ENVIRONMENTAL HYDROLOGY OF JORDAN

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ABSTRACT : The rainfall availability and optimal use of water have always been important to agriculture, particularly in areas which are deficient in water. Among the many countries in the Middle East, Jordan is one which has sizable part of its land under arid and semi-arid conditions and the farmers have to adjust the crop pattern and regime to suit the water availability conditions.

The present paper attempts of an appreciation of the actual water availability and the possible adjustment of crops to these conditions, to understand the conditions of water availability, water balance approach has been adopted. After a thorough review of available literature it was found that basically the Thornthwaite's formulae of book keeping procedures are satisfactory and fit very well within the framework of the water balance approach. Therefore, it was chosen in this study for the determination of water surplus, water deficit, soil moisture detention, water run off and environmental stress. Almost every process occurring in plants is affected by the water balance parameters which have a great impact upon the environment.

INTRODUCTION

When talking about Jordan, I have in mind the two circles in which one should be active, these are water and agriculture. In this regard, the rate of development is very important. Its not enough to say that Jordan is doing better than the others. What has been done in these fields have to be adjusted to suit the great changes that are overwhelming this area, geographically, geopolitically and geoeconomically. While talking about Jordan also, I have in mind the rivers, the kingpin, which determine the climate, the soil and the very atmosphere of all this area. A round have sprung up over the centuries, great culture, religion and empires.

Indeed, water as a relatively scarce resource, many problems surround its exploitation or supply, the reconcilation of local values with national needs, the desirability of working out overall strategy rather than a series of short-term policies, and the organizational and psychological constraints in securing adequate future amount. The longterm organizational barrier to a national approach to the exploitation of Jordan's water resources was the existence of several water supply undertaking. The psychological barrier is to be found in the public's

unwillingness to bear the real cost of a level of water consumption. In Jordan, the local versus national clash of interest derives from spatial dichotomy between the supply and demand for water. The conflict between local and wider interest and between short and long term solutions may be highlighted from the north of the country.

METHODOLOGY

The main climatic constraints in crops regime is potential evapotranspiration which represent the water need. It defines the degree of moisture or dryness of the climate in which crops are raised. Thornthwaite (1) gave an empirical relation for estimating potential evapotranspiration. This relation is based on three parameters:

1. Mean temperature.

2. Length of the day.

3. The latitude of the place.

The computation of potential evapotranspiration by Thornthwaite was a means of showing the income from rainfall and its distribution through evapotranspiration and run off, the reserve which is the storage in the soil, the water deficit and the water surplus in the process of running off. The input data used for computing the water balance of Jordan are:

1. Mean monthly temperature.

2. Mean monthly rainfall.

3. Information on the water holding capacity of the depth of soil, and

4. Necessary conversion and computational tables.

A large number of stations have no recorded temperature data, and adjustment calculations are made to get the mean, monthly and annual temperature for the concerned stations. The precipitation data are available for all the stations under study,

as published by the Jordan Meteorological Department. For computing the water holding capacity of the soils of the country, two different factors have been considered:

1. The soil type and texture.

2. The vegetation grown on the surface.

The relation between the above two factors is the depth of the root zone. Measurements of the water holding capacity of the soils in Jordan are not available for many places, and the estimating of water holding capacity has been done from indirect evidence of the natural vegetation (2) and soil maps (3).

The tables for use in the computation of the water balance have been prepared for value of water holding capacity varies from 75–200 mm.

The basic procedures in computation of the water balance of Jordan to work out the following steps (4):

1. The heat index (i) correspond to mean monthly temperature.

2. Unadjusted potential evapotranspirations using the necessary Thornthwaite's tables.

3. Adjusted potential evapotranspiration, is the adjustment of the daily values of potential evaporation for month and day length by multiplying the proper correction factor (5).

