

Drought occurrence and impact on the Eastern Groundwater Basin—West Bank/Palestine

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Abstract The past few years have witnessed annual precipitation of less than average in the West Bank. The most severe decrease in precipitation occurred in the year 1998–1999. This paper presents a quantitative characterization of the 1998–1999 droughts and assesses its hydrological impact on the Eastern Groundwater Basin in the West Bank/Palestine. Various climatic time series were gathered and a detailed statistical analysis was made. Such analyses assisted in the understanding of the impact on water yield and on the state of the natural resource. The preliminary results reveal that pumping rates can be adapted to fluctuations in natural replenishment by adopting a dynamic operating rule. Yet, the regression analysis used establishes the initial steps in modelling the groundwater system. Both the level of hydrological system modelling and monitoring fall short of those required for planning the management of drought conditions in this area.

Key words climate change; drought event; drought frequency; drought year; groundwater basin; precipitation; West Bank

INTRODUCTION

Drought is a natural phenomenon that may have a grave impact on the availability of fresh water resources if it occurs frequently, especially in semiarid areas where no alternative water resources are available and the only source for replenishment is rainfall. Despite the fact that the concept of drought means different things to different people, its quantification is very crucial in managing water resources in a sustainable manner. Several types of drought have been differentiated in the literature: meteorological, hydrological, agricultural, environmental and socio-economical. Panu & Sharma (2002) defined three types of drought: meteorological, hydrological and agricultural droughts. Bachmat & Khaled (2000) defined a drought as below average annual rainfall.

Furthermore, the duration and frequency of drought are the determining factors in setting up suitable water resources management plans. Pandy & Ramsastri (2002) developed the concept of drought year and drought event. The latter is more crucial since it is defined as consecutive years of droughts. Therefore, it is likely to cause more severe damage and might cause substantial losses.

The current paper focuses on the meteorological and hydrological types of drought, since all other types of drought occur as a result of these two types. In addition, the paper will attempt to analyse the rainfall of the year 1998–1999 and investigate its impact on the replenishment of the Eastern Groundwater Basin. Finally, the paper will address how far the year 1998–1999 can be denoted as a year of socio-economic and agricultural drought.

