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FACTORS AFFECTING VARIATIONS OF MEAN ANNUAL RAINFALL IN ISRAEL[1]

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ABSTRACT

A stepwise multiple linear regression analysis was used to study factors that affect the mean annual rainfall in Israel. The factors investigated were latitude, elevation, and easterly distance from the sea. Separate equations, relating the 30-year mean rainfall to these factors were derived for the northern and southern parts of the country. The regression equations reduced most of the variance of the rainfall data for the 211 rain-gaging stations included in the study.

INTXODUCTION

The mean annual rainfall in Israel varies considerably throughout the country despite its small size. The mean annual rainfall decreases from about 550 mm to 50 mm in a southeasterly distance of about 120 km from the Mediterranean Coast near Tel Aviv to the Dead Sea. Over approximately the same distance in the NNE. direction, between Tel Aviv and the Upper Galilee, the mean annual precipitation increases to over 950 mm. Considering all stations in the country for which values of mean annual precipitation (normals for the period 1931-1960) are available, the smallest value of 25 mm is found for Elat on the Red Sea shore, and the highest value of 1010 mm is found for Tirat Yael in the Upper Galilee. The steepest gradients of the isohyctal map are found in the eastern slopes of the Judean Mountains where the mean annual precipitation increases by about 400 mm over a distance of some 9 km or approximately 45 mm/km.

This high variability in mean annual rainfall is the result of the location of the country on the boundary between two different climatic regions. One region is the subtropical humid Mediterranean climate which prevails in the northern part of the country. The second region is a semiarid climate in the southern part of the country, influenced by the proximity of the Arabian and adjoining deserts. A second reason for the variability in the mean rainfall is the change from a maritime climate along the coastal strip to a continental climate farther inland. Finally, there are orographic effects due to elevation, which ranges from 390 m below to about 1,000 m above sea level.

The distribution of the mean annual precipitation across the country is governed, according to Katsnelson (1968), by the following four rules:

(*a*) Mean annual precipitation decreases with the distance from the sea;
(*b*) Mean annual precipitation increases with the elevation above sea level;
(*c*) Mean annual precipitation depends on the aspect of the slope, westerly slopes having higher precipitation than easterly slopes;
(*d*) Mean annual precipitation increases with the latitude of the locations considered.

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The same four rules, but in a different order, were also given by Mane and Rosenan (1957). In both references the rules are given qualitatively, without an evaluation of the magnitude of the influence of each factor.

This paper examines three of the above four rules quantitatively, using available data, and evaluates the influence of each of the factors separately. The three factors investigated were the distance from the sea, the elevation, and the latitude of the stations. Lack of data prevented evaluating the effect of the aspect of the rain-gaging stations.

DATA SELECTION

The basic data used in the analysis were taken from a table of climatological standard normals of rainfall published by the Israel Meteorological Service (1967). The table contains mean monthly and yearly precipitation for rain-gaging stations throughout the country, as well as their coordinates and elevation. The values of mean rainfall reported were normalized by the Israel Meteorological Service for a common reporting period of 30 years, from 1931 to 1960. The normalizing was done with reference to 47 base stations, most of which have records for the full 30-year period, and all but two base stations have records for 27 years or longer.

To reduce possible errors in the correlations sought due to the normalizing procedure mentioned above, only stations with records for 15 years or more were selected. An exception was made for a few stations in the southern part of the Negev where, because of the low density of available rain-gaging stations, those having records for 11 to 14 years were also included. The distribution of the length of record for the 211 rain-gaging stations thus selected is shown in table 1. The mean period of observation for the stations selected was 21.4 years, but it should be emphasized again that the values of rainfall depths used were those adjusted to the common 30-year reporting period.

The latitude of the stations selected varied from 29°33′N to 33°15′N, and their longitude varied from 34°26′E to 35°39′E. The elevation of the stations ranged from 390 m below to 934 m above sea level. The mean annual rainfall for the stations ranged from 25 mm to 925 mm. The average mean annual precipitation for all stations considered was 490 mm, with a standard deviation of 154 mm.

