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Introduction

Analytical studies of the important kinds of winter cereals (e.g., wheat and barley) that are grown in the Syrian Arab Republic have shown great changes in productivity from year to year during recent times. The total area of rainfed land usually cultivated throughout the country during this period is about 84 percent of the total cultivated area. Also, the rainfed land cultivated with these winter cereals represents most of the area of such crops.

The productivity of these crops depends mainly on the average rainfall throughout the year and on the distribution of this rainfall throughout the growing period. The purpose of this paper is to analyze the variability in annual rainfall quantities using the following methodology:

I. Dividing the country statistically into four homogeneous rainfall regions.

II. Estimating the rainfall cycle's length, after excluding the general trend in the annual rainfall series. A sinusoidal form is assumed for the residuals to represent the cyclical components--this form contains two parameters.

III. Predicting rainfall quantities during the cycle.

I. Dividing The Country Into Four Homogeneous Rainfall Regions

In studying winter crops in S.A.R., we saw that it would be useful to divide the country into a number of homogeneous rainfall regions based on rainfall averages. Each region contains those provinces that have no significant difference in their rainfall averages.

Because of the large variations in rainfall averages over the last 40 years and because more homogeneous data were not available, the intermediate period between 1945 and 1985 was selected. By carrying out analysis of variance rainfall quantities for years and provinces, we constructed the following table:

Table 1. Analysis of Variance of Rainfall Averages

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F 5%	Tabular F 1%
Province	10	8719237	871924	91		2.41
Years	25	2316410	92656	9.7		1.88
Error	250	2385382	9542			
Total	285	13421029				

Comparing the computed F value with the tabular F value, we can conclude that there were significant differences among the provinces' rainfall at the 1 percent level of significance. So a comparison table (Table 2) has been made to show the significant and nonsignificant differences among the provinces' rainfall at the 1 percent and 5 percent level of significance.

Subsequently, the provinces have been distributed into four homogeneous regions such that each region contains those provinces which are most alike in terms of their rainfall averages.

First Region

The annual rainfall averages in this region reach more than 800 m.m. This region includes only Latakia province.

Second Region

The annual rainfall averages in the second region tended to lie between (450-500) m.m. This region includes both Idlib and Homs provinces.

Table 2. Comparisons between the rainfall averages of provinces during the selected period (1951-1979)

	The Mean	Deir-ezzor	Damascus	Idlib	Latakia	Dera	Alhaseka	Hamah	Alraqqa	Homs	Aleppo	Elsuweiyda
		166	211	495	819	296	287	359	219	469	366	359
Deir-ezzor	166	--	45	329**	653**	130**	121**	193**	53	303**	200**	193**
Damascus	211		--	284**	608**	85**	76*	148**	8	258**	155**	148**
Idlib	495			--	324**	-199**	-208**	-136**	-276**	-26	-129**	-136**
Latakia	819				--	-523**	-532**	-406**	-600**	-350**	-453**	-460**
Dera	296					--	-9	63*	-77**	173**	70*	63*
Alhaseka	287						--	72**	-68**	182**	79**	72*
Hamah	359							--	-140**	110**	7	0
Alraqqa	219								--	267**	164**	140**
Homs	469									--	-103**	-110**
Aleppo	366										--	-7
Elsuweiyda	359											--

* Indicates a significant difference at the 5 percent level of significance.

** Indicates a significant difference at the 1 percent level of significance.

Third Region

The annual rainfall averages in this region tended to lie between (275-375) m.m. The third region includes the following provinces: Aleppo, Hamah, Elsuweiyda, Dera, and Alhaseka.

Fourth Region

The fourth and final region had low annual rainfall averages between (150-225) m.m. This region includes three provinces: Alraqqa, Damascus, and Deir-ezzor. Table 3 shows these rainfall regions.

Table 3. Division of the country statistically into homogeneous rainfall regions (the overall mean is 368)

Rainfall Region	Province	Rainfall Average	Index Number (368=100)
First	Latakia	819	223
Second	Idlib	495	135
	Homs	469	127
Third	Aleppo	366	99
	Hamah	359	98
	Elsuweiyda	359	98
	Dera	296	80
	Alhaseka	287	78
Fourth	Alraqqa	219	60
	Damascus	211	57
	Deir-ezzor	160	45

II. Estimating The Rainfall Cycle Length In S.A.R.

A forecasting model system proves its worth if it provides accurate and useful predictions. The use of a formal model for forecasting purposes is most successful when accurate and appropriate data are available for estimating the model.

A. Estimation By The Residuals Method

First of all, cyclical variations for rainfall averages during the median period (1951-1975) were determined. First, however, effects, such as trend, have to be excluded.