4. Rainfall : The mean monthly values of rainfall for the stations based on 50 years data are considered and the average depth of rainfall over the area is calculated according to the Theissen's method. This method is a means of weighing the precipitation at gauge in proportion to their representative areas. Each gauge is assumed to represent all points closer to it than any other

gauge. A Thiessen network is constructed for the country by locating the stations on the map and drawing the perpendicular bisectors to the lines connecting the station. The polygons thus formed around each station are the boundries of the affective area assumed to be controlled by the station. The volume of rainfall over the stations is computed by multiplying each station's rainfall by its area. (Fig. 1)
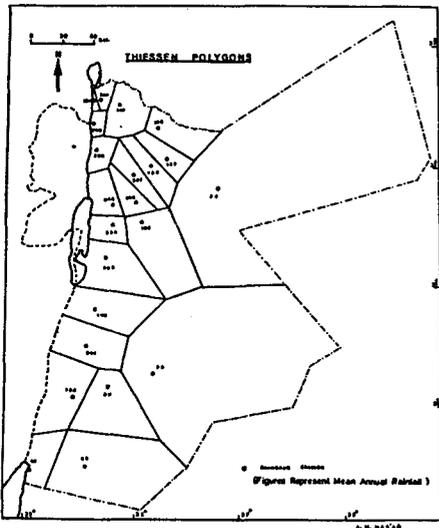

Fig. 1

5. Rainfall minus potential evapotranspiration to determine the periods of moisture excess and deficiency.

6. Accumulated potential water loss gives an estimate of the moisture stored in the soil at the end of the negative period, (P–PE)

7. Soil moisture storage, obtained from the tables available.

8. Change in soil moisture storage, which shows the difference in the amount of soil moisture storage from one month to the next.

9. Actual evapotranspiration is the real or the measured amount of evapotranspiration at any time.

10. Moisture deficit, which is the difference between actual evapotranspiration and potential evapotranspiration.

11. Moisture surplus, which is any excess rainfall after the soil mosisture storage reaches the water holding capacity.

12. Water run off which is considered as 50% of the surplus water, and the other 50% is detained on the watershed and made available for run off during the next month (6).

13. Moisture detention is total water stored within the soil.

The hydrological characteristics of Jordan are delimited by the above parameters. The most useful aspect ·of these parameters is that no data other than temperature and rainfall are required. Since these are more readily available data than the river discharge the water yield in the country has been computed by taking the mean annual values of different water balance parameters.

$$P = AE + S \quad (1)$$
$$D = PE - AE \quad (2)$$
$$AE = PE - D \quad (3)$$
$$S = P - (PE - D) \quad (4)$$
$$RO = S / 2 \quad (5)$$

Where, P = Precipitation (income).
AE = Actual evapotranspiration.
S = Surplus.
D = Deficit.
PE = Potential evapotranspiration (expenditure).
RO = Runoff.

WATER BALANCE PARAMETERS

Potential evapotranspiration is the main parameter to determine the water need of the country. It is the water loss from an extensive, closed cover of the homogeneous vegetation that never suffers from a

lack of water (7). It is the maximum loss of water through evapotranspiration under the optical conditions of soil moisture and vegetation where the water supply is un-limited. It indicates the optimal water need for irrigation and it is considered a varying factor which varies from region to region depending on the factors to the region that influences evaporation and transpiration (8). It is independent of rainfall and can be equal, higher or lesser than the rainfall.

This is because that the factors controlling the PE are not the same for rainfall.