The geographical distribution of the rain-gaging stations was not uniform as a result of the historical development of the network. Using the regional subdivisions adopted by the Israel Meteorological Service (1967), the geographic distribution of stations selected is given in Table 2. Also given are the mean rainfall and standard deviation for stations within each subdivision. The approximate locations of the centers of the various subdivisions are shown by the circled numbers on the map given in figure 1.

TABLE 1

Distribution of rain-gaging stations selected, by their length of record

Number of years of record	Number of raingaging stations	Percentage of total selected
11-14	8	3.8
15-18	72	34.1
19-22	49	23.2
23-26	36	17.1
27-30	46	21.8
Total	211	100.0

Method of analysis

The relationship between mean annual precipitation and the various factors that affect its magnitude was investigated by means of a stepwise multiple linear regression analysis using a computer program (Huszar, 1969) available at the Computer Center of the University of Arizona. The program considers all the variables entered and selects the variables that reduce most significantly the variance of the quantity for which a regression equation is sought. The variables are introduced in the order of their contribution to the reduction of the variance,

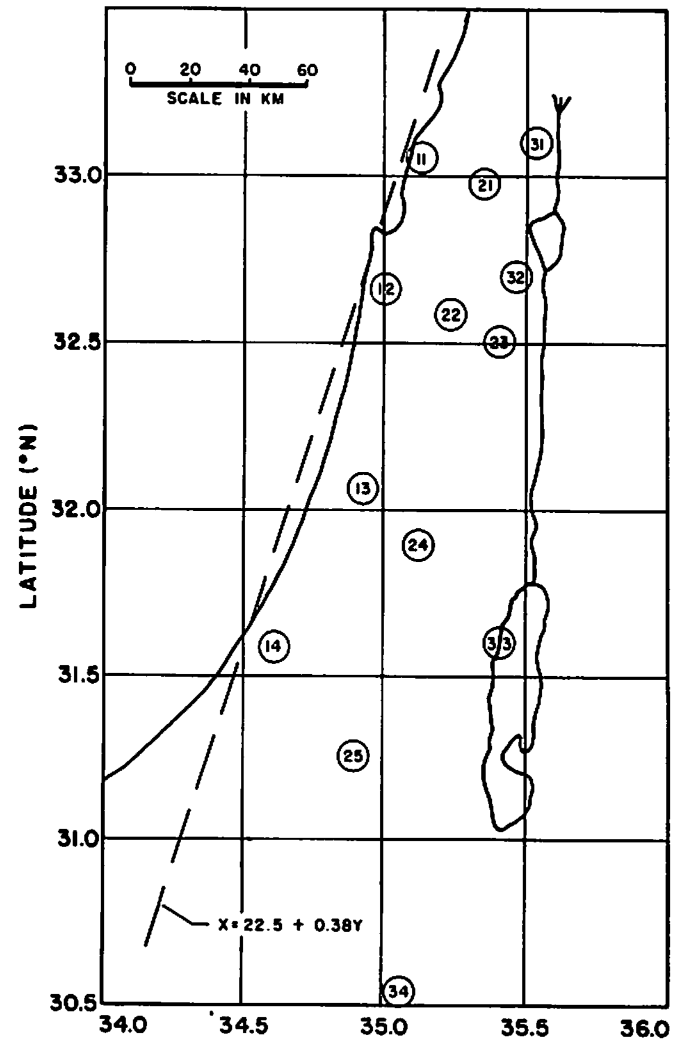

FIGURE 1. MAP WITH SIMPLIFIED SHORE LINE.

TABLE 2

Geographic distribution of rain-gaging stations

Region	Subregion	Number of stations	Mean rainfall	Standard deviation
			(mm)	(mm)
1. Coastal Region	11. Haifa-Akko plain	11	561	31
	12. Karmel area	20	589	74
	13. Central Coastal plain	43	548	40
	14. Southern Coastal plain	15	416	61
2. Hill Region	21. Hills of Galilee	30	619	145
	22. Valley of Yizreel	11	517	64
	23. Harod Bet-Shean Valley	9	380	45
	24. Samarian-Judean Hills	25	544	77
	25. Negev	10	221	93
3. Jordan Rift Valley	31. Hula area	10	506	67
	32. Central Jordan Valley	18	366	58
	33. Dead Sea area	4	99	—
	34. Arava area	5	42	—

but if subsequently the contribution of any variable becomes insignificant, at a specified F-level, it is removed from the regression equation.