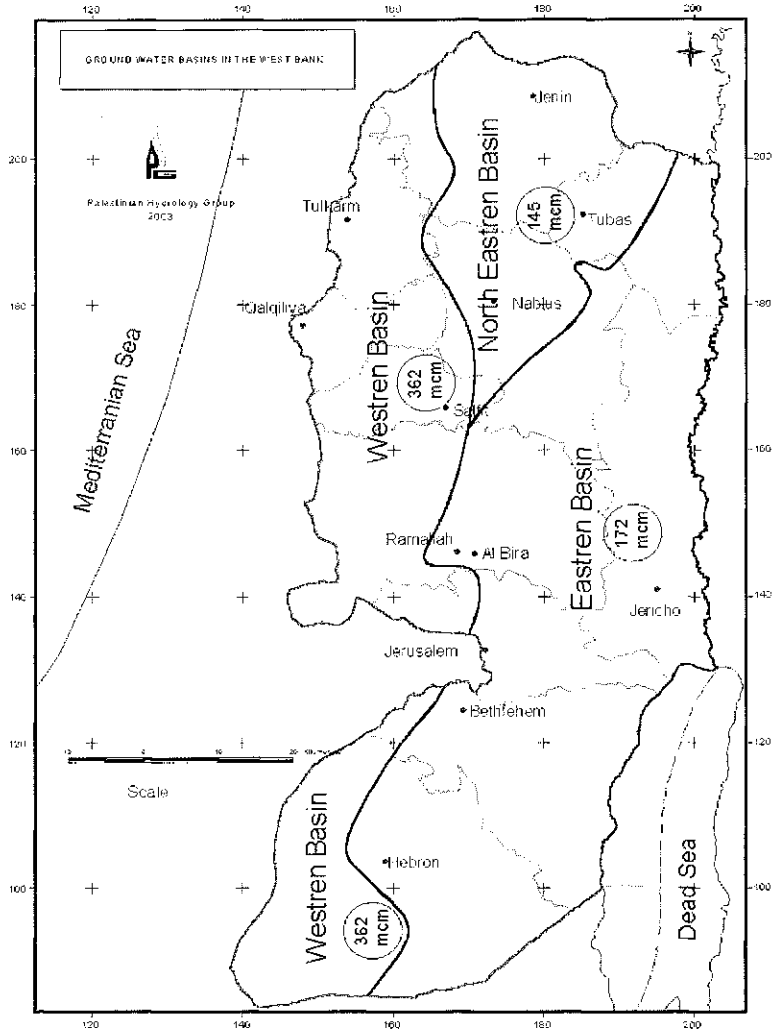


Fig. 1 The groundwater basins in the West Bank.

The basin has a surface area of 3078 km². It is confined by the Jordan River in the east and the mountain ridge of the West Bank in the West (Fig. 1).

RAINFALL CHARACTERISTICS

The annual rainfall ranges between 150 mm in the east and about 600 mm in the north. Rabi (1999) demonstrated that the number of rainy days is limited and rarely exceeds 60 days a year.

Rainfall depth has a non-uniform distribution and exhibits high spatial and temporal variability. In order to verify the variability in time and space, data from six rainfall stations was analysed. The analysis of rainfall data shows that the variability in

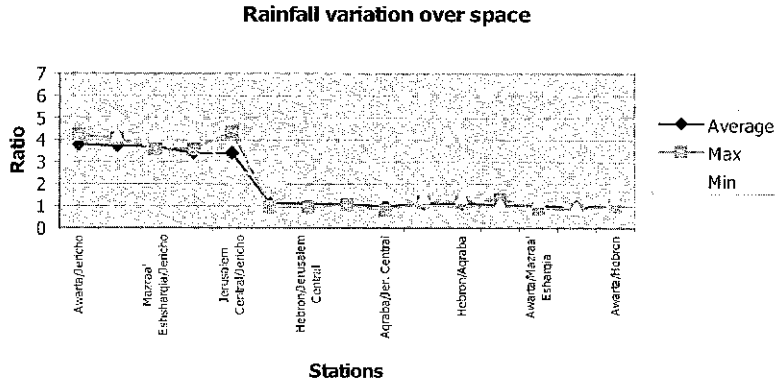


Fig. 2 Statistical measures of spatial variability in rainfall depth between stations.

yearly rainfall depth varies spatially by more than four-fold (Fig. 2). In addition, there is high temporal variability in yearly rainfall depth. Moreover, in certain years, one location may receive extraordinary (low or high) rainfall quantities as compared to other locations that usually receive similar ratios.

Homogeneity of rainfall data (stability tests)

Homogeneity tests are important tools to ensure that there is no inconsistency in the records, which may have been brought about naturally or may be man-made. These tests include two types: the F-test for the stability of variances, and the t-test for the stability of the mean. These two tests are further coupled with a third test, Spearman's rank correlation test, to indicate the trend analysis. Upon detailed analysis of the data from the six rainfall stations, it was observed that there are no changes in the mean and the variance is stable over the time of records. Moreover, there was no trend defined in any of the stations which may indicate that there is no serious climate change in the area over the past 20–30 years of records.

FREQUENCY OF OCCURRENCE OF METEOROLOGICAL DROUGHTS

The frequency of occurrence of drought years (annual rainfall depth below the average) in the region is variable in time. In other words, the time between two occurrences of drought can be described as random variable. For example, the year 1999 can be classified as a meteorological drought year, however, there would be no assurances that the following year will not be a drought year as well. The analysis of drought years over the past 30 years shows non-uniform return periods. This means that drought may occur in two consecutive years with equal probability of occurrence. Figure 3 shows how the frequency of rainfall deficits. A relative rainfall deficit greater than 50% has a nearly 8% frequency of occurrence, while a relative rainfall deficit of less than 20% is more frequent (about 30%).

