	(145	-	145)	+	0	±	0
Aug	0	=	(148	-	148)	+	0	±	0
Sep	1	=	(118	-	117)	+	0	±	0
Oct	26	=	(97	-	71)	+	0	±	0
Nov	90	=	(50	-	0)	+	0	+	40
Dec	162	=	(28	-	0)	+	74	+	60

* Source: by author.

6.3:Nablus

Nablus is located to the south of Jenin in the north of West bank,(32° 13' N 35° 16' E), with an elevation of 533 m. Table (7) illustrates the average water supply and demand conditions for the area of Nablus. It is apparent that Nablus experiences a net supply from January through March and from November to December, while the net demand periods for water appear from April to October owing to warm periods, decreasing rainfall and dry periods.

Table (7) P – PE for Nablus. (mm)*

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	141	147	104	20	8	0	0	0	2	21	77	141
PE	18	21	36	63	96	117	136	131	108	84	45	23
Net Supply (+) Or Demand (-)	**123**	**126**	**68**	**-43**	**-88**	**-117**	**-136**	**-131**	**-106**	**-63**	**32**	**118**

* Source: by author.

Table (8) shows the annual water budget for Nablus, and the average monthly water budget is shown in Figure (4). They clearly show that, on average, P receipt is sufficient to meet water need from December to March.

Table (8) Water budget for Nablus. (mm)*

Mon.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	141	147	104	20	8	0	0	0	2	21	77	141	**661**
PE	18	21	36	63	96	117	136	131	108	84	45	23	**878**
P-PE	123	126	68	-43	-88	-117	-136	-131	-106	-63	32	118	-
P+ST	241	247	204	120	65	0	0	0	2	21	77	173	-
Δ ST	0	0	0	-43	-57	0	0	0	0	0	32	68	**± 0**
ST	100	100	100	57	0	0	0	0	0	0	32	100	-
AE	18	21	36	63	65	0	0	0	2	21	45	23	**294**
D	0	0	0	0	31	117	136	131	106	63	0	0	**584**
S	123	126	68	0	0	0	0	0	0	0	0	50	**367**

* Source: by author.

P amounts are greatest (over 100 mm) in this period when PE is less; consequently this is when the largest surpluses are generated. During the period from April to November, PE exhibits a symmetrical pattern with maximum values of 136 mm occurring in July. It is in the months of April to October that PE exceeds P and water is drawn from storage

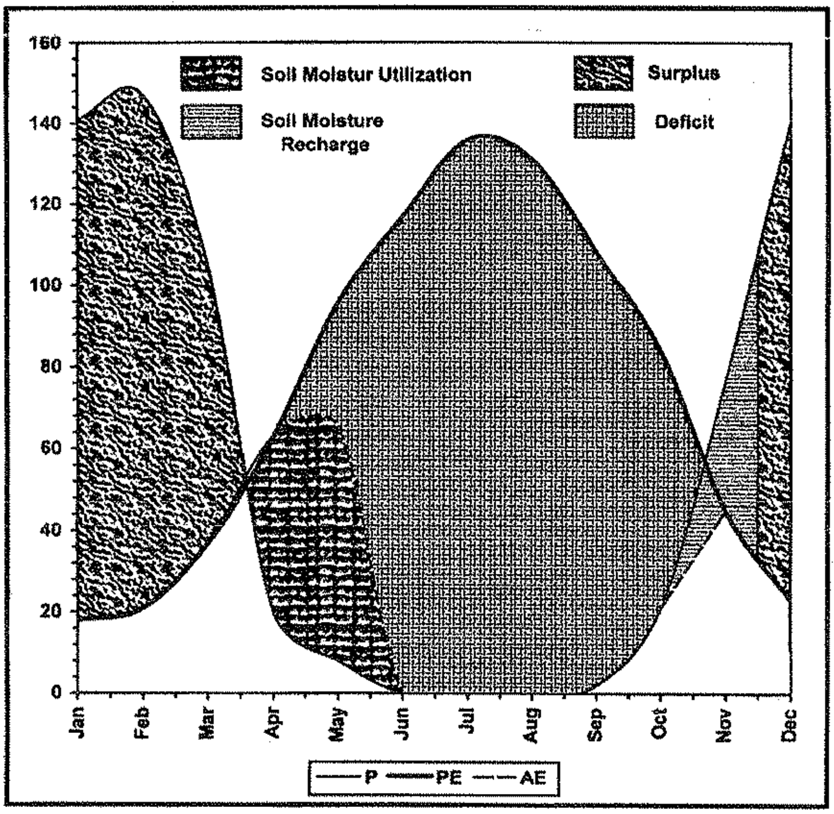

Fig. (4) Average monthly water budget for Nablus. (mm)

However, AE in these months is still less than PE so that a large D occurs. This withdrawal is quickly replaced by the end of November during which P exceeds PE for Nablus. From December onwards the S generated increases with each month, for example, in January and February, 123 mm and 126 mm of the 141 mm and 147 mm of P is S respectively (87.2% and 85.7%). The annual values for P, PE and S are 661 mm, 878 mm and 367 mm, which compare favorably with those quoted earlier. Table (8) shows the annual P expended in AE, which form about 44.5% of total P.

The annual and months water budget equation for Nablus is isolated in Table (9) to show the interaction of the various components. It is apparent that 367 mm of the total of P (55.5%) forms a surplus. This means that less than a half of P is lost by AE.

Table (9) Annual and Monthly water budgets for Nablus. (mm)*

	P	=	(PE	-	D)	+	S	±	Δ ST
Annual	**661**	=	**(878**	-	**584)**	+	**367**	±	**0**
Jan	144	=	(18	-	0)	+	123	±	0
Feb	147	=	(21	-	0)	+	126	±	0
Mar	104	=	(36	-	0)	+	68	±	0
Apr	20	=	(63	-	0)	+	0	-	43
May	8	=	(96	-	31)	+	0	-	57
Jun	0	=	(117	-	117)	+	0	±	0
Jul	0	=	(136	-	136)	+	0	±	0
Aug	0	=	(131	-	131)	+	0	±	0
Sep	2	=	(108	-	106)	+	0	±	0
Oct	21	=	(84	-	63)	+	0	±	0
Nov	77	=	(45	-	0)	+	0	+	32
Dec	141	=	(23	-	0)	+	50	+	68

* Source: by author.