The independent variables used in the stepwise multiple linear regression analysis were the elevation of the rain-gaging station H, in meters, its longitude E, in degrees, and its latitude N, in degrees. The dependent variable was the mean annual precipitation P, in millimeters. The means of the three independent variables, their standard deviation, and their correlation with the dependent variable are listed in Table 3. The rather poor value of the coefficient of correlation between mean annual precipitation and the longitude can be greatly improved if the easterly distance from the sea shore is substituted for the longitude.

A simplified shore line, shown by the dashed line in figure 1, was adopted for the purpose of computing easterly distances of rain-measuring stations from the shore. The line is represented

TABLE 3

Means, standard deviations, and correlations of independent variables

Independent variable	Unit	Mean value	Standard deviation	Correlation to precipitation
Elevation H	m.	139.1	261.50	0.467
Longitude E	deg.	35.1	0.30	0.020
Latitude N	deg.	32.3	0.61	0.601
Easterly Distance D	deg.	0.35	0.25	−0.531

by the equation:

$$X = 22.5+0.38\,Y \tag{1}$$

where X and Y are the longitude and latitude, respectively, of points along the simplified shore line. The easterly distances of rain-measuring stations from the simplified shore line were computed by the following equation:

$$D = E-22.5-0.38\,N \tag{2}$$

where D is the easterly distance from the shore (in degrees), and E and N are the longitude and latitude of the stations.

The coefficient of correlation between the mean annual precipitation and the easterly distance from the sea as defined above was 0.531, compared to the corresponding coefficient for the longitude which was only 0,020. The coefficient of correlation between mean annual precipitation and latitude was 0.601, and the value of the coefficient for the elevation was 0.467.

Results of analysis

The order of introduction of the independent variables into the regression equation was latitude N, elevation H, and longitude E. The order was not changed when the easterly distance from the shore D was substituted for the longitude. The above order represents the order of decreasing contributions of the various factors to the reduction of the variance of the mean annual precipitation from its initial value of 5.0×10^6 (in mm^2 units).

Considering only the mean annual precipitation P as the dependent variable and the latitude N as the independent variable, the program produced the following regression equation:

$$P = 151\,N-4\,397 \tag{3}$$

or

$$P = 151\,(N-29.1) \tag{4}$$

The standard error of the coefficient (151) was 14, leading to a value of $T = 10.8$, which is highly significant. The sum of the squared deviations was reduced by the regression equation from the original value of 5.0×10^6 to a residual value of 3.2×10^6. The standard error of values predicted by the regression equation was 124 mm, as compared with a standard deviation of 154 mm in the original data. The coefficient of determination for the regression equation was $r^2 = 0.36$.

Introducing into the regression equation the variable with the second highest reduction in variance, the elevation H led to the following regression equation:

$$P = 0.300\,H+160\,N-4\,704. \tag{5}$$

The standard errors of the two coefficients were 0.025 and 11, leading to highly significant t values of 11.8 and 14.7, respectively. The sum of squares of the deviations was further reduced to 1.9×10^6, and the standard error of predicted precipitation values was reduced to 96 mm. The coefficient of determination for this regression equation was $r^2 = 0.62$.

Finally, considering all three independent variables, the regression equation obtained was:

$$P = 0.302\,H-257\,E+233\,N+1\,961 \tag{6}$$

With standard errors of 0.019, 20, and 10, the three coefficients were again found to be highly significant with t values of 15.8, 12.7, and 23.3, respectively. Using this regression equation, the sum of squared deviations was finally reduced to 1.1×10^6, and the standard error of values predicted by the equation was 72 mm. The coefficient of determination for the final equation was $r^2 = 0.79$.

Using equation 6 as a prediction equation for the 211 rain-gaging stations included in the original analysis led to predicted values that deviated from the measured values by less than 10 mm for 24 stations. The absolute deviation was between 10 mm and 100 mm for 156 stations and more than 100 mm for 31 stations. Of the latter group, eight stations had deviations larger than 150 mm. The largest deviation between predicted and measured precipitation was 282 for the Nizzana station in the Negev region. However, the length of record for this station was only 14 years, and its mean rainfall was adjusted to the 30-year value with respect to the Beer Sheva station.