PE equals the AE in the period when rainfall is greater or equal to PE. The difference between PE and AE during certain period is an indicator of how much of water supply is necessary to facilitate normal growth to prevent drought (9). In Jordan as a normal condition, AE never exceeds PE but it falls considerably below it due to shortage of water supply in the soil. Precipitation is greater than PE from Decem-ber — March, and this period decreases by going towards the south and reaches only 2–3 months from December–February. Again this period decreases rapidly by go-ing towards the east and the south—east where the rainfall never exceeds the PE. (Fig. 2.1).
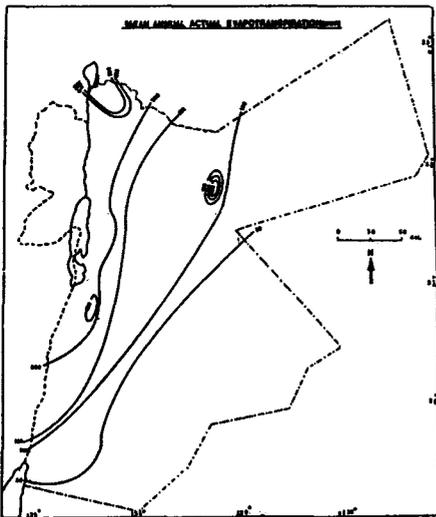
In the period of higher rainfall than the PE, the soil remains at field capacity, and some water is added to surplus. In Jordan, April is the first month in which the rapid rise of PE which exceeds the supply of water from rainfall, and the rain-fall has failed to supply the water needs. Some of this need is supplied by the water stored in the upper layer of the soil, but ultimately this amount of water is not suppli-ed by rainfall. As the soil dries, water is not available from the upper soil layers and nothing is removed from the soil to help supply the need. This is, therefore, the water deficit which is the highest in June, July and August all over the country. (Fig. 2.2).
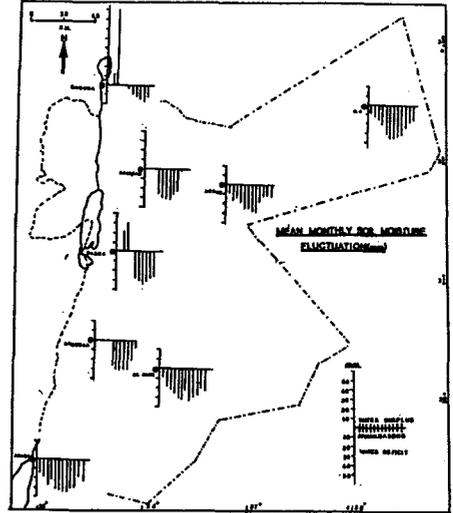

Fig. 2.2

In general, the surplus water, that moisture over what is needed for evapo-transpiration or storage in the soil, is ulti-mately lost as runoff. This is not immediate for it takes some time for the water to move down to the groundwater table and through the soil to emerge again in surface streams or rivers. The rate of runoff is higher in the northern hilly zone of the country depends on the size of the water shed, its slope and the type of the soil in this region which the water must move. It is assumed that 50% of the surplus water available in any month is actually lost by runoff, while the remain-ing 50% is held over and added to available

Fig. 2.1

surplus in the next month. Surplus and run-off are totalling the same amount on an average annual but the monthly distribution of each of them is different.

DEW AS A SOURCE OF MOISTURE

Dew formation is considered as an additional moisture source for winter crops in Jordan. In January the crops in the rabi ·tracts reach the peak consumptive stage, and the water stress (P—PE) is the lowest in this month, so the additional source of moisture will be from dew which ranges from 0.5—0.7 mm. But in the arid zone of south and east Jordan, dew formation is negligible and has no contribution to soil moisture where the water stress increase.

SEASONAL VARIATIONS OF WATER BALANCE PARAMETERS

POTENTIAL EVAPOTRANSPIRATION

In July the monthly potential evapotranspiration reaches about 800 mm in the southern desert where as in the north the monthly values do not exceed 350 mm As it is illustrated, average PE in January is less than 50 mm in the mountainous regions. It increase to more than 70 mm in the southern parts to reach 300 mm in the Badia. The average annual PE varies from 2000 mm to 4600 mm.

The comparison of seasonal march of rainfall and potential evapotranspiration shows that the rainfall is greater than potential evapotranspiration from December to March in the north, and there is a fair balance between the water surplus and deficiency, both are small, but the area has got the advantage of location where a good amount of water resources originate primarily from catchments in Syria. Towards the south and the east the rainfall never exceeds the potential evapotranspiration and the deficit become higher with absence of any type of soil moisture recharge.

WATER SURPLUS

Most of the country has no water surplus. A small area of winter water surplus is found in the mountains of Ajlun and Balqa. The areas of more than 500 mm of rainfall are the areas of 200 mm water surplus which is mainly a few pockets in the north of the country. (Fig. 3).
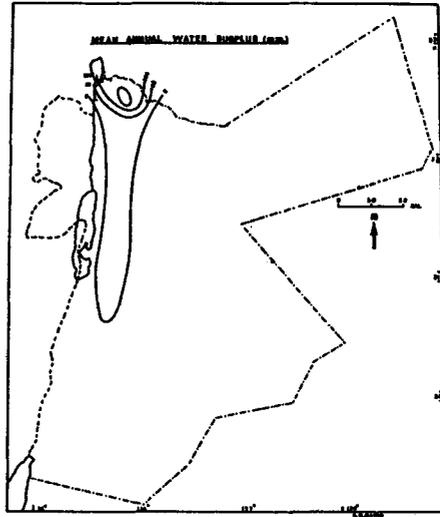