6.4:Jerusalem:

P amounts are greatest (over 100 mm) in this period when PE is less; consequently this is when the largest surpluses are generated. During the period from April to November, PE exhibits a symmetrical pattern with maximum values of 136 mm occurring in July. It is in the months of April to October that PE exceeds P and water is drawn from storage

Table (10) presents the average water supply and demand conditions for the area of Jerusalem. It is clear that the net supply periods occur from January through March, while the net demand periods for water appear from April to October. The warm and dry periods from April to October result in net demands for water.

Table (11) presents the annual water budget for Jerusalem, and Figure (5) graphs the water budget components of these same monthly averages.

Table (10) P – PE for Jerusalem. (mm)*

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	133	118	93	25	3	0	0	0	0	15	61	106
PE	16	17	31	64	98	118	136	132	108	82	44	24
Net Supply (+) Or Demand (-)	**117**	**101**	**62**	**-39**	**-95**	**-118**	**-136**	**-132**	**-108**	**-67**	**17**	**82**

* Source: by author.

Table (11) Water budget for Jerusalem. (mm)*

Mon.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	133	118	93	25	3	0	0	0	0	15	61	106	554
PE	16	17	31	64	98	118	136	132	108	82	44	24	870
P-PE	117	101	62	-39	-95	-118	-136	-132	-108	-67	17	82	-
P+ST	233	218	193	125	64	0	0	0	0	15	61	123	-
Δ ST	0	0	0	-39	-61	0	0	0	0	0	17	82	-1
ST	100	100	100	61	0	0	0	0	0	0	17	99	-
AE	16	17	31	64	64	0	0	0	0	15	44	27	275
D	0	0	0	0	34	118	136	132	108	67	0	0	595
S	117	101	62	0	0	0	0	0	0	0	0	0	280

* Source: by author.

Table (11) illustrates that soil moisture estimates are at FC through March, with the excess supply crediting S each month. In April -39 mm, net demand, is withdrawn from soil moisture, consequently the soil moisture capacity down to 61 mm at the end of April, and it didn't appear any D in this month. In May the net demand is –95 mm, most of which is withdrawn from soil moisture storage, bringing soil moisture capacity down to zero at the end of that month. The other 34 mm of net demand appears as D; and the soil moisture storage down to zero at the end of May.

From June to October AE is less than PE, and high D continues to be record. April and May feature soil moisture utilization of –39 mm and –61 mm, so that by the end of May shallow rooted soil moisture is at WP. This case continues through October.

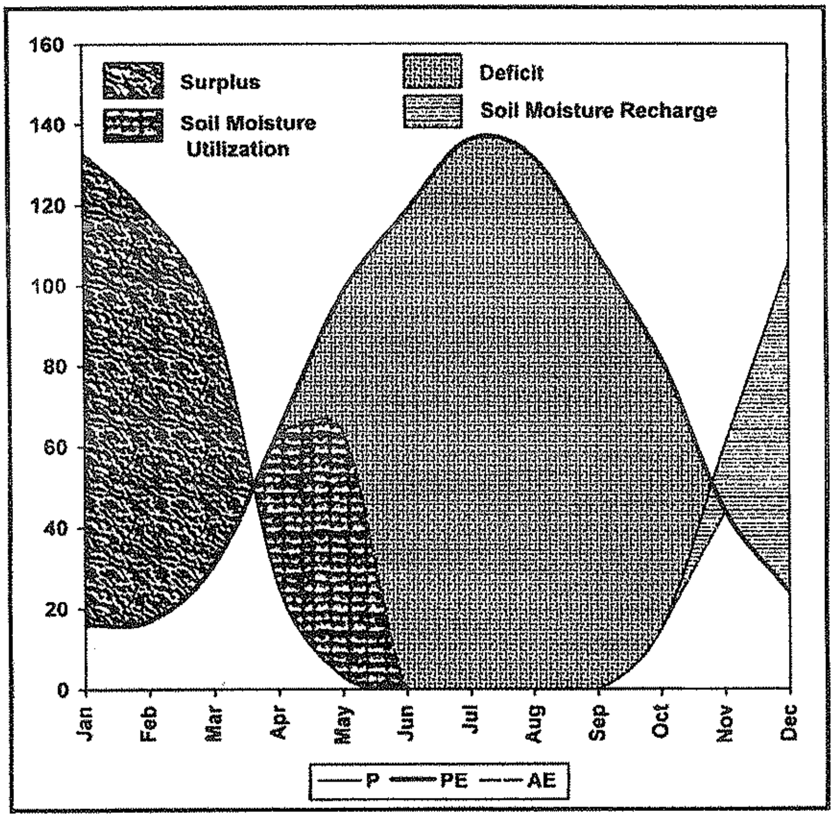

Fig. (5) Average monthly water budget for Jerusalem. (mm)

In November 17 mm of net supply is generated and is credited as soil moisture recharge. Recharge occurs in November and December, bringing the soil moisture backs up to near FC by the end of the year, with no S.

The annual and months water budget equation for Jerusalem is isolated in Table (12) to show the interaction of the various components. It is apparent that about a half of the total of P forms surplus. This means that other half is lost by AE

6.5 Jericho (Ariha) :

Jericho (*Ariha*), area in the West Bank, located in the Jordan Rift, north of the Dead Sea and west of the Jordan River. (31° 52' N 35° 27' E) Jericho is the world's oldest known city, dating back to ca. 8000 B.C., (Orni, E. and Efrat, E., 1976) and is famous in biblical history. Located about 260 m below sea level, Jericho is one of the lowest cities in the world. Its climate is hot, dry in summer and mild in winter. Table (13) presents the average water supply and demand conditions for the area of Jericho.