Two of the predicted values of mean annual precipitation were negative. These were for the Sedom station at the southern tip of the Dead Sea at an elevation of 390 m below sea level, and the station at Elat on the shore of the Red Sea, which is the most southern station in the country. Considering the possibility of obtaining negative values, the use of the regression equation for prediction purposes should be subjected to the following condition:

$$P = 0 \quad \text{if} \quad (0.302\,H - 257\,E + 233\,N + 1\,961) < 0. \tag{7}$$

Considering the records of all stations in the country, a value of 25 mm would probably be a better choice as the minimal value instead of the zero value used in equation 7.

The regression equation obtained when the easterly distance D is substituted for the longitude E is:

$$P = 0.302\,H - 257\,D + 135\,N - 3\,833. \tag{8}$$

The equation can, of course, be obtained also by substituting equation 2, defining the easterly distance, into the regression equation (equation 6).

Grouping of rain-gaging stations

Examination of the table of deviations between predicted and observed values led to the conclusion that prediction could be improved if the data were partitioned into two groups depending on the latitude of the stations. The division line adopted for this partitioning was the 31.5°N parallel, which corresponds roughly to the northern boundary of the Negev region. Stations falling on the 31.5°N parallel were included in the northern group.

The northern and southern groups contained 195 and 16 stations, respectively. The mean annual rainfall for stations in the northern group was 518 mm, and that for the southern group was 150 mm. The standard deviations of the mean annual rainfall for the two groups were 121 and 102 mm, respectively. The means, standard deviations, and correlations of the independent variables for the two groups are given in Table 4.

TABLE 4

Means, standard deviations, and correlations of independent variables for grouped stations

		Group 1 (North)			Group 2 (South)		
Independent variable	Unit	Mean value	Standard deviation	Correlation coefficient	Mean value	Standard deviation	Correlation coefficient
Elevation H	m.	140.5	267.7	0.604	122.1	172.1	0.258
Longitude E	deg.	35.1	0.29	−0.170	34.8	0.30	−0.696
Latitude N	deg.	32.4	0.47	0.296	30.9	0.53	0.800
Easterly distance D	deg.	0.33	0.22	−0.460	—	—	—

The regression equation obtained for the stations in the northern group is:

$$P = 0.311\,H - 288\,E + 211\,N + 3\,760. \qquad (9)$$

or, using the easterly distances from the shoreline,

$$P = 0.311\,H - 288\,D + 102\,N - 2\,720. \qquad (10)$$

The standard errors of the three coefficients in these equations were 0.016, 19, and 12, respectively.

Applying the multiple regression equation to stations in the second group showed that the elevation of gaging stations did not contribute significantly to the reduction of the variance, so that the equation obtained was:

$$P = -139\,E + 123\,N + 1\,191. \qquad (11)$$

The standard errors of the two coefficients were 59 and 33, respectively.

The root mean square deviation between observed and computed values was reduced appreciably by using equations 9 and 11 instead of equation 6. The values of the r.m.s. deviations for the two groups were 57 mm and 59 mm, respectively, whereas the value obtained using equation 6 was 72 mm. The distribution of the magnitudes of the deviations for all 211 stations is given in table 5. The residual variance not explained by the regression equations for the two groups was 0.63×10^6 and 0.05×10^6, or a total of 0.68×10^6, compared to the value of 1.1×10^6 obtained with a single regression equation.

TABLE 5

Distribution of the magnitude of deviations between predicted and observed mean annual precipitation

Range of deviations	Number of stations	Percent of of total
(mm)		
0-10	22	10.4
10-20	27	12.7
20-60	109	51.7
60-100	32	15.2
100-150	21	10.0
Total	211	100.0

The grouping of rain-gaging stations also eliminated the negative predicted value of rainfall for the Sedom station. The negative value for the Elat station was reduced, but not eliminated. If equation 11 is used for prediction purposes, it is therefore subjected to the following condition:

$$P = 0 \quad \text{if} \quad (123\,N - 139\,E + 1\,191) < 0. \qquad (12)$$

Again, a value of 25 mm may be more appropriate than the zero value.