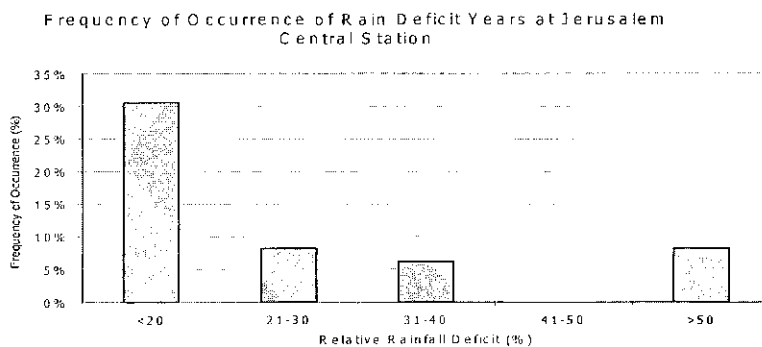


Fig. 3 Frequency of occurrence of rain deficit years.

The year 1998/99 as a drought year

There are several rainfall descriptors that classify the year 1998/99 as drought year:

- (a) The hydrological year usually starts in the middle of October, while in 1998/99, rainfall was delayed for about three months; it started in January.
- (b) Monthly totals of rainfall are much less than the average values, while the yearly total depth of the selected stations was the minimum recorded value over the whole period. The ratio between the rainfall of the year 1998/99 versus the long-term average of rainfall recorded in the six stations varies between 32 and 45%. Figure 4 shows the value of yearly rainfall depths in year 1998/99 in comparison with the historical average monthly rainfall depths. As can be observed from the figure, the crucial rainfall for agriculture, which occurs during October and November, was only 16% and 10% of the long term average respectively. Accordingly, the year 1998/99 can be denoted as an agricultural drought year. The total cultivated area during 1998/99 was nearly 28% of the cultivated area during the previous years. This has led to a huge loss in income from agriculture. Given that agriculture is considered the back bone of the Palestinian economy, contributing nearly 20% of the Gross Domestic Product and involving nearly 30% of the labour force in Palestine (Rabi, 1999), one can easily conclude that the drought of 1998/99 has had a substantial impact on the social and economic aspects. Therefore, the drought of the year 1998/99 can also be denoted as a socio-economic drought.
- (c) Drought takes place over an extended area simultaneously including the neighbouring countries.

HYDROLOGICAL DROUGHTS

A hydrological drought is defined as a decrease in stream flow or a drop in groundwater levels (Panu & Sharma, 2002). In this paper, hydrological droughts will be defined as the decrease in spring discharge and the drop in water levels. Most of the springs in the West Bank are affected by seasonal changes in rainfall quantities. They

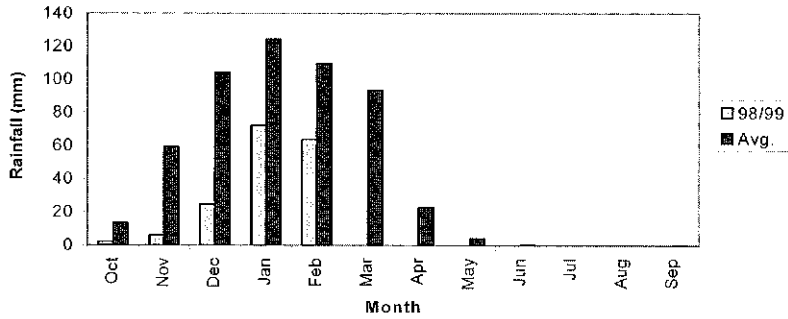


Fig. 4 Total monthly rainfall depth of year 1998/99 compared to average.

show rapid responses to variation in precipitation. Rabi (1999) reported that there is a strong correlation between rainfall and spring discharge. He also reported that the gradual increase in spring discharge during the months of December until March suggests that the springs are rapidly affected by the rainfall of the same season. The amounts of rainfall percolating increase the storage of the springs during the rainy months of November–March. When rainfall ceases (generally towards the end of March), spring recharge is halted. Consequently, storage depletion starts and continues until the next rainy season. Furthermore, the time lag between the beginning of rainfall and the rise in spring discharge is very short, nearly two months.