Table (12) Annual and Monthly water budgets for Jerusalem. (mm)*

	P **	=	(PE	-	D)	+	S	±	Δ ST
Annual	**554**	=	**(870**	-	**595)**	+	**280**	-	**1**
Jan	133	=	(16	-	0)	+	117	±	0
Feb	118	=	(17	-	0)	+	101	±	0
Mar	93	=	(31	-	0)	+	62	±	0
Apr	25	=	(64	-	0)	+	0	-	39
May	3	=	(98	-	34)	+	0	-	61
Jun	0	=	(118	-	118)	+	0	±	0
Jul	0	=	(136	-	136)	+	0	±	0
Aug	0	=	(132	-	132)	+	0	±	0
Sep	0	=	(108	-	108)	+	0	±	0
Oct	15	=	(82	-	67)	+	0	±	0
Nov	61	=	(44	-	0)	+	0	+	17
Dec	106	=	(24	-	0)	+	0	+	82

* Source: by author.

Table (13) P – PE for Jericho. (mm)*

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	36	31	25	10	2	0	0	0	0	7	22	23
PE	18	24	44	84	145	193	224	214	169	113	52	24
Net Supply (+) Or Demand (-)	18	7	-19	-74	-143	-193	-224	-214	-169	-106	-30	-1

* Source: by author.

The net supply periods occur in two months, January and February, where the P exceeds the PE, but the net demand periods for water appear from March through December.

Table (14) shows the annual water budget for Jericho, and the average monthly water budget is shown in Figure (6). The water budget values for Jericho indicate an average annual P total of 156 mm. Although in winter AE reaches the potential amount, in summer it falls well.

Table (14) Water budget for Jericho. (mm)*

Mon.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	36	31	25	10	2	0	0	0	0	7	22	23	**156**
PE	18	24	44	84	145	193	224	214	169	113	52	24	**1304**
P-PE	18	7	-19	-74	-143	-193	-224	-214	-169	-106	-30	-1	-
P+ST	136	131	125	91	9	0	0	0	0	7	22	23	-
Δ ST	0	0	-19	-74	-7	0	0	0	0	0	0	0	**-100**
ST	100	100	81	7	0	0	0	0	0	0	0	0	-
AE	18	24	44	84	9	0	0	0	0	7	22	23	**231**
D	0	0	0	0	136	193	224	214	169	106	30	1	**1073**
S	18	7	0	0	0	0	0	0	0	0	0	0	**25**

* Source: by author.

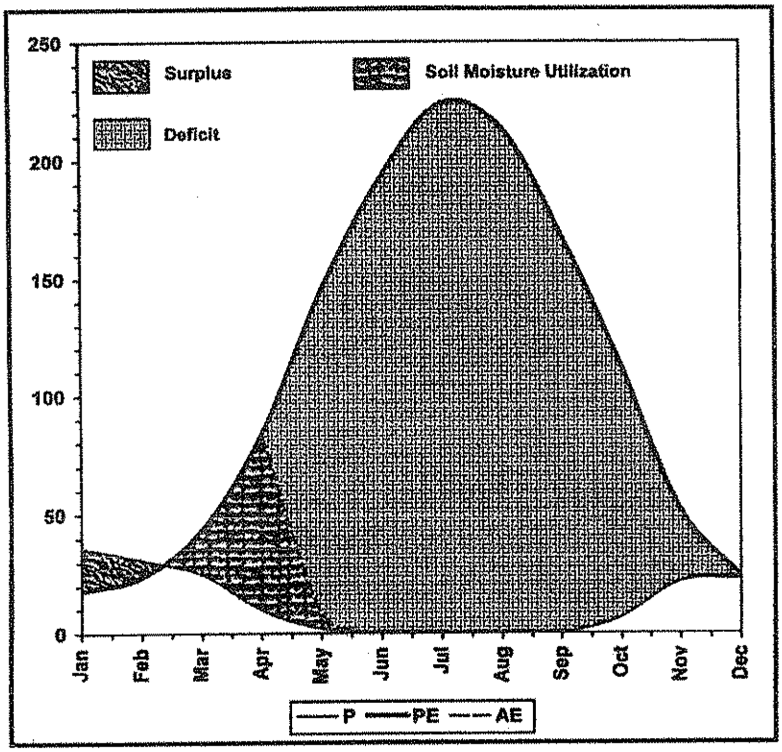

Fig. (6) Average monthly water budget for Jericho. (mm)

In January and February, P exceeds the PE, but from May through December there is water D. Starting in March, when PE surpasses P, soil moisture from below the ground is used in evaporation. Most of it is drawn up through the roots of plants and evaporates from their leaves. This is shown in the table by value of 19 mm. The 19 mm is taken out of storage reducing its value to 81 mm. This process continues until the end of April where the water held in storage is down to mere 7 mm. There is still no D as water remains in storage. The D starts in May and continues until the end of December. When P once more exceeds PE and the stock of available soil water is recharged. During this time, in January and February, surplus is plentiful from Jericho's winter storm.

Table (15) shows the interaction of the various components of water budget for Jericho. It is clear that 25 mm of the total of P (16%) forms a surplus. This means that 84% of P is lost by AE.

Table (15) Annual and Monthly water budgets for Jericho. (mm)*

	P	=	(PE	-	D)	+	S	±	Δ ST
Annual	**156**	=	**(1304**	-	**1073)**	+	**25**	-	**100**
Jan	36	=	(18	-	0)	+	18	±	0
Feb	31	=	(24	-	0)	+	7	±	0
Mar	25	=	(44	-	0)	+	0	-	19
Apr	10	=	(84	-	0)	+	0	-	74
May	2	=	(145	-	136)	+	0	-	7
Jun	0	=	(193	-	193)	+	0	±	0
Jul	0	=	(224	-	224)	+	0	±	0
Aug	0	=	(214	-	214)	+	0	±	0
Sep	0	=	(169	-	169)	+	0	±	0
Oct	7	=	(113	-	106)	+	0	±	0
Nov	22	=	(52	-	30)	+	0	+	0
Dec	23	=	(24	-	1)	+	0	+	0

* Source: by author.

6.6 Hebron (*Al Khalīl*) :

Hebron (*Al Khalīl*), area in the south West Bank. It lies in a mountainous region near Jerusalem (31° 32' N 35° 06' E), and is situated at an altitude of 930 m above sea level.

Table (16) shows the average water supply and demand conditions for the area of Hebron. It is apparent that Hebron has a net supply from January through March and from November to December, while the net demand periods for water appear from April to October owing to warm periods, decreasing rainfall volume and dry periods.