Values of mean annual rainfall for stations on or near the 31.5° parallel will be different if computed by the equation developed for the northern group than if computed by the equation for the southern group. When the various equations were applied to 9 stations with latitudes between 31°25′ and 31°35′, equation 9 gave values that were higher than the observed values, and equation 11 produced values lower than the observed. The mean difference for the former was +133 mm and for the latter, −106 mm. Using equation 6 for the same 9 stations gave results that were higher than the observed values by an average of +100 mm.

Summary and conclusions

Three of the four factors recognized as affecting the distribution of mean annual rainfall in Israel were investigated quantitatively, using a stepwise multiple linear regression analysis. The three factors were found to be significant in the northern half of the country. In the southern half, or the Negev region, only two of the factors were significant. It must, however, be recognized that this conclusion may not be well founded since it is based on data from a small number of stations, with records for only part of the standard period.

The three factors found to affect the mean annual precipitation in the northern half of the country were the latitude of the rain-gaging station, its elevation, and its longitude or easterly distance from the shore line. In the southern half of the country only the latitude and longitude appear to affect significantly the magnitude of the mean annual precipitation. The various factors are listed above in the order of their contribution to the reduction of variance of the mean annual precipitation.

Qualitatively, the effect of the various factors was found to be as stated by previous investigators. Mean annual rainfall increased with the latitude of the station and with its elevation and decreased with the longitude of the station or its easterly distance from the sea.

The orographic effect on mean annual precipitation in the northern half of Israel is of the order of 30 mm increase in precipitation for each 100 meters increase in elevation. The effect of longitude or easterly distance from the sea is of the order of 290 mm per degree of longitude or about 3.1 mm/km for the northern part of the country and 140 mm per degree or 1.5 mm/km in the southern part. A change of latitude of one degree causes a change of precipitation of about 210 mm (1.9 mm/km) in the northern part of the country and about 120 mm (1.1 mm/km) in the south. If the change in latitude is not made along the meridian, but along a line parallel to the shoreline, the change in the mean annual precipitation in the northern part is about 100 mm (0.9 mm/km).

The original variance of the set of mean annual precipitation data for the 211 rain-gaging stations used in the analysis was 5.0×10^6 (mm^2 units). A regression equation (equation 6 or 8) based on data for all 211 stations reduced the variance to 1.1×10^6. If the data are split into two groups, depending on locations of the stations north or south of the 31.5°N parallel, the total variance about the two regression lines is reduced to 0.68×10^6. The standard deviations of the independent variable are 154 mm for the original data, 72 mm for values produced by the single regression equation (equation 6 or 8), and 58 mm for the values predicted by separate regression equations (equations 9 or 10, and 11) for the two parts of the country. It should be noted here that values of the independent variables used in the analysis were reported to the nearest 5 m in elevation and to the nearest 1′ in location. The magnitude of the error in precipitation due to this rounding is about 5 to 8 mm.

The results reported herein are probably subjected to some uncertainty because the records of most stations were adjusted to a standard 30-year reporting period. It is possible that this adjustment has influenced the values of the parameters in the regression equations. A similar analysis to be carried out on rainfall records for the next reporting period (1941-1970) should be more meaningful, as it will be possible to base it on a larger number of truly independent observations.

REFERENCES

Huszar, C. K., 1969. A generalized stepwise multiple regression analysis, (mineographed notes), University Computer Center, University of Arizona.

Israel Meteorological Service, 1967. Climatological standard normals of rainfall 1931-1960, Ministry of Transportation, Meteorological Service, Pub. Series A, No. 21.
KATSNELSON, J., 1968. Rainfall in Israel as a basic factor in the water budget of the country, (in Hebrew), Ministry of Transportation, Meteorological Service, Pub. Series A, No. 24.
MANE, U., and ROSENAN, N., 1957. Rainfall, Section 2/IV of Israel Atlas, Pub. by The Bialik Inst., Tel Aviv.

NOTATION

- D Easterly distance of rain-gaging station from shore line (degrees).
- E Longitude of rain-gaging station (degrees).
- H Elevation of rain-gaging station (meters).
- P Mean annual precipitation (mm).
- r^2 Coefficient of determination.
- t Statistic used to judge significance of coefficients in regression analysis.
- X East coordinate of point on simplified shore line (degrees).
- Y North coordinate of point on simplified shore line (degrees).