To measure the general trend parameters, an analysis of variance was accomplished (Table 4). The results shown in this table indicate that there were no significant estimators for the general trend of the rainfall averages at the first and second degree. Consequently, no systematic general trend for the rainfall averages was detected, and averages tended to be varied around their arithmetic mean.

Table 4. Analysis of variance for testing parameters of the orthogonal polynomial equation

					F tabular	
S.V.	df	SS	MS	F	Fo.05 (23,1)	Fo.05 (22,1)
Total S.S.	24	208448				249
(S.S.R) ϵ_1'	1	1300	1300			
(R.S.S.)	23	207148	9006	6.9	249	
(S.S.R.) ϵ_2'	1	278	278			
(R.S.S.)	22	206870	9403	33.8	249	

Thus, the deviations of annual rainfall quantities from their mean have been calculated and considered as residuals which contain both cyclical component and random errors.

A graphical representation for those residuals is shown in Figure 1. Looking at this graph and figuring out the horizontal distance between the shown peaks, we can verify that the peaks are repeating themselves almost every five years: 1957, 1962, 1967, and 1972. An exception is noticed for 1952. And the annual rainfall for

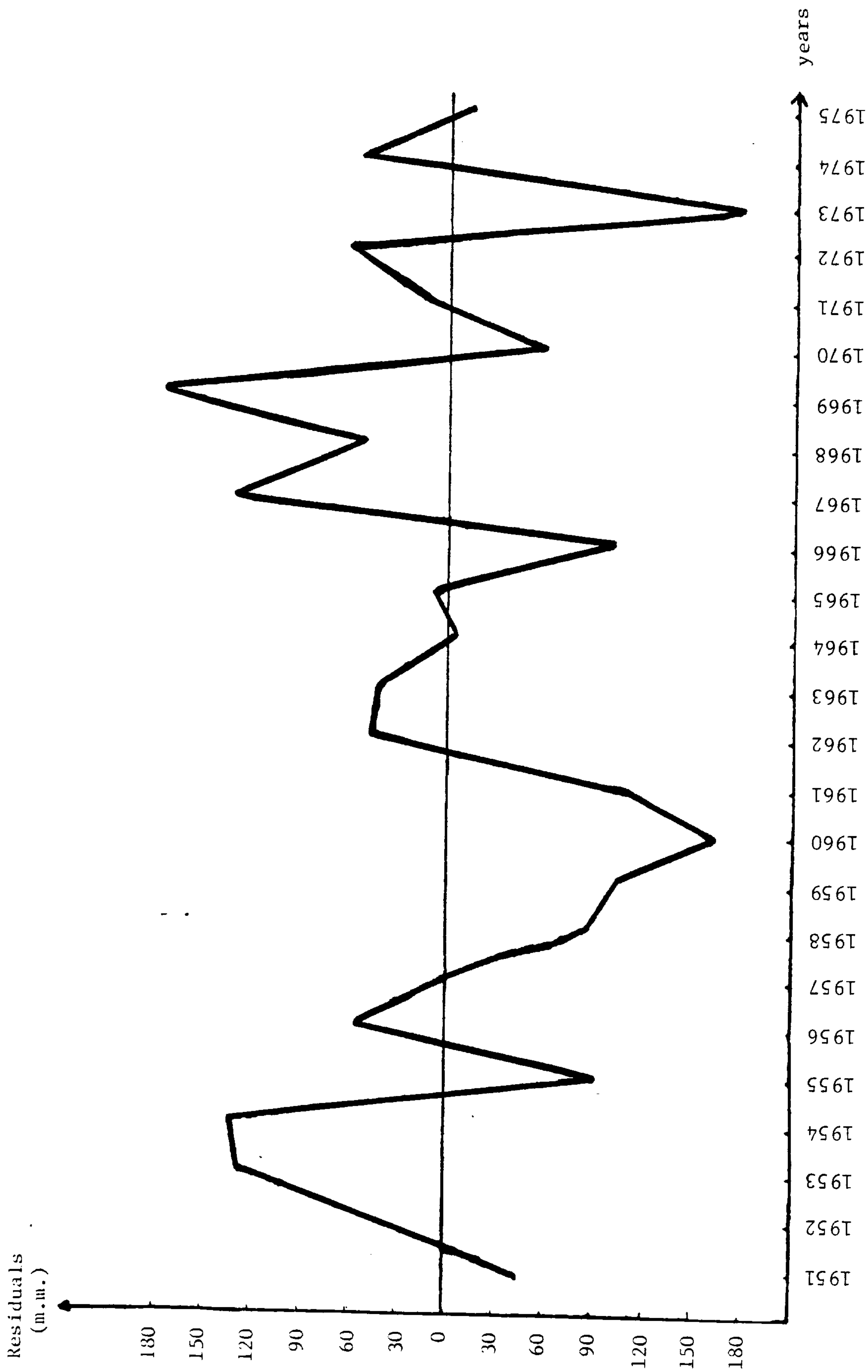

Figure 1. Graphical representation for the residuals of rainfall quantities

Table 5. Estimating orthogonal polynomial coefficients for the annual rainfall averages during the studied period (m.m.)