Table (16) P – PE for Hebron. (mm)*

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	134	142	92	25	5	1	0	0	2	15	67	116
PE	14	18	31	56	88	107	120	114	93	74	41	20
Net Supply (+) Or Demand (-)	**120**	**124**	**61**	**-31**	**-83**	**-106**	**-120**	**-114**	**-91**	**-59**	**26**	**96**

* Source: by author.

Table (17) shows the annual water budget for Hebron, and the average monthly water budget is shown in Figure (7). At the end of October the soil is considered dry and the storage of water is equal zero..

Table (17) Water budget for Hebron. (mm)*

Mon.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	134	142	92	25	5	1	0	0	2	15	67	116	**599**
PE	14	18	31	56	88	107	120	114	93	74	41	20	**776**
P-PE	120	124	61	-31	-83	-106	-120	-114	-91	-59	26	96	-
P+ST	234	242	192	125	74	1	0	0	2	15	67	142	-
Δ ST	0	0	0	-31	-69	0	0	0	0	0	26	74	**± 0**
ST	100	100	100	69	0	0	0	0	0	0	26	100	-
AE	14	18	31	56	74	1	0	0	2	15	41	20	**272**
D	0	0	0	0	14	106	120	114	91	59	0	0	**504**
S	120	124	61	0	0	0	0	0	0	0	0	22	**327**

* Source: by author.

P amount in November is 67 mm and PE requires 41 mm. Therefore, P satisfies the need for water with 26 mm of water left over. This amount becomes the storage in this case and there is no D. During November the soil has some water and no S. In December, PE has dropped to 20 mm and the difference between P and PE is 96 mm but not all is placed into storage because the soil at the end of November was within 74 mm of being at its FC. Therefore, only 74 mm of 96 mm available is added into the soil and remainder (22 mm) forms as S, and the soil has reached its FC in December. Any excess water that falls on the surface will likely generate S

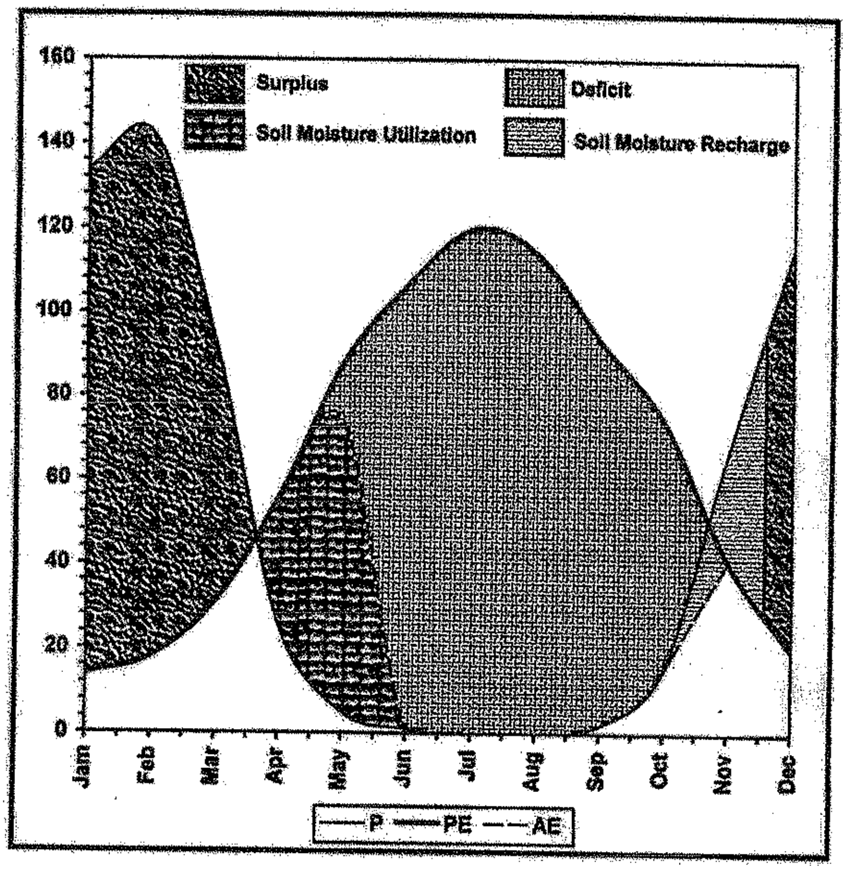

Fig. (7) Average monthly water budget for Hebron. (mm)

We note in January that P exceeds PE with 120 mm and Δ ST is 0 mm. This indicates that it can't change the amount in storage as the soil is at its capacity to hold water. As a result the amount in storage (ST) remains at 100 mm. Note that all excess water shows up as S (S= 120 mm). Similar conditions occur for the months of February and March. These are all wet months and soil remains at its FC so all-excess water becomes S water. By the time April temperature has increased to the point where evaporation is proceeding quite rapidly and plants are withdrawing more water. As a result, PE is approaching its maximum value. P, however, is falling off in value. During April the difference between P and PE is 31 mm. This means that P cannot able to meet the demand of PE. In order to meet this need for water, plants must extract water that is stored in the soil from previous months. The 31 mm is taken out of storage (100 mm) reducing its value to 69 mm. So the month of April is considered a dry month because the P is less than PE. Hence, AE is equal to P plus the absolute value of Δ ST. It is apparent that there is no S as the soil moisture storage has dropped below its FC and there is still no D as water remains in storage. The period from May through October is considered dry where PE still exceeds P and the differences are –83, –106, -120, -114, -91 and –59 mm respectively. May begins with only 69 mm of water in storage (ST of April). Thus only be able to extract 69 mm of the 83 mm of water needed to meet the demand of PE. So, of the 83 mm of water would need to extract from the soil. The amount in storage falls to zero and the soil dried out. The remaining 14 mm of the original of 83 mm shows up as soil moisture deficit. In other words, it has been able to meet the need for water from P and what it can extract from storage. AE is therefore equal to 74 mm (5 mm of P + 69 mm of Δ ST). Similar conditions occur for June, July, August, September and October, just in different values.

Table (18) shows the interaction of the various components of water budget for Hebron. It is clear that 327 mm of the total of P (54.6%) forms a surplus. This means that 45.4% of P is lost by AE.

