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# Empirical models of rain-spells characteristics – A case study of a Mediterranean-arid climatic transect

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ABSTRACT

Environmental (geomorphological, hydrological and ecological) processes are controlled by rainfall, particularly in the Mediterranean, semi-arid and arid regions. Rainfall was analyzed using the concept of rain-spells, i.e., a period of successive rain days preceded and followed by at least one day without rainfall. Daily data from 13 stations along a climatic transect extending from the Judean Mountains with a Mediterranean climate to the Dead Sea arid region in Israel were studied. Rain-spell characteristics (number, yield and duration), based on these data, are presented for different rainfall thresholds, which might be used for different environmental processes such as rock weathering, soil organic matter dynamics, landslides, overland flow and floods and soil erosion. Three estimation models have been developed in order to predict the mean annual Number of Rain-Spells (NRS), mean Rain-Spell Yield (RSY), and mean Rain-Spell Duration (RSD) for the mean annual rainfall and for any given rainfall threshold. These models can be used for current climatic conditions and for scenarios in which the rainfall total changes.



## 1. Introduction

Rainfall is a critical factor in many environmental – geomorphological, hydrological, and ecological – processes, particularly in the semi-arid and arid regions (Lavee et al., 1998). Rainfall characteristics affect soil–plant–atmosphere relationships and determine runoff development, soil erosion and the dynamics of plant communities.

Most of the rainfall analyses have emphasized the total rainfall falling during a fixed time interval, using many time scales, i.e., one day, a pentad (De Arruda and Pinto, 1980; Gramzow and Henry, 1972), 10-days (Arnold and Elliot, 1996; Bartzokas et al., 2003), a month (Flynn and Griffiths, 1980; Holland, 1962; Jackson, 1986), a rainy season (Lázaro et al., 2001; Tennant and Hewitson, 2002), and an annual total (Lázaro et al., 2001).

The fixed time interval is mainly a statistical time unit that may be difficult to link explicitly with the synoptic situation or with the hydrological processes. Therefore, for a better understanding of rainfall – environmental processes relationships, analyses of rainfall with regard to the synoptic conditions and not to a fixed time interval is required (Houssos et al., 2009; Robinson and Henderson, 1992; Striem and Rosenan, 1973). Accordingly, the use of rain-spells (a period of successive rain days preceded and followed by at least one day without rainfall) is more appropriate.

The Number of Rain-Spells, which represents the number of wet/dry cycles is an important factor for several processes, such as rock weathering (Pejon and Zuquette, 2002), soil erosion (Rajaram and Erbach, 1999), aggregate stability (Lavee et al., 1996; Sarah, 2005; Shiel et al., 1988), and soil organic matter dynamics and microbial activity (Denef et al., 2001; Sarah and Rodeh, 2003).

The Rain-Spell Yield, which is the total amount of rainfall accumulated during a rain-spell, controls the state and evolution of soil moisture (Yoo et al., 1998). In addition, it plays an important role in determining the frequency and magnitude of several processes, such as: erosion (Richardson et al., 1983), landslides and debris flows (Gerrard and Gardner, 2000; Stoffel et al., 2011) and runoff from artificial catchments (Li et al., 2004).

The Rain-Spell Duration is an important factor for landslides and debris flows (Chien-Yuan et al., 2005), runoff (Weiler et al., 2003) and floods (Viglione and Blöschl, 2009). In the interaction between rainfall and watershed characteristics, the term "*critical rainfall*

*List of abbreviations:* DRT, Daily Rainfall Threshold; NRS, Mean annual Number of Rain-Spells; RSD, Mean Rain-Spell Duration; RST, Rain-Spell Threshold; RSY, Mean Rain-Spell Yield.

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*duration*" is used for evaluating overland flow and floods (Meynink and Cordery, 1976; Schmid, 1997).

The aims of the present study are:

1. To characterize the rainfall regime by the Number of Rain-Spells, the rain-spell's yield and their duration.
2. To develop estimation models for the prediction of the above mentioned variables as a function of the mean annual rainfall for any given rainfall threshold.

These targets will be demonstrated in a case study representing a climatic transect from a Mediterranean to an extreme arid climate in Israel.

## 2. Study area and data

### 2.1. Study area

The study area is located near the easternmost part of the Mediterranean Sea. The climatic transect is running from the Judean Mountains near Jerusalem in the west, to the Dead Sea in the east. This transect, over a distance of 33 km, represents a very steep rainfall gradient, from a Mediterranean climate (mean annual rainfall 690 mm) to an extreme arid climate (less than 100 mm) or −18 mm/km. Thirteen rain stations, located along this transect, represent the various climatic conditions (Fig. 1a, Table 1). In most stations, 60%–70% of the rainfall is in winter (DJF). The remaining falls in autumn (SON) and spring (MAM), while the summer (JJA) is dry (Fig. 1b). Therefore, the hydrological year is used, i.e., from September to August of the next calendar year. In such a case, no rain-spell crosses-over years. Most rains originate from cold fronts associated with the Cyprus low (Alpert and Warner, 1986), but some are associated with the Red-Sea Trough.