years	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	sum of square	λ
y	273	346	491	494	278	423	377	286	260	202	261	416	409	365	375	270	496	421	541	308	377	422	197	421	364	3502673	
ε_1'	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	1300	1
ε_2'	92	69	48	29	+12	-3	-16	-27	-36	-43	-48	-51	-52	-51	-48	-43	-36	-27	-16	-3	12	29	48	69	92	53820	1

$\varepsilon_1 = X_t^1 = t - \frac{n+1}{2}$

$\varepsilon_2 = (X_t^1)^2 - \frac{n^2-1}{12}$

$\Sigma y = 9073$

$\Sigma \varepsilon_1 y = 1300$

$\Sigma \varepsilon_1 y = 3866$

' n = number years

' λ = adjusting coefficient

$\alpha_a' = 363$

$\alpha_1' = 1$

$\alpha_2' = 0.072$

$\bar{y} = 363$

$n\bar{y}^2 = 3294225$

$(SSR)_1 = 1300$

$(SSR)_2 = 278$

1957 was less than in 1956. However, the difference in rainfall averages for these two years was not significant.

B. Cycle Length Estimation By Variance Analysis Method

Thus far the length of the rainfall cycle has been determined by using the well known residuals method as an analytical technique. Another procedure has been developed to verify the results and to show the adequateness of the variance analysis procedure in estimating cycle length. Also, estimations have been made for the rainfall averages during cycle years.

1. Distinctive years with respect to their annual averages

Referring to Table 1 and carrying out a comparison between the computed and tabular F, a significant difference can be found among the annual rainfall averages as well as among the provinces.

By setting up Table 6 for possible comparisons among the annual rainfall averages at the country level throughout the studied period, the following years can be distinguished: 1974, 1973, 1972, 1969, 1968, 1967, 1963, 1962, 1961, 1960, 1959, 1958, and 1952. So it will be quite possible to determine the years in which rainfall averages are more or less than the rainfall averages of the distinctive years mentioned above. Looking at Table 6, the following comparisons can be made:

1974 The annual rainfall average in this year is significantly greater than the annual rainfall averages of the following years: 1955, 1958, 1959, 1961, 1966, 1970, and 1973.

1973 The annual rainfall average in this year is significantly less than the annual rainfall averages of the following years: 1951, 1952, 1953, 1954, 1956, 1957, 1962, 1963, 1964, 1965, 1967, 1968, 1969, 1970, 1971, and 1972.

1972 The annual rainfall average in this year is significantly greater than the annual rainfall averages of the years: 1955, 1958, 1959, 1960, 1961, 1966, and 1970. However, 1972's rainfall is significantly less than 1969's average.

1969 The annual rainfall average in this year is significantly greater than the annual rainfall averages of the years: 1951, 1952, 1955, 1957, 1958, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, and 1968.

1968 The annual rainfall average in this year is significantly greater than the annual rainfall averages of the years: 1955, 1958, 1959, 1960, 1961, and 1966.

1967 The annual rainfall average in this year is significantly greater than the annual rainfall average of the years: 1951, 1955, 1957, 1958, 1959, 1960, 1961, 1964, 1965, and 1966.

1963 The annual rainfall average in this year is significantly greater than the annual rainfall averages of the years: 1955, 1958, 1959, 1960, and 1961.

1962 The annual rainfall average in this year is significantly greater than the annual rainfall averages of the years: 1955, 1958, 1959, 1960, and 1961.

1961 The annual rainfall average in this year is significantly less than the annual rainfall averages of the following years: 1952, 1953, 1954, and 1956.

1960 The annual rainfall average in this year is significantly less than the annual rainfall averages of the following years: 1952, 1953, 1954, 1956, and 1957.

1959 The annual rainfall average in this year is significantly less than the annual rainfall average of the following years: 1952, 1953, 1954, 1956, and 1957.

1958 The annual rainfall average in this year is significantly less than the annual rainfall averages of the following years: 1952, 1953, 1954, 1956, and 1957.

1957 The annual rainfall average in this year is significantly greater than the annual rainfall average in 1955 and significantly less than those in 1953 and 1954.