Fig. 3

There is no prolonged water surplus period in Jordan and is confined to a few months extending from January to April and covers a limited areas. The first surplus is noticed in the month of January when the Northern hilly tracts receive the early rains ·in excess of the potential evapotranspiration. Thereafter, there is a progressive shift of zero line of water surplus, towards the east. in these months, the excess in rain will go into soil moisture storage and it will be available to the crops in the following months. In the case of excess rainfall exceeds the water holding capacity of the soil, the surplus water will go into runoff which is mainly concentrated in small pockets in the western zone of the country. Summer months are a soil moisture utilization season and there is no surplus but moisture deficit occurs.

WATER DEFICIT

Annual moisture deficit varies from 350 mm in Ras Muneif and 400 mm in Naur to a maximum of 1800 mm in Ghor Safi and 1600 mm in Aqaba. (Fig. 4).
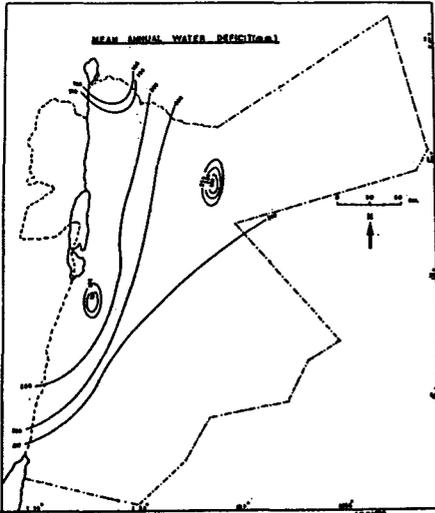

Fig. 4

After considering the potential evapotranspiration values for every month, it was possible to trace following pattern of water deficit. From November, when the rainfall starts, the zero line of water deficit moves towards the east. In January, this line moves further towards the east and divides the country into the western deficit free zone and the eastern deficit zone. In April, the zero line moves again towards the west and there is no surplus, but moisture deficit in various degrees occurs. May to October are dry months with negligible soil moisture, low actual evapotranspiration and higher water deficit.

WATER STRESS

The water stress is the difference between the income from rainfall and the expenditure from potential evapotranspiration which shows the parts of the country which has a positive values on a monthly base. The positive values (P–PE) in the western part indicates the amount of excess water available during the concerned period for soil moisture recharge and runoff. The negative values indicates the amount by which the rainfall short of the supply to the potential water needs of the crops. In summer months, the crop reach the peak consumptive stage, and the water stress is the lowest, so the additional source of moisture will be from dew. But in the arid zone in the east and south the dew formation is negligible and has no contribution to soil moisture where the water stress increase. (Fig. 5.1 - 5.2).
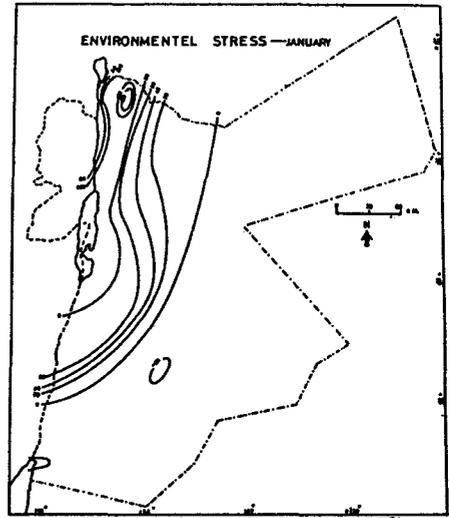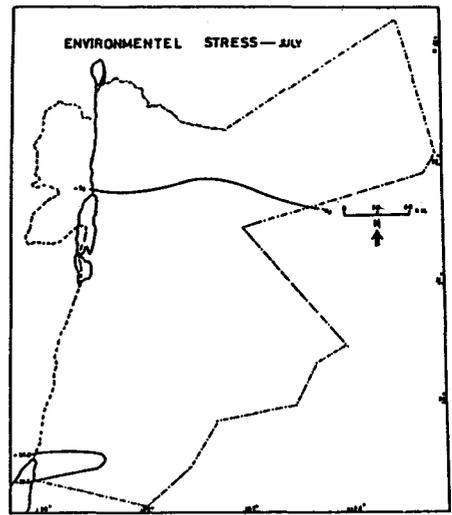