### 2.2. Data

Daily rainfall data sets, of variable lengths, from 19 to 50 years, within the period 1960/61-2009/10, were provided by the Israel Meteorological Service (Table 1). Rainfall was measured using rain gauges with a standard orifice of 200 cm$^2$ and a resolution of 0.1 mm. All rainfall data were subject to a quality control performed by the Israel Meteorological Service. In addition a rainfall data quality was tested using a standard normal homogeneity test (Alexandersson, 1986).

**Table 1**
Characteristics of the stations and their temporal rainfall distribution.

| Name | | Climatic region | Alt. a.s.l (m) | No. of years | Annual rainfall (mm) | |
|---|---|---|---|---|---|---|
| | | | | | Mean | Median |
| Kiryat Anavim | (KRAN) | Med. | 700 | 50 | 690 | 649 |
| Zova | (ZOVA) | Med. | 722 | 39 | 634 | 580 |
| Jerusalem, Bait Vegan | (JRBG) | Med. | 810 | 37 | 619 | 581 |
| Mevo Betar | (MBTR) | Med. | 760 | 41 | 577 | 558 |
| Jerusalem, Central | (JRCT) | Med. | 815 | 50 | 544 | 501 |
| Gitit | (GTIT) | Semi arid | 290 | 19 | 366 | 342 |
| Kohav Hashahar | (KOSH) | Semi arid | 600 | 26 | 294 | 253 |
| Ma'ale Adumim | (MALD) | Semi arid | 482 | 25 | 249 | 240 |
| Fazael | (FZEL) | Arid | −250 | 25 | 173 | 158 |
| Jericho | (JERO) | Arid | −260 | 36 | 159 | 151 |
| Arad | (ARAD) | Arid | 568 | 45 | 132 | 127 |
| Kalya | (KLYA) | Arid | −392 | 33 | 93 | 89 |
| Sdom | (SDOM) | Arid | −390 | 48 | 44 | 38 |

## 3. Methods

### 3.1. Rain day and rain-spell definitions

A *day* is defined as a 24 h period starting at 08:00 LT (06:00 UTC) and ending at 08:00 LT of the following day.

A *rain day* is defined when the daily rainfall total equals or exceeds a Daily Rainfall Threshold (DRT), otherwise it is considered as a *dry day*.

A *rain-spell* is defined as a series of successive rain days preceded and followed by at least one dry day and the total rainfall yield equals or exceeds a rain-spell threshold (RST).

### 3.2. Daily Rainfall Thresholds

The commonly used DRT is 0.1 mm, due to the usual precision of rain gauges (Ceballos et al., 2004; Tennant and Hewitson, 2002). Other thresholds are related to the definition of a "significant rainfall", which is usually determined by the daily evaporation, such as: 1.0 mm (Jackson, 1981; Lázaro et al., 2001), 2.0 mm (Olaniran, 1988), 2.75 mm (Harrison, 1983), and 5.0 mm (Cook and Heerdegen, 2001).

In this study, the Daily Rainfall Threshold pertaining to each station was defined as the daily rainfall amount that 96% of the total

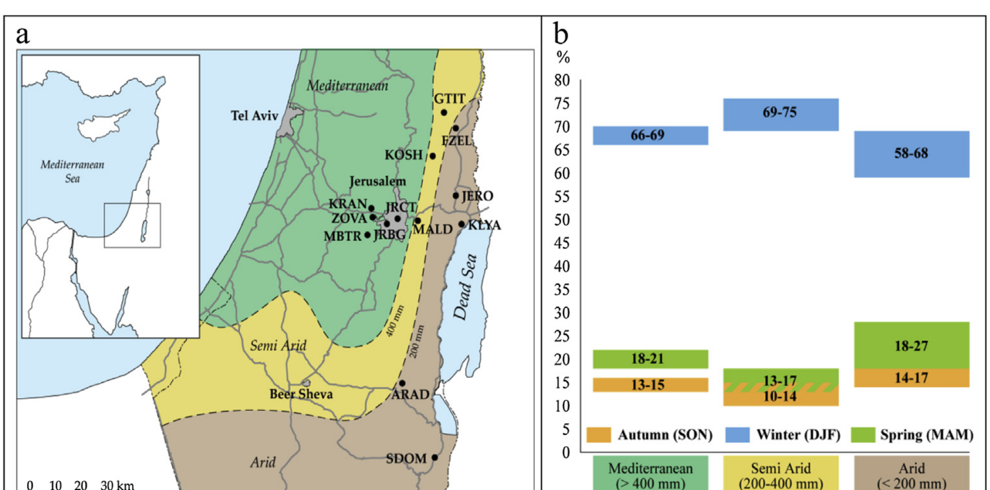


**Fig. 1.** Location of the rain stations (see Table 1 for details) (a) and the seasonal repartition of rainfall (b) along the climatic transect.

rainfall exceeded it, meaning that the lowest 4% of the total rainfall were omitted from the analysis. This was done in order to avoid "noise" in the data due to a large number of events that contribute together a negligible amount of rainfall (Reiser and Kutiel, 2008). This percentage criterion has two advantages: 1. Deleting a relative large number of days with small rainfall amounts, 2. Determining thresholds that are appropriate to the various climatic regions. This was done as the total annual rainfall varies along the transect and therefore a fixed threshold for all stations would have omitted different percentages of the annual total. Table 2 presents the selected Daily Rainfall Thresholds in each station, the percentage of omitted rain days and two additional parameters that emphasize the usefulness of the DRT.