6.7 Average Water Budget for West Bank:

Figures (8) and (9) show the annual average P and its partitioning into estimated AE and surplus for the period 1975-1997. The P map displays the well-known pattern of higher mountain P superimposed on general west-east gradient. The percentage of P that is evapotranspired is shown in Figure (9). It will be noticed that the patterns on this map are nearly opposite those established in Figure (8): the lowest values are to be found in the west and at higher elevation and the highest values are found in the east at Jordan rift or valley. This relationship is to be expected, as areas of higher P will generally be areas of greater cloudiness and less sunshine. Water D, defined here as a difference between actual and potential evapotranspiration, is shown in Figure (10). The values here are very high, for most of the West Bank there has an annual D (accumulated during the summer months) more than 600 mm

The average monthly water budget for the entire West Bank is shown in Table (19) and figure (11). They clearly show that, on average, P receipt is sufficient to meet water need in some months. P amounts are greatest (over

75 mm) from December to March when evapotranspiration is less; consequently this is when the largest surpluses are generated.

Table (18) Annual and Monthly water budgets for Hebron. (mm)*

	P	=	(PE	-	D)	+	S	±	Δ ST
Annual	**599**	=	**(776**	-	**504)**	+	**327**	±	**0**
Jan	134	=	(14	-	0)	+	120	±	0
Feb	142	=	(18	-	0)	+	124	±	0
Mar	92	=	(31	-	0)	+	61	±	0
Apr	25	=	(56	-	0)	+	0	-	31
May	5	=	(88	-	14)	+	0	-	69
Jun	1	=	(107	-	106)	+	0	±	0
Jul	0	=	(120	-	120)	+	0	±	0
Aug	0	=	(114	-	114)	+	0	±	0
Sep	2	=	(93	-	91)	+	0	±	0
Oct	15	=	(74	-	59)	+	0	±	0
Nov	67	=	(41	-	0)	+	0	+	26
Dec	116	=	(20	-	0)	+	22	+	74

* Source: by author.

From April, evapotranspiration exhibit a symmetrical pattern with maximum values of 154 mm occurring in July. It is in the months of April, June, July, August, September and October PE surpasses P locally and water is drawn from storage. However, AE in these months is still less than PE so that a high D occurs. This withdrawal is quickly replaced by the end of November during which P exceeds PE for most of the West Bank (the D in this month is due to the fact that the spatial distribution of P and PE are not perfectly correlated). From December to March the S generated increases with each month, for example, in January, about 83.5% of P is S. On an annual basis, it was estimated that AE equaled 55.8% of precipitation, leaving a water surplus of 44.2%. In other words, more than half of the water returns to the atmosphere and the rest becomes as runoff or ground water recharge. Thornthwaite considered that 50% of water surplus in any month as a runoff, while the other half recharge the ground water. (Shahada, N., 1983) As 224 mm of precipitation per year illustrates water surplus, average ground-water recharge would be 112 mm per year. Consequently, this value forms more than 650 million cubic meters recharged to the aquifers in West Bank. The annual water surplus for West Bank is shown in Figure (12). It will be noticed that the patterns on this map are nearly compatible with established in Figure (8). The highest values are to be found in the West and North and the lowest values are found in the East and Southeast.

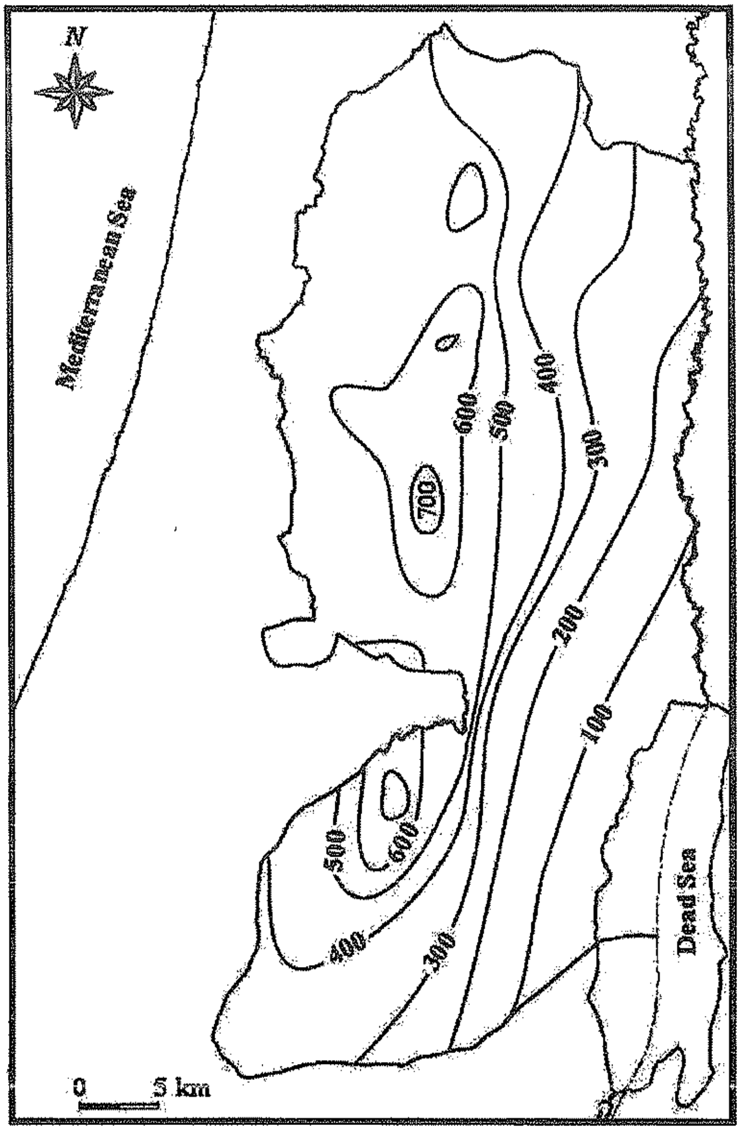

Fig. (8) Average annual precipitation (mm) for West Bank
(Source: After Applied Research Institute- Jerusalem, 2000)