Fig. 5.1

Fig. 5.2

WATER DETENTION

The following factors are relevant for studies of the water detained in the soil:

1. Both parent material and geomorphology of the site are significant for soil moisture storage, percolation, and infiltration-runoff characteristics.

2. The stage of weathering of geological deposits and the extent of decay of organic matter help to determine basic soil features such as clay content, humus content, clay mineralogical composition and depth of soil formation.

All these influence the soil moisture detention. The increase of plant available from coarse to fine textured soils is very well shown in the following table (10):

Soil texture	Permeablility mm/hour	Total pore space (%)	Apparent specific gravity (g/cm^3)	Moisture at field capacity (Volume %)	Moisture at permanent wilting (Volume %)
Sandy	25–250	32–42	1.55–1.8	9–22	3–11
Sandy loam	12– 25	40–47	1.04–1.6	14–29	6–13
Loam	8– 20	43–49	1.35–1.5	24–39	11–18
Clay loam	2– 15	47–51	1.03–1.4	30–43	14–21
Silty clay	2– 5	49–53	1.25–1.35	34–47	16–23
Clay	1– 10	51–55	1.02–1.3	37–51	18–25

3. Topographic features as a landscape are usually indicated on general soil maps by contour lines. From this and the system of surface water flow, the drainage pattern and slope position of soils can be interpreted. It is normally safe to conclude that soils on hillslopes are less deeply developed and contain less fine material than those in low-lying land, and any drainage impediment is more likely to occur in the lowland area.

4. Finally, the effects of land use and improvement have to be considered Land use maps combined with soil maps provide a workable basis for estimating the influence by agriculture and urbanization on soil water related.

Soil water detention are of particular interest to farmers who practise irrigation or systematic soil moisture conservation. Soil salinization may have a natural origin influenced by high groundwater tables, but it can be produced artificially by irrigation. (Fig. 6.1–6.2).
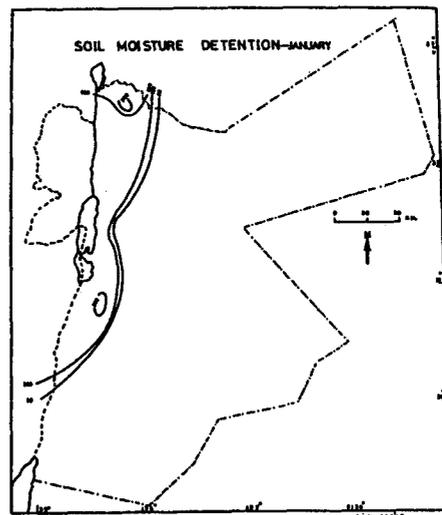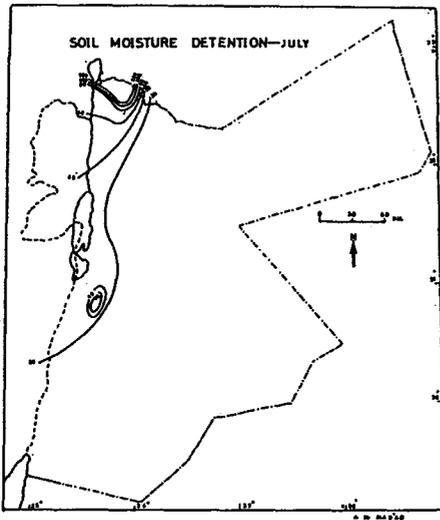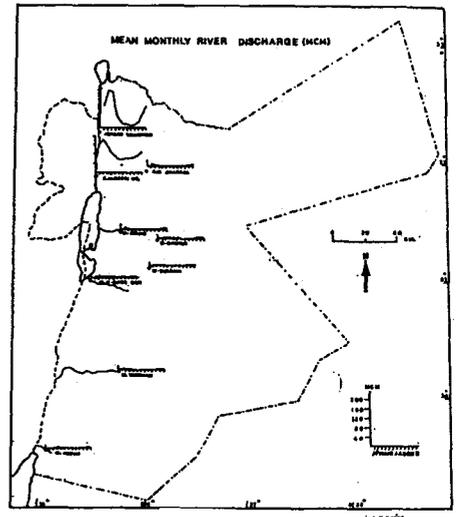