### 3.3. Rain-Spell Thresholds

In the present study, the analyses were performed for various RSTs as these are relevant for different environmental processes. For example, RST of about 10 mm is relevant for triggering seedling emergence (Keya, 1997), for grassland cactus (*Opuntia polyacantha*) responding to rain events (Dougherty et al., 1996), for affecting soil water content (Ceballos et al., 2002), and for generating runoff (Ceballos and Schnabel, 1998; Yair and Lavee, 1985), and RST of about 25 mm is relevant for triggering phenological events on desert shrubs (Veenendaal et al., 1996), and for producing a channel flow of short duration (Ceballos and Schnabel, 1998). A total of 57 RSTs were selected as follows: 1.0 mm, from 2.5 mm to 80 mm with increments of 2.5 mm, and from 80 to 200 mm with increments of 5.0 mm.

### 3.4. Rain-Spells characteristics and models

The dependence of three variables characterizing the rainfall regime, on the RST and on the mean annual rainfall ($R_m$), was analyzed:

1. Mean annual Number of Rain-Spell – NRS.
2. Mean Rain-Spell Yield [mm] – RSY.
3. Mean Rain-Spell Duration [days] – RSD.

For each of these variables a statistical model enabling its estimation based on RST and $R_m$ was developed.

#### 3.4.1. Mean annual Number of Rain-Spells (NRS)

As rain-spells' amounts follow, usually, a log-normal distribution, i.e., many rain-spells with small amount and relatively very few with large amount (e.g., Ananthakrishnan, and Soman, 1989; Harrison, 1983; Jackson, 1986; Kutiel, 1990), the relationship between NRS and RST should be of the form:

$$\mathrm{NRS} = c_n \ln(\mathrm{RST}) + b_n \quad (1)$$

where: $c_n$ and $b_n$ are empirical coefficients.

In the present study, the coefficients $c_n$ and $b_n$ in Equation (1) were found to be statistically dependent on the mean annual rainfall ($R_m$) as follows:

$$c_n = c_{n0}R_m + c_{n1} \quad (2)$$

$$b_n = b_{n0}R_m^{\,b_{n1}} \quad (3)$$

where: $c_{n0}$, $c_{n1}$, $b_{n0}$ and $b_{n1}$ are empirical coefficients.

Substitution of Equations (2) and (3) into Equation (1) leads to a combined model for estimating the mean Number of Rain-Spell (NRS) as a function of Rain-Spell Threshold (RST) and the mean annual rainfall ($R_m$):

$$\mathrm{NRS} = (c_{n0}R_m + c_{n1})\ln(\mathrm{RST}) + b_{n0}R_m^{\,b_{n1}} \quad (4)$$

#### 3.4.2. Mean Rain-Spell Yield (RSY)

This variable represents the total rainfall amount [mm] accumulated within a rain-spell. In the present study the relationship between RSY and RST was analyzed according to the following equation:

$$\mathrm{RSY} = c_y\,\mathrm{RST} + b_y \quad (5)$$

where: $c_y$ and $b_y$ are empirical coefficients.

In the present study, the coefficients $c_y$ and $b_y$ in Equation (5) were found to be statistically dependent on the mean annual rainfall ($R_m$) as follows:

$$c_y = c_{y0}R_m + c_{y1} \quad (6)$$

$$b_y = b_{y0}R_m^{\,b_{y1}} \quad (7)$$

where: $c_{y0}$, $c_{y1}$, $b_{y0}$ and $b_{y1}$ are empirical coefficients.

Substituting Equations (6) and (7) into Equation (5) leads to a combined model for estimating the mean Rain-Spell Yield (RSY) as a function of Rain-Spell Threshold (RST) and the mean annual rainfall ($R_m$):

$$\mathrm{RSY} = (c_{y0}R_m + c_{y1})\mathrm{RST} + b_{y0}R_m^{\,b_{y1}} \quad (8)$$

#### 3.4.3. Mean Rain-Spell Duration (RSD)

This variable represents the total rainfall duration [days] of a rain-spell. A power function (e.g., Lall et al., 1996; Longley, 1953) was fitted to represent the relationship between RSD and RST:

$$\mathrm{RSD} = c_d\,\mathrm{RST}^{b_d} \quad (9)$$

where: $c_d$ and $b_d$ are empirical coefficients.