1952 The annual rainfall average in this year is significantly greater than the annual rainfall average in 1951.

Table 6. Comparisons between the annual rainfall across the years during the selected period at the country level (m.m.)

		1951 334	1952 422	1953 491	1954 494	1955 278	1956 425	1957 377	1958 286	1959 260	1960 202	1961 261	1962 416	1963 409
1951	334	—	88**	157**	160**	56	89	43	-48	74	-132**	-73	82	75
1952	422		—	69	72	144**	1	-45	-136**	-162**	-220**	-161**	6	-13
1953	491			—	3	213**	68	-114**	-205**	231**	-289**	-230**	75	82
1954	494				—	-216**	71	-117*	-208**	-234**	-292**	-233**	78	85
1955	278					—	145**	99*	8	18	76	17	138**	131**
1956	425						—	46	-137**	-163**	-221**	162**	7	14
1957	377							—	-91*	-117**	-175**	116	39	32
1958	286								—	26	84	25	130**	123**
1959	260									—	58	1	156**	149**
1960	202										—	59	214**	207**
1961	261											—	155**	148**
1962	416												—	7
1963	409													—
1964	365													
1965	375													
1966	270													
1967	496													
1968	421													
1969	541													
1970	308													
1971	377													
1972	422													
1973	197													
1974	421													
1975	364													
1976	384													

		1964 365	1965 375	1966 270	1967 496	1968 421	1969 541	1970 308	1971 377	1972 422	1973 197	1974 421	1975 364	1976 384
1951	334	31	41	-64	162**	87	207**	-26	43	88	-137**	87	30	50
1952	422	-57	-47	-152**	74	-1	119*	-114*	-45	0	-225**	-1	-58	-38
1953	491	126	-116	-221**	5	70	50	-183**	114	69	-294**	70	127*	107*
1954	494	-129**	119	-224**	2	73	47	-186**	117	72	-297**	73	-130*	110*
1955	278	87	97	8	218**	145**	263**	30	99	144**	81	143**	86	106
1956	425	58	48	-153**	73	2	118	115	46	1	-226**	2	59	39
1957	377	12	2	107	119	44	164**	69	0	45	-180**	44	13	7
1958	286	79	89	16	210**	135**	255**	22	91	136**	89	135**	78	90
1959	260	105	115	10	236**	161**	281**	48	117	162**	63	161**	104	124
1960	202	163**	173**	68	294**	219**	339**	106	175**	220**	5	219**	162**	182**
1961	261	104*	-114*	9	235**	160**	280	47	116*	161**	64	160**	103	123*
1962	416	51	41	-146	80**	5	125*	108	39	6	-219**	5	52	32
1963	409	44	34	-139**	87	12	132**	-101**	32	13	-212**	12	45	25
1964	365	—	10	95	131**	56	176**	57	12	57	-168**	56	1	19
1965	375		—	-105*	121**	46	166**	67	2	47	-178**	46	11	9
1966	270			—	226**	151*	271**	38	-107*	152**	73	151**	96	114
1967	496				—	75	45	-188**	119	74	-259**	75	-132**	112
1968	421					—	120**	-113**	44	1	224**	8	57	37
1969	541						—	-233**	-164**	-149**	-344**	-120*	-177**	-157**
1970	308							—	69	114*	-111*	113*	56	76
1971	377								—	54	-180**	44	13	7
1972	422									—	-225**	1	58	38
1973	197										—	224**	167**	187**
1974	421											—	57	37
1975	364												—	20
1976	384													—

* Indicates the significant difference the 5 percent level of significance.
** Indicates the significant difference the 1 percent level of significance.

2. Cycle length estimation

The previous analysis shows that the years 1972, 1967, 1962, 1957, and 1952 have a relatively greater number of years that have significantly lower annual rainfall averages. This is especially evident when comparing each of these years with the surrounding years. One exception, as mentioned before, is a comparison between 1957 and 1956. However, this difference is not significant. Table 7 shows the detail of the years in which rainfall averages were significantly less than the rainfall averages in the indicated five years.

The periods among those years tend to be fixed and equal to five years. That means, a five-year cycle can be confirmed. The annual rainfall averages in those years can be considered as values of the peaks in the successive cycles.

Table 7. Years in which annual rainfall averages are significantly less than peak years' annual rainfall average

peak years \ other years	1951	1952	1955	1957	1958	1959	1960	1961	1964	1965	1966	1970
1952	*											
1957	-	-	*									
1962	-	-	*	-	*	*	*	*				
1967	*	-	*	*	*	*	*	*	*	*	*	
1972	*	-	*	-	*	*	*	*	-	-	*	*

A test for differences among the peak years' annual rainfall averages