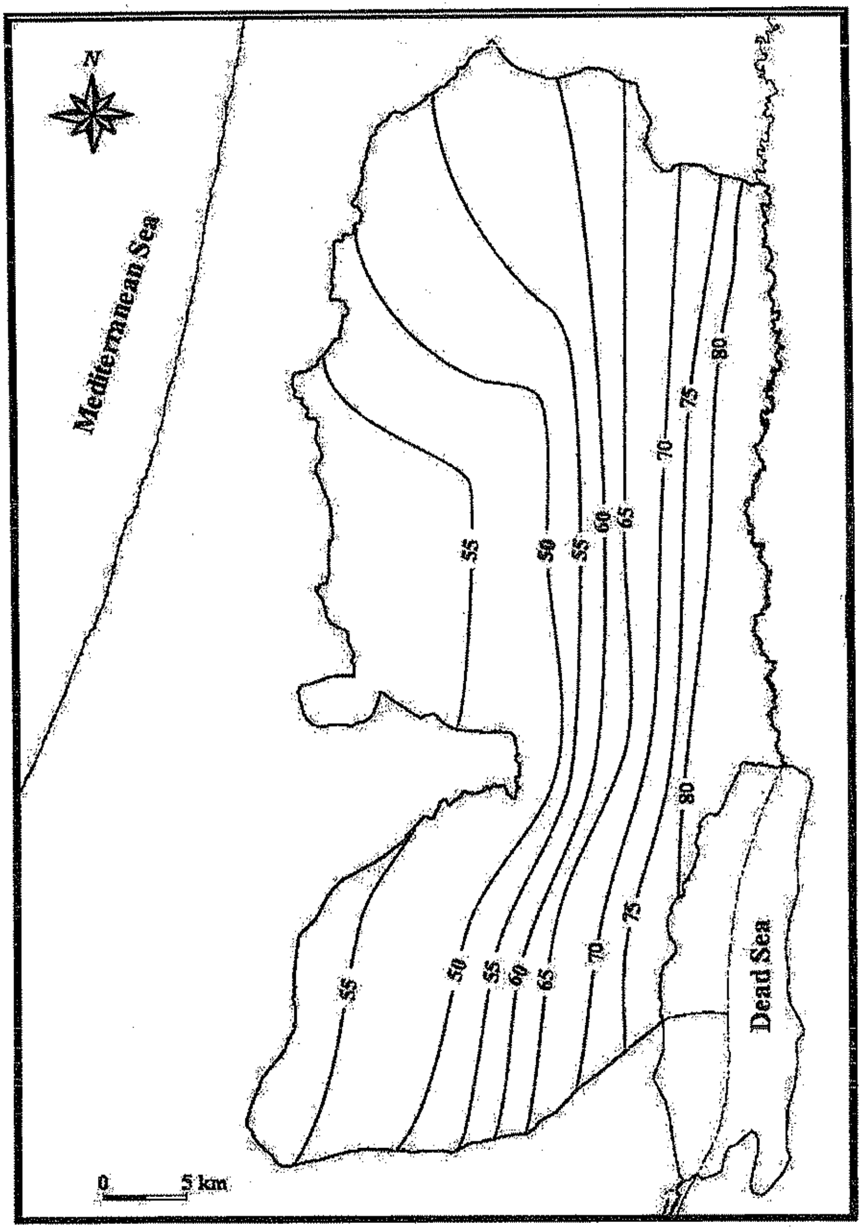

Fig. (9) Average estimated actual evapotranspiration as a percentage of annual precipitation 1975-1997.

*Source: by Author.

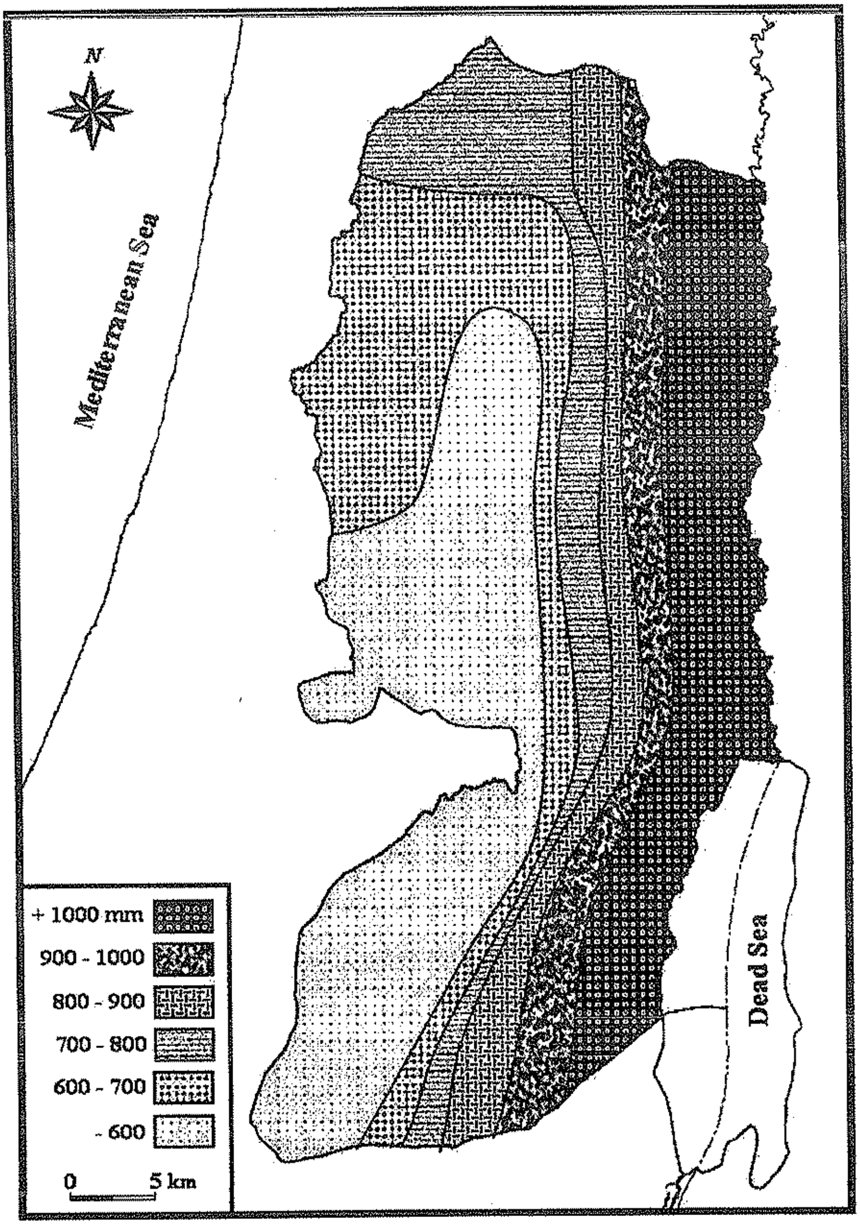

Fig (10) Average annual deficit (mm) 1975-1997

* Source: by Author.