In the present study, the coefficients $c_d$ and $b_d$ in Equation (9) were found to be statistically dependent on the mean annual rainfall ($R_m$) as follows:

$$c_d = c_{d0}R_m + c_{d1} \quad (10)$$

$$b_d = b_{d0}R_m^{\,b_{d1}} \quad (11)$$

where: $c_{d0}$, $c_{d1}$, $b_{d0}$ and $b_{d1}$ are empirical coefficients.

**Table 2**
The Daily Rainfall Threshold as a result of omitting the lowest 4% of the rainy days.

| Station | Daily Rainfall Threshold (mm) | Percentage of omitted rainy days | Mean daily rainfall amount of omitted days (mm) | Mean daily rainfall amount of remaining days (mm) |
|---|---|---|---|---|
| KRAN | 3.1 | 39.8 | 1.18 | 18.8 |
| ZOVA | 3.3 | 38.4 | 1.25 | 18.7 |
| JRBG | 3.0 | 37.7 | 1.21 | 17.5 |
| MBTR | 3.3 | 35.1 | 1.39 | 18.1 |
| JRCT | 2.5 | 43.3 | 0.84 | 15.3 |
| GTIT | 2.0 | 25.0 | 1.64 | 13.2 |
| KOSH | 2.5 | 31.7 | 1.18 | 13.2 |
| MALD | 1.4 | 39.3 | 0.60 | 9.4 |
| FZEL | 2.0 | 21.2 | 1.19 | 7.8 |
| JERO | 1.0 | 35.1 | 0.44 | 5.8 |
| ARAD | 1.0 | 33.1 | 0.49 | 5.9 |
| KLYA | 1.0 | 26.1 | 0.57 | 4.8 |
| SDOM | 0.6 | 32.2 | 0.33 | 3.8 |

A substitution of Equations (10) and (11) into Equation (9) leads to a combined model for estimating the mean Rain-Spell Duration (RSD) as a function of Rain-Spell Threshold (RST) and the mean annual rainfall ($R_m$):

$$\mathrm{RSD} = (C_{d0}R_m + C_{d1})\mathrm{RST}^{b_{d0}R_m{}^{b_{d1}}} \quad (12)$$

### 3.5. Model testing

In order to verify the above three models (Equations 4, 8 and 12), two data sub-sets were created, each contains half of the years, for each station. One sub-set includes the odd years and the second, the even years. The empirical coefficients of the models were calculated again using one sub-set. These coefficients were applied to the second sub-set in order to predict these three variables (NRS, RSY and RSD). The validation was done by comparing the observed and the predicted variables.

## 4. Results and discussion

### 4.1. Rain-spell characteristics along the transect

Fig. 2 presents the spatial distribution of the Number of Rain-Spells (NRS) (a), Rain-Spell Yield (RSY) (b) and Rain-Spell Duration (RSD) (c) for Rain-Spell Threshold (RST) = 5 mm.

It can be seen that NRS decreases with aridity from above 15 in the Mediterranean stations, to around 10 in the semi-arid and less than 9, in the arid region (Fig. 2a).

The RSY decreases from above 34 mm in the Mediterranean region to less than 17 mm in the arid region and 17–34 mm in the semi-arid region (Fig. 2b).

No clear trend of the RSD is evident when moving from the Mediterranean region to the arid region. In all regions the average RSD is around 2 days, slightly longer in the northern part and slightly shorter in the southern part of the transect (Fig. 2c).

Table 3 presents some examples of NRSs, RSYs and RSDs at the various stations for five selected thresholds. It can be noticed that the same spatial behavior is evident also for higher thresholds.

The presented results emphasize the fact that increasing aridity in the studied transect is a combination of decrease in both the number and the yield of the rain-spells in that region. This decrease is probably due to the orography that forces the air masses to descend from the Judean Mountains to the Dead Sea and therefore to warm adiabatically. This descent causes part of the rainfall systems reaching the Judean Mountains to dissipate once they pass the top of the mountains and therefore the NRS to decrease, and/or their intensity to diminish, as reflected by the decrease in the RSY. However, as the length of the transect is relatively short, no significant difference was found in the RSD especially when the duration is measured in days.

### 4.2. Model testing

As mentioned in Section 3.5, the coefficients of Equations 4, 8 and 12, were calculated twice, for odd and for even years. The two sets of coefficients obtained for each of the above equations were used to predict the variables NRS, RSY and RSD. For each of the variables two comparisons were conducted:

1. The data of the odd years served to calculate the coefficients of Equations 4, 8 and 12. These coefficients were used to calculate the values of the even years that were compared to the observed values of the even years.
2. The same procedure was repeated, but this time data of the even years served to calculate the coefficients. The predicted odd years' values were compared with the observed ones.