When the relationship between the rainfall depths and spring discharge was investigated further, it was found that the adjusted correlation improves when the rainfall of the previous years is taken into consideration. This means that the amount of spring discharge in any particular year is a function of rainfall during the same year, as well as that of the past years. The best correlation was found to be a three-year model. Once a higher number of years is taken into account, the correlation coefficient does not improve and the percentage of contribution is negligible. The type of model used to conduct the analysis could be described by the following:

$$Q_i = a_1[R_i - R_0] + a_2[R_{(i-1)} - R_0] + \dots + a_n [R_{(i-n)} - R_0] \tag{1}$$

Where: Q_i = total discharge of springs in year i ; a_n = coefficient of effective area of outcrops; R_i = yearly rainfall sum at the specified stations in year i ; $R_{(i-n)}$ = yearly rainfall sum at the specified station in years before; R_0 = threshold of effective rainfall.

The results obtained from using the above model show that, at any specific location, the effective rainfall threshold is approximately half the average areal rainfall value in any given cell or sub-basin, despite the spatial variability and distribution of rainfall. Meanwhile, the percentage of contribution of the same year rainfall in spring discharge has approximately 60% effect while the previous year has 30% effect.

Nonetheless, the impact of the 1998–1999 drought year can still be noticed. The total spring discharge recorded during the year was equivalent to 59% of the long-term total average discharge. This means that 41% of the recharge was lost to the springs during the year 1998–1999.

Groundwater levels–rainfall depth correlation

To correlate the impact of rainfall on groundwater levels, the same approach adopted in correlating the spring discharge and rainfall depth was applied. The type of model used to conduct the analysis could be described by the following:

$$D_i = a_1[R_i - R_0] + a_2[R_{(i-1)} - R_0] + \dots + a_n [R_{(i-n)} - R_0] \quad (2)$$

Where D_i = difference in water levels between year i and year $i - 1$. The rest of parameters are as defined in equation (1).

The analysis of groundwater level–rainfall depth relationship shows that the best correlation is a one-year model. Once higher time steps are considered, or the number of years of delay time is changed, the correlation coefficient does not improve and the percentage of contribution shows a negative effect. This means that the effect of rainfall on groundwater levels is a yearly event. However, when the whole aquifer system is considered, the best correlation model appears to be a three-year model. The percentage of contribution in the first year has 80% effect, which confirms the above results. It is also important to notice that the effective threshold value of rainfall (in one cell) is approximately around the mean average rainfall depth in that cell.

The above results can be explained given that the aquifer is mostly karstic; the groundwater flow velocity is relatively high, and/or the storage coefficient is high. In other words, when the rainfall in one cell (during the wet season) is above the average value, groundwater levels will rise. While during the dry season, the aquifer will drain quickly and groundwater levels return to more-or-less the original levels. In the case of a deficit year (rainfall below the average), the aquifer will relatively (and naturally) drain until groundwater levels return to the original levels.

CONCLUSIONS

The current drought is the most severe over the period of at least 60 years. Analysis of rainfall data from six stations has exhibited spatial and temporal variability. Homogeneity tests indicate that there has been no significant climate change in the area over the past 20 to 30 years of records. The analysis of drought years over the past 30 years shows non-uniform return periods. The impact of the 1998–1999 drought on spring discharge and groundwater levels has been best described via a three-year model and a one-year model, respectively. However, in order to recommend drought management plans, further monitoring and hydrological modelling is required.

REFERENCES

- Bachmat, Y. & Khaled, A. (2000) Drought impact on water resources in the Jordan River Basin, Jerusalem (unpublished report).
- Pandy, R. P. & Ramsastri, K. S. (2002) Incidence of droughts in different climatic regions. *Hydrol. Sci. J.* **47**, S31–S40.
- Panu, U. S. & Sharma, T. C. (2002) Challenges in drought research: some perspectives and future directions. *Hydrol. Sci. J.* **47**, S19–S30.
- Rabi, A. (1999) Optimum intersectoral water allocation in the West Bank. PhD Thesis, Washington International University, Pennsylvania, USA.