Table (19) Water budget for West Bank. (mm)*

Mon.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	109	107	79	19	4	0	0	0	1	16	63	109	**507**
PE	18	21	36	67	105	133	154	151	122	91	47	21	**966**
P-PE	91	86	43	-48	-101	-133	-154	-151	-121	-75	16	88	**-**
P+ST	209	207	179	119	56	0	0	0	1	16	63	125	**-**
Δ ST	0	0	0	-48	-52	0	0	0	0	0	16	84	**± 0**
ST	100	100	100	52	0	0	0	0	0	0	16	100	**-**
AE	18	21	36	67	56	0	0	0	1	16	47	21	**283**
D	0	0	0	0	49	133	154	151	121	75	0	0	**683**
S	91	86	43	0	0	0	0	0	0	0	0	4	**224**

* Source: Prepared by author.

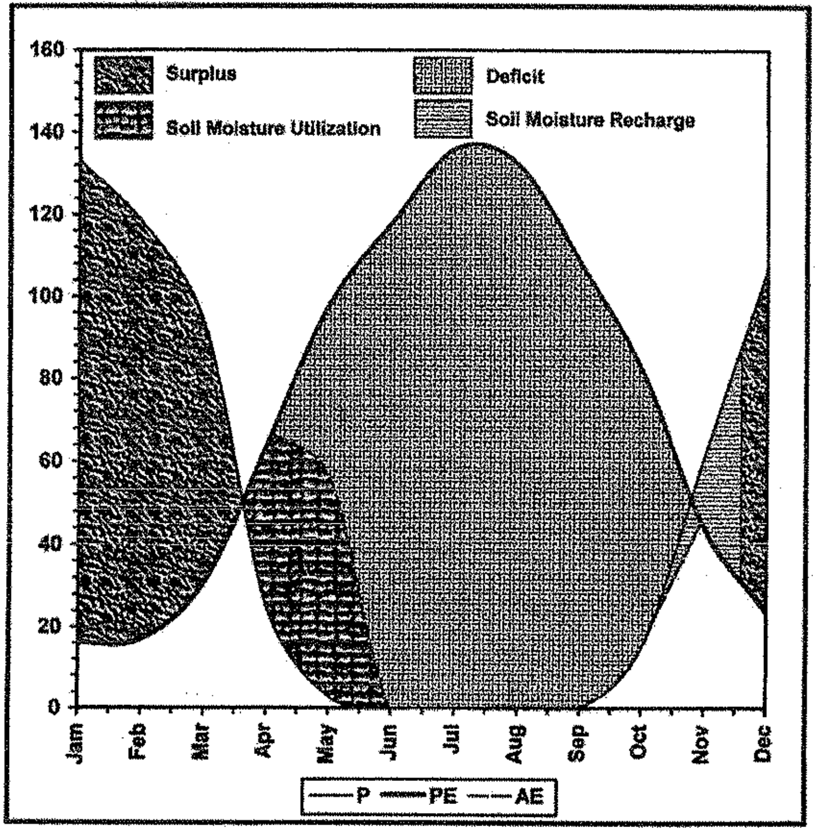

Fig. (11) Average monthly water budget for West Bank. (mm)