The models validation is based on: (a) analysis of the explained variance ($r^2$) and (b) calculation of the difference between the predicted ($P$) and the observed ($O$) values, using the root mean square of the differences (RMSD) (Willmott, 1984), as follows:

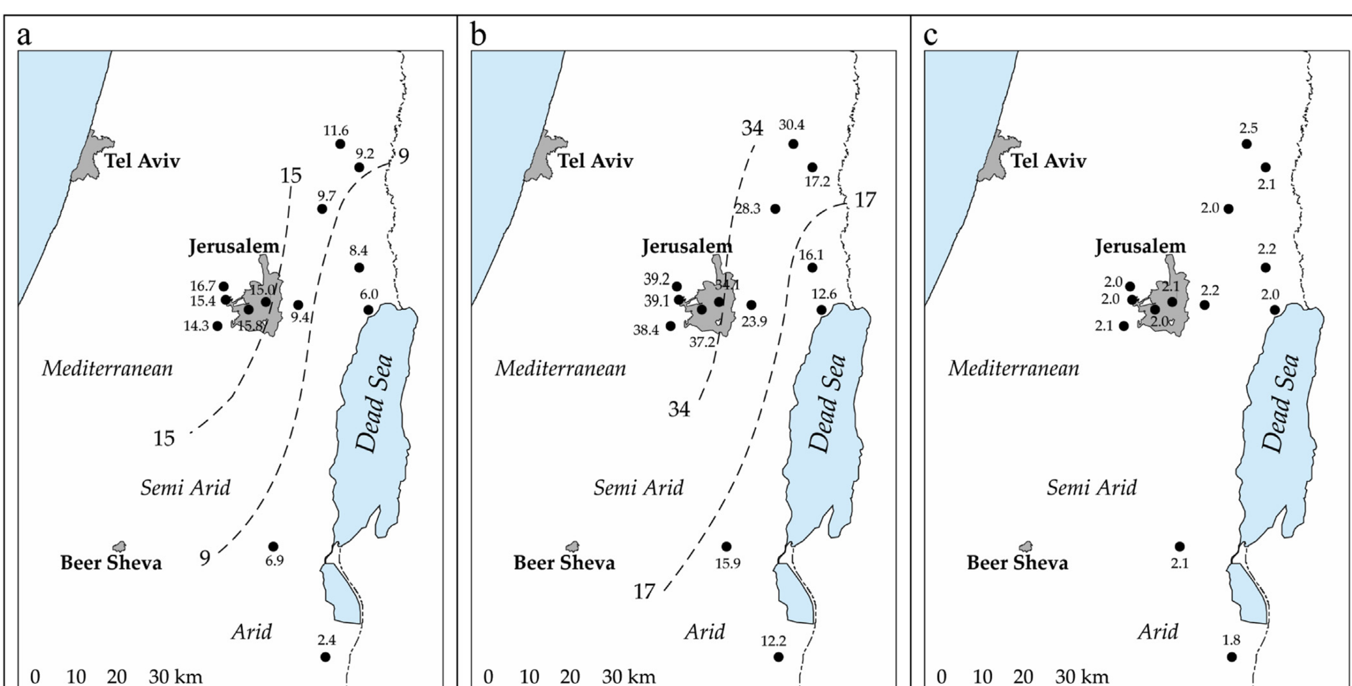


**Fig. 2.** The spatial distribution of mean annual NRS (a), mean annual RSY [mm] (b) and mean annual RSD [days] (c) for RST = 5 mm.

**Table 3**
Number of Rain Spells, Rain Spell Yield and Rain Spell Duration for 5 selected Rain Spell Thresholds.

| Station | Number of Rain Spells | | | | | Rain Spell Yield [mm] | | | | | Rain Spell Duration [day] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 40 | 80 | 5 | 10 | 20 | 40 | 80 | 5 | 10 | 20 | 40 | 80 |
| KRAN | 16.7 | 13.3 | 9.3 | 5.7 | 2.1 | 39.2 | 47.4 | 61.9 | 82.9 | 126.2 | 2.0 | 2.2 | 2.6 | 3.1 | 3.7 |
| ZOVA | 15.4 | 12.1 | 8.5 | 5.2 | 2.2 | 39.1 | 47.7 | 61.6 | 83.1 | 119.3 | 2.0 | 2.2 | 2. 6 | 3.0 | 3.7 |
| JRBG | 15.8 | 12.7 | 8.7 | 5.1 | 1.8 | 37.2 | 44.4 | 58.2 | 79.4 | 117.8 | 2.0 | 2.3 | 2.6 | 3.1 | 3.7 |
| MBTR | 14.3 | 11. 8 | 8.1 | 4.9 | 1.9 | 38.4 | 45.1 | 59.3 | 79.9 | 114.5 | 2.1 | 2.3 | 2.6 | 3.1 | 3.7 |
| JRCT | 15.0 | 11.4 | 7.5 | 4.4 | 1.5 | 34.1 | 42.6 | 57.2 | 77.4 | 117.9 | 2.1 | 2.4 | 2.8 | 3.2 | 4.1 |
| GTIT | 11.6 | 9.0 | 5.7 | 3.1 | 0.7 | 30.4 | 37.5 | 50.8 | 71.6 | 127.4 | 2.5 | 2.8 | 3.2 | 3.9 | 4.9 |
| KOSH | 9.7 | 7.3 | 4.3 | 2.0 | 0.5 | 28.3 | 35.2 | 49.6 | 72.8 | 126.1 | 2.0 | 2.2 | 2.6 | 3.1 | 4.1 |
| MALD | 9.4 | 6. 6 | 3.7 | 1.5 | 0.3 | 23.9 | 31.3 | 44.2 | 67.4 | 109.3 | 2.2 | 2.4 | 2.8 | 3.4 | 4.0 |
| FZEL | 9.2 | 5.6 | 2.5 | 0.8 | 0.1 | 17.2 | 23.9 | 36.0 | 57.3 | 104.0 | 2.1 | 2.5 | 3.1 | 3.6 | 6.0 |
| JERO | 8.4 | 5.2 | 2.2 | 0.4 | <0.1 | 16.1 | 21.6 | 31.6 | 55.3 | 115.0 | 2.2 | 2.5 | 2. 9 | 3.9 | 6.0 |
| ARAD | 6. 9 | 3.9 | 1. 8 | 0.4 | <0.1 | 15.9 | 22.8 | 32.8 | 53.1 | 113.0 | 2.1 | 2.5 | 2.9 | 3.4 | 7.0 |
| KLYA | 6.0 | 3.0 | 0.9 | 0.1 | <0.1 | 12.6 | 18.3 | 30.2 | 67.3 | 98.0 | 2.0 | 2.3 | 2.9 | 4. 7 | 7.0 |
| SDOM | 2.4 | 1.1 | 0.3 | 0.1 | a | 12.2 | 18.6 | 31.9 | 51.1 | a | 1.8 | 2.0 | 2.1 | 2.3 | a |