Fig. 6.1

Fig. 6.2

Fig. 7.1

STREAM FLOW

The volume of rainfall over the country is computed by multiplying each station's rainfall by its area. Accordingly the total volume of rainfall has been estimated at 12129.4 mcm. Out of this, the run off is of the order of 880 mcm. It is to be noted that large portion of this runoff are to be attributed to the resources in the Yarmouk River at Adasiya. They originate primarily from catchments in Syria, and the analysis indicate that considerable parts of these flows result from groundwater discharge rather than from direct rainfall runoff, during the annual rainy season between November and May. The estimated potential annual stream flow reflect the general tendency of decreasing resources, when comparting the catchments from the north to the south of Jordan. (Fig. 7.1).

In the northern areas, the computed difference between rainfall and stream flow correspond to about 20% of the calculated potential evapotranspiration. Higher values refer for Wadi Umm ed Dananeer and Wadi Abdoun, where the percentages reach 28% and 25% respectively, the groundwater recharge seems to be high. The lowest values refer to the southern desert regions,

where only two per cent of the annual potential evapotranspiration seem to be satisfied by the available precipitation. It should be further considered that the calculated surface flow in these areas is most likely percolating to the ground water. (Fig. 7.2).
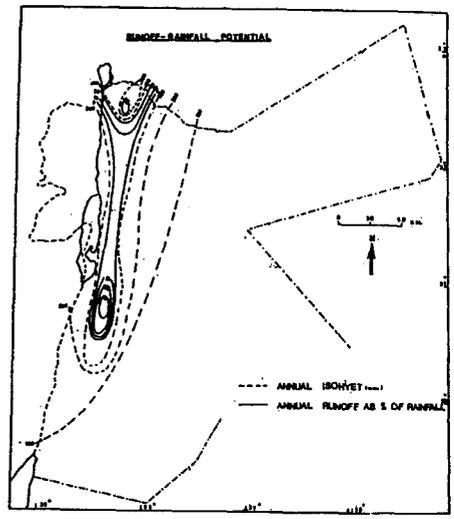

Fig. 7.2

DROUGHT PARAMETERS

Thornthwaite's formula has been equipped with a number of ratios and indices to use in climatic classification. The moisture ratio is used to obtain the relative humidity and aridity. Humidity and aridity

indices are used in determining the climatic type of Jordan.

The humidity index is a ratio between water surplus and water need, and the aridity index is a ratio between water deficit and the water need. Both the ratios are expressed in terms of percentage:

	Ih	=	100 S / PE
	Ia	=	100 D / PE
where	Ih	=	is a humidity index
	S	=	surplus.
	PE	=	Potential Evapotranspiration
	Ia	=	Aridity index.
	D	=	Deficit.

In the event of total absence of rainfall all the time, the aridity index will be 100%. But for the humidity index to become 100%, the water supply must be twice that of the water need, and the water surplus should be equal to PE. Because water supply and the water need are based on different climatic parameters and independent of each other, the water surplus does not equal to water need.

The water surplus of one month may prevent water deficiency in the other month. Thornthwaite (1948), emphasized that six inches of water surplus in one season will compensate for ten inches of deficiency in another. That's why he considered the ratio of the humidity index higher than the aridity index.

According to the moisture regime, large areas of the country are semi-arid and the southern and eastern parts are classified as arid zone. The negative values of the moisture index are found all over Jordan with the exception of a few stations in the north.

The moisture index is used to delimit the moisture regions of Jordan, and is determined by whether the water deficiencies and surplus are large, moderate or small.

1. The arid climate occurs in a large areas of the country, where the values of moisture index are higher than (−66.7) and the values of the aridity are higher than (60), while the value of the humidity index is zero.

2. The semi-arid climate occurs in the rest of the country where the values of moisture index ranges from −33.3 to −66.7 and the aridity index varies from 40−60. The humidity index for this region is less than 16.7.