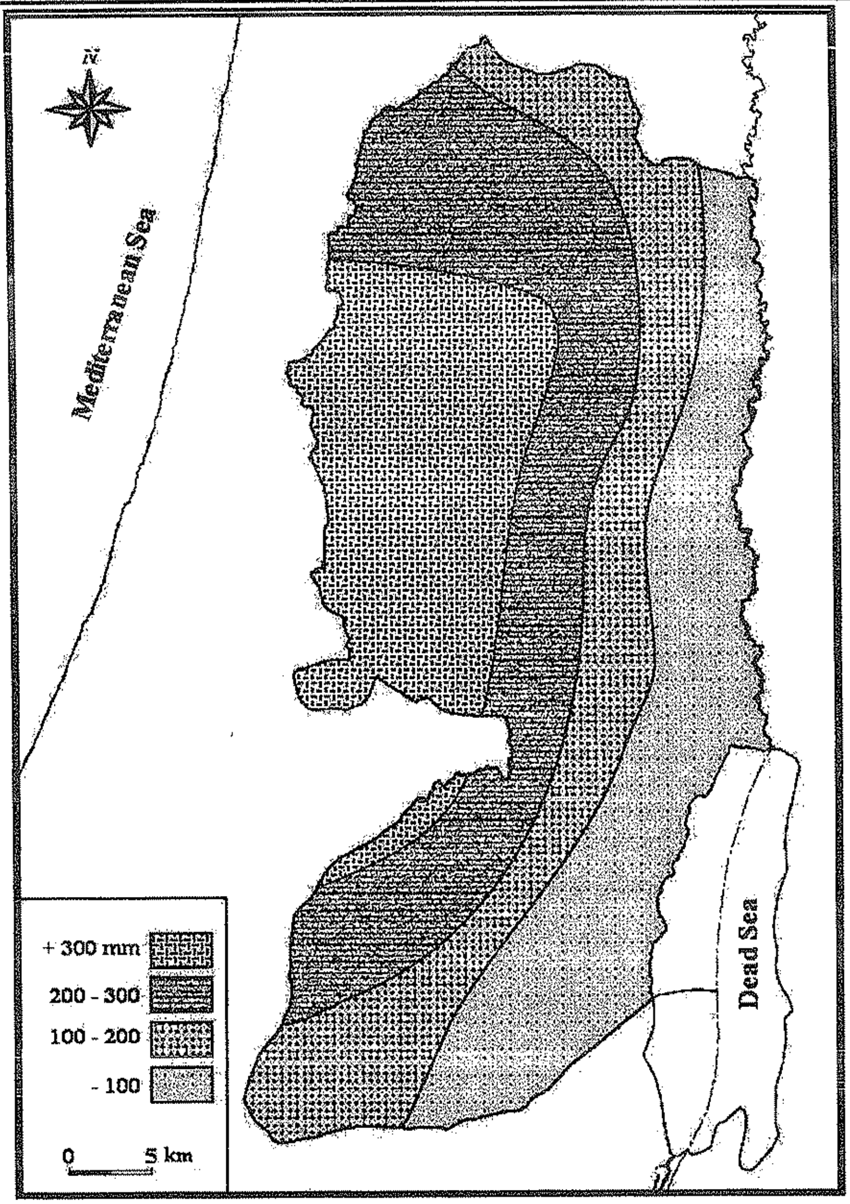

Fig. (12) Average annual surplus (mm) 1975-1997.

Source: by Author

7. Summary and Conclusions:

The water budget approach offers a comprehensive assessment of evapotranspiration, soil water, surplus and deficit. This paper has described the application of a simple water budget (Thornthwaite water budget) on the West Bank. This work has provided the most detailed temporal and spatial evaluation of the components of the water budget over a significant period of time. The results indicate that while West Bank as a whole receives sufficient water in some months, from December to March, to meet vegetation or soil needs there can be substantial deficits. The period of deficit extends from May to October and forms in average 683 mm.

In this water budget a variety of meteorological data has been used. Estimation of potential evapotranspiration is the most problematic of budget terms. The limited number of stations and the absence of widespread measurements of wind, potential evapotranspiration, temperatures, and humidity prevent the application or development of more realistic or comprehensive methodologies. So, a mathematical and statistical approach is employed here to estimate PE and other variables like daylight, which is needed to estimate PE, in each area.

REFERENCES

1) Applied Research Institute – Jerusalem, (2000), ***An Atlas of Palestine, The West Bank and Gaza***, Jerusalem, (ARIJ), p. 80.

2) Barringer, J. & Lilburne, L., (1999), "Scale Issues in Developing Regional-Scale Soil Water Balance Surfaces", ***Presented at SIRC 99 – The 11th Annual Colloquium of the Spatial information Research Center***, University of Otago, Dunedin, New Zealand, December 13-15th 1999, pp. 1-9.

3) Broner, I., (2001), ***Irrigation Scheduling: The Water Balance Approach***, Colorado State University Cooperative Extension, Report No. 4.707, pp. 1-7.

4) Christopherson, Robert W., (1992), ***Geosystems: An Introduction to Physical Geography***, New York: Macmillan Publishing Co., pp.230-233.

5) Critchfield, J. Howard, (1974), ***General Climatology***, 3rd edition, New Jersey, Prentice-Hall, p. 250.

6) Heine, R. W., (1984) ***How to keep a soil moisture balance***, New Zealand Meteorological Service Information Publication 10, p.7.

7) Huang, J., Dool, H. V. D., and Georgakakos, K. P., (1996), "Analysis of Model-Calculated Soil Moisture over the United States (1931-93) and Application to Long-Range Temperature Forecasts", ***Journal of Climate, Vol.9, No.6,*** pp. 1350-1362.

8) Jensen, M. E., R. D. Burman and R. G. Allen (1990), ***Evapotranspiration and Irrigation Water Requirements***, ASCE – Manuals and Reports on Engineering Practice, No. 70.

9) Maidment, David R. and others, (1997), Water Balance of the Niger River Basin in West Africa, ***Presented at the 17th Annual ESRI User Conference, San Diego, CA, July 1997***, p. 10.

10) Martens, Daniel M., (2001), ***Technical Sheet Reference***, Department of Local Government & Martens & Associates Pty Ltd, pp. 1-3.

11) Microsoft Corporation, (1993-1999) "West Bank", in ***Microsoft Encarta Encyclopedia 2000***, p.1

12) Orni, E. and Efrat, E., (1976), ***Geography of Israel***, 3rd Revised Edition, Jerusalem, Israel Universities Press, p.196.

13) Palestinian National Authority, Ministry of Transport, Metrological Office, (1998), ***Palestine Climate Data Handbook***, Ramalla, West Bank.

14) Reed, Sean M., (1997), ***Soil-Water Budget, PART I: Methodology and Results***, FAO/UNESCO Water Balance of Africa Project, pp.1-16.

15) Sabaev, M. & Miretskiy, Y., (1997), ***Soil Water Budget***, Project Java Webmaster: Glem A. Rivhard, Center for High Pressure Research, Sunny Stony Brook. http://www.esere.stonybrook.edu/ProjectJava/SoilMoisture/.

16) Sabaeve, M. & Miretskiy, Y., (1997), ***Soil Water Budget***, Project Java Webmaster: Glenn A. Richard, Center for High Pressure Research, SUNY Stony Brook, pp. 1 F.

17) Shahada, N., (1983), ***The Practical Climate*** (In Arabic), Jordan, The Typical Annour Press, p. 128.

18) Te Kung, H, (2003), ***Lectures in Water Resources***, Lecture No. 5, Department of Geography, Memphis University, USA, http://cas.memphis.edu/~hkung/geog4231/ Lecture5%20%20Water%20Budget.DOC

19) Thornthwaite, C. W. & Mather, J. R., (1955), "The water budget and its use in irrigation", in ***Water***, Washington, USDA Yearbook of Agriculture, pp. 346-357.

20) Thornthwaite, C. W., (1948), "An approach toward a rational classification of climate", ***Geographical Review***, N0. 38, pp. 55-94.

21) U.S. National Academy of Science, (1999), ***Water for the Future, The West Bank and Gaza Strip, Israel, and Jordan***, Washington, DC, National Academy Press, pp.28-30.

22) Wanielista, M. P., (1990), ***Hydrology and Water Quantity Control***, Canada, John Wiley & Sons, Inc, p.92.

23) World Weather Information Service, (2003) ***Weather Information for Jerusalem***, http://www.worldweather.org