[a] Rain-spell amount exceeding 80 mm does not exist in this station.

$$\mathrm{RMSD} = \sqrt{\frac{\sum (P-O)^2}{N}} \quad (13)$$

where $N$ is the number of cases.

The validity of the models is shown by the high correlation between the predicted and observed NRS, RSY and RSD values and by their relatively small RMSD values (Table 4).

### 4.3. Application of the models to the transect

The empirical coefficients of Equations 4, 8 and 12 pertaining to the study area, were calculated based on the entire data set in order not to lose information. It should be mentioned that the models are valid for all Rain-Spell Thresholds up to the threshold that produces only one rain-spell per year (NRS = 1, Table 5). Table 5 represents the maximum rainfall yields accumulated in each station in a single rain-spell with a recurrence period of one year. This was done in order to avoid very extreme rainfall events with very long recurrence periods which are very rare.

$$\mathrm{NRS} = (-0.0022R_\mathrm{m} - 3.45)\ln(\mathrm{RST}) + 1.9738R_\mathrm{m}^{0.3818} \quad (14)$$

$$\mathrm{RSY} = (-0.0004R_\mathrm{m} + 1.28)\,\mathrm{RST} + 0.1440R_\mathrm{m}^{0.8731} \quad (15)$$

$$\mathrm{RSD} = (-0.0003R_\mathrm{m} + 1.55)\mathrm{RST}^{0.1245R_m{}^{0.1026}} \quad (16)$$

Fig. 3 presents the observed NRS (a), RSY (b) and RSD (c) values in three stations representing the various climatic regions (dots) and the predicted values according to Equations 14–16 respectively (solid lines).

Since the predicted and the observed NRS, RSY and RSD values are highly correlated ($r^2 = 0.988$, $r^2 = 0.992$ and $r^2 = 0.840$, respectively) and RMSD values are relatively small (0.39, 3.03 mm and 0.26 days, respectively). These models may serve as an efficient tool for the estimation of NRS, RSY and RSD for any desired threshold and/or mean annual rainfall. Application to other Mediterranean, semi-arid or arid regions may require a calculation of different coefficients. These models may be used for current climatic conditions. Given a future climatic scenario, they may serve to predict in details the characteristics of the rainfall regime. An example of using the models is illustrated in Fig. 4, which presents the predicted values of NRS (a), RSY (b) and RSD (c) for various Rms and RSTs. The white areas in each panel are beyond the limits of the models.

It can be easily noticed that each of the three presented variables varies differently with changes of the mean annual rainfall and the rain-spell thresholds. NRS varies with changes of both $R_\mathrm{m}$ and RST, It increases with increasing of the annual rainfall and decreases with increasing of the rain-spell threshold. RSY varies solely with changes in the annual rainfall. It increases with increasing of the annual rainfall and almost doesn't change with changes of the rain-spell threshold. RSD varies solely with changes in the rain-spell threshold. It increases with increasing of the rain-spell threshold and almost doesn't change with changes of the annual rainfall. These results are in a complete agreement with Fig. 2. Fig. 2 represents the spatial distribution of these three variables for one selected threshold (5 mm). As the spatial distribution reflects changes in annual rainfall, the gradient from the Mediterranean to the arid region is more pronounced for the RSY, less so for the NRS and completely absent for RSD.