3. Dry sub-humid climate occurs in eastern hilly tracts of Jordan. The values of moisture index are between 0 to −33.3, while the ardity index is below 60 and above 20, which is still classified under the large water deficit region according to Thornthwaite's classification. The humidity index varies from 16.7−33.3, and it is considered as a region of moderate water surplus.

Moisture sub-humid climate occurs in small area in the north where the values of moisture index ranges between 0−20, while the aridity index is below 20. The humidity index is above 33.3. (Fig. 8).
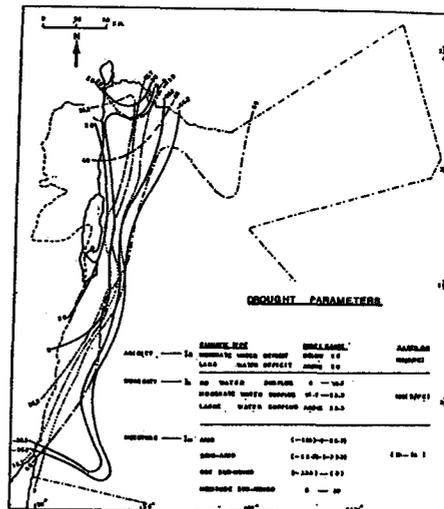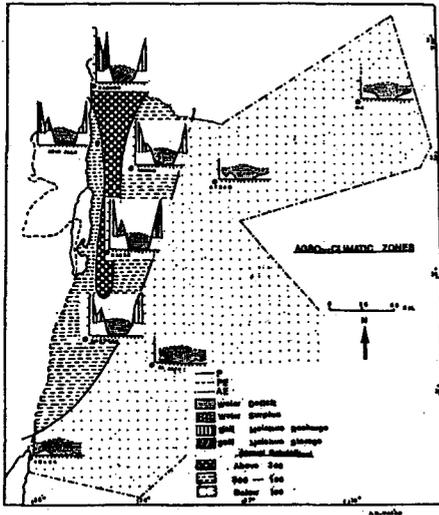

Fig. 8

Fig. 9

Consequently, Jordan can be divided into three agroclimatic zones: (Fig. 9).

1.   In the high mountains of Ajlun and Balqa, the water deficit occur in the nonrainy season, the water deficit is the result of rainfall variability and irrigularity. The climatic water balance shows water surplus in the rainy month and low water deficit in the following months as well as substantial runoff rate. Here agriculture should be supported by irrigation if necessary to the needs of the individual years and crops. It should be adjustable irrigation.

2.   The Jordan Valley, has the driest climate and experienced water deficit in different degrees, it increased towards the south. Here agriculture should be supported by substantial and if possible by Permial Irrigation.

3.   The arid zone in the east and the south. This region experienced water deficit in high degrees. Water deficit is the result of the low rainfall and high evapotranspiration. The climate water balance shows no

surplus in any season. Here agriculture in some pockets should be supported by peremial irrigation based on ground water resources.

Water balance parameters for Jordan shows a uniform drought pattern over the country, and this indicate that the water deficit is the dominant. But how large the water deficit is? Since the aridity index for the country is above 20, Jordan should be considered a large water deficit region.

After considering the Potential Evapotranspiration and actual evapotranspiration (11) values for every month, it was possible to trace two main seasons:

WINTER SEASON

In general this season spreads from November to April. In this season the rainfall can exceed potential evapotranspiration. The excess in rainfall will go into soil moisture storage and it will be available to the crops in the following months. In case the excess rainfall exceeds the water holding capacity of the soil, the surplus water will go into the runoff. This is the only season in which water storage and water surplus occurs. However, the south and eastern parts remain deficit areas throughout the rainy season, though the water deficit decreases. Rainy months vary from 3—4 months in high mountains of Ajlun and Balqa, to 2—3 months in the Jordan Valley, where it is only 1—2 months in the southern and eastern desert. The two main rainy months are December and January. Spring is a soil moisture utilization season and there is no surplus, but moisture deficit occurs.

SUMMER SEASON

This is the dry season negligible soil moisture, low actual evapotranspiration and high water deficit. It extends from May to September approximately.

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