However, these results can be looked also in a different way: which of the three variables (NRS, RSY and RSD) affects more the annual rainfall? From the presented results it is evident that rainier

**Table 4**
The models validity parameters for the two scenarios.

| Variable | Explained variance ($r^2$) | | RMSD | |
|---|---|---|---|---|
| | Odd years | Even years | Odd years | Even years |
| NRS | 0.985 | 0.978 | 0.48 | 0.56 |
| RSY | 0.987 | 0.982 | 5.73 | 5.94 |
| RSD | 0.806 | 0.813 | 0.36 | 0.33 |

**Table 5**
Rain Spell Threshold that produces only one rain-spell per year (NRS = 1).

| Station | RST (mm) |
|---|---|
| KRAN | 113.3 |
| ZOVA | 108.1 |
| JRBG | 107.5 |
| MBTR | 100.0 |
| JRCT | 96. 7 |
| GTIT | 71.3 |
| KOSH | 63.8 |
| MALD | 52.5 |
| FZEL | 33.3 |
| JERO | 29.4 |
| ARAD | 26.9 |
| KLYA | 18.6 |
| SDOM | 10.9 |

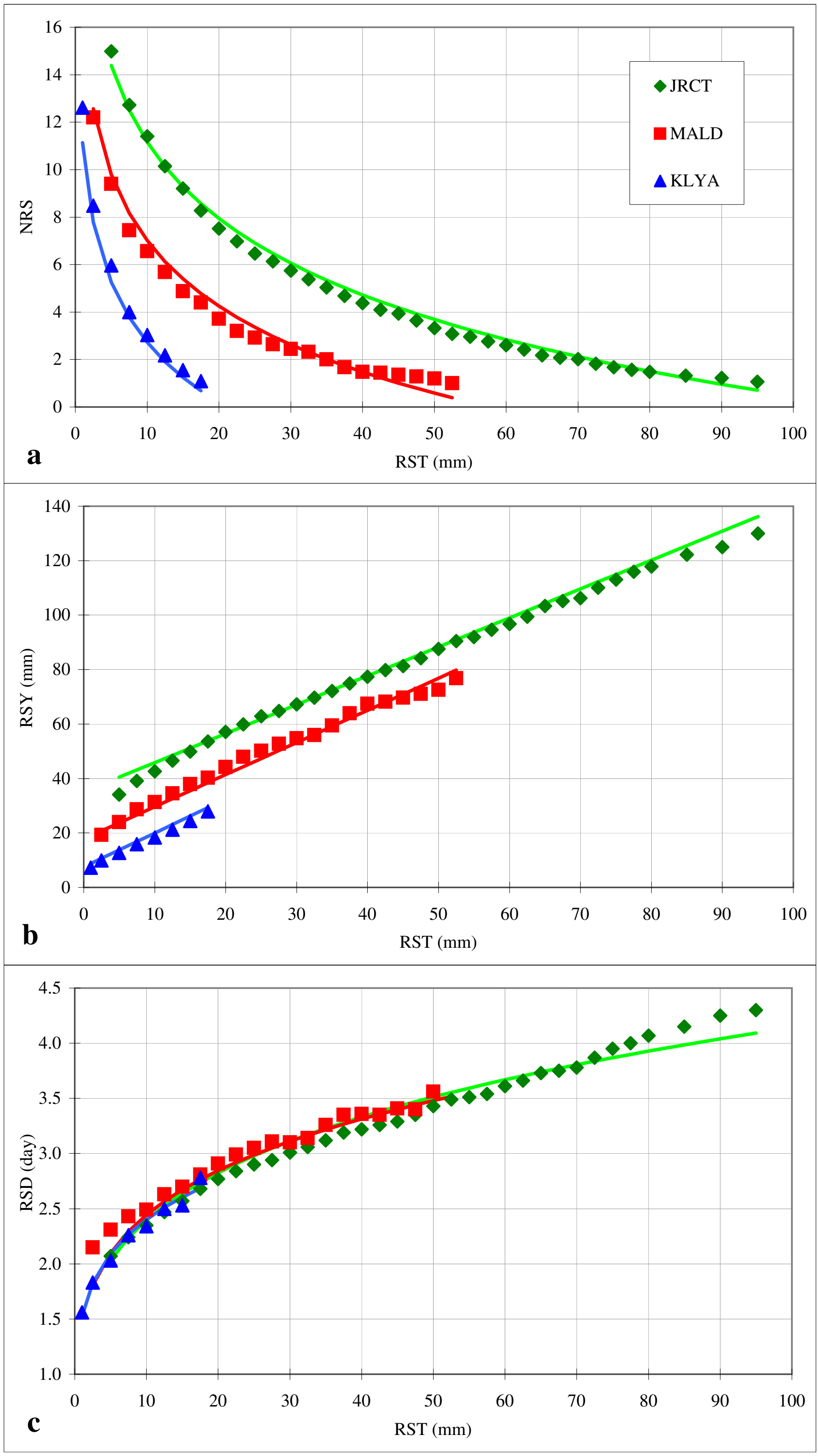


**Fig. 3.** Observed NRS (a), RSY (b) and RSD (c) in three selected stations and the predicted values according to Equations 14, 15 and 16 respectively.

regions are mainly a result of higher Rain-Spell Yields, less so of larger Number of Rain-Spells and completely not dependent of the Rain-Spell Duration. These results are in complete accordance with results presented by Reiser and Kutiel (2012). In that study, the authors analyzed data from 41 stations in the Mediterranean basin and found that the main factor that causes a rainy season to be above or below average is changes in RSY and much less so in NRS. Therefore, we can state with a high level of confidence that the present results are valid for wider regions far beyond the analyzed transect.

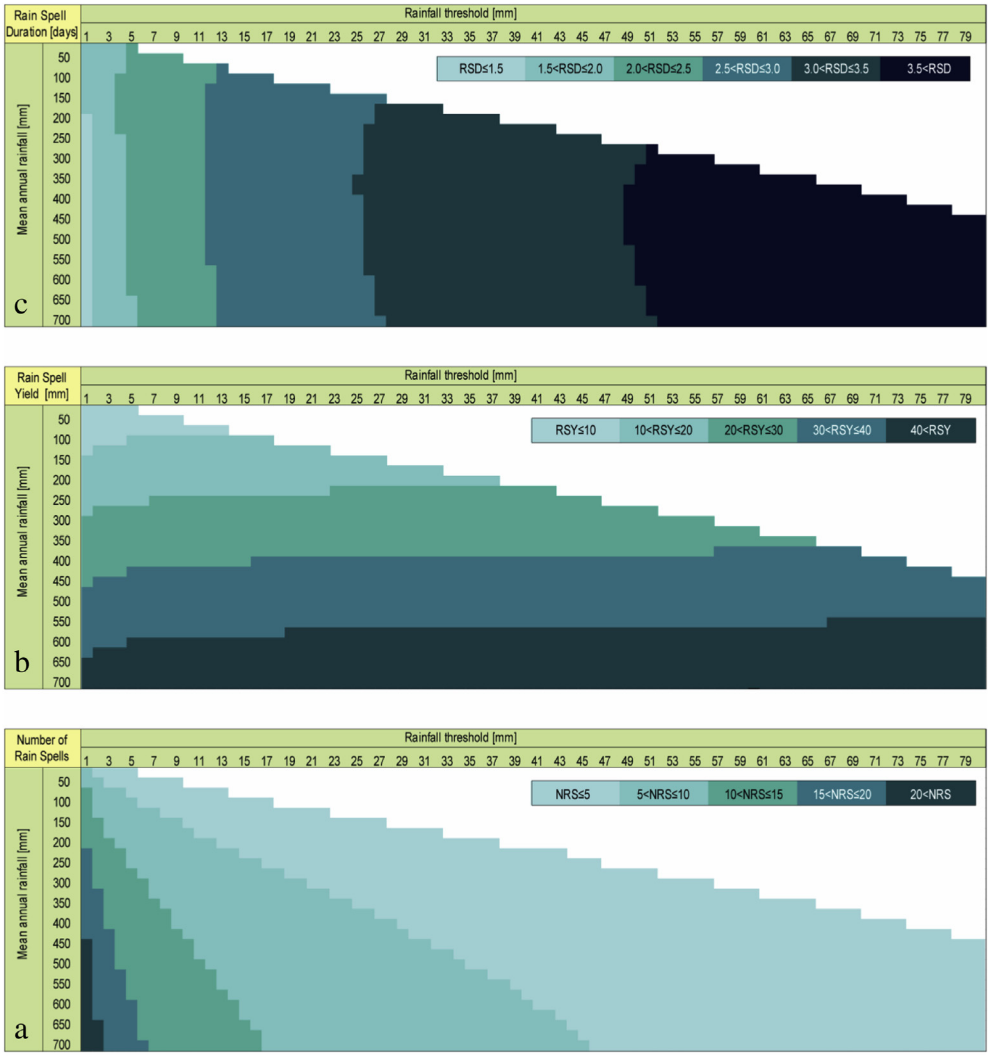


**Fig. 4.** The dependence of the NRS (a-bottom), RSY (b-middle) and RSD (c-upper), on the rainfall threshold and the mean annual rainfall.

## 5. Summary and conclusions

Daily rainfall data from 13 stations along a climatic transect from a Mediterranean to an arid climate served to calculate rain-spells. The distributions of the number, yield and duration of these rain-spells were analyzed for various rainfall thresholds.

Three theoretical models relating the Number of Rain-Spells, the Rain-Spell Yield and the Rain-Spell Duration to the mean annual rainfall for various Rain-Spell Threshold values were developed. These models were verified using half of the data set for estimating the other half.

The equations using the empirical calculated coefficients for the above models provided predicted values which are in a close agreement with the measured values. Since the mean annual rainfall is one of the models input, it can be used for scenarios of changes in the annual rainfall.

These models can be used as input to other simulations models, particularly in arid and semi-arid areas where rainfall stations are sparse and there is paucity of available rainfall data in those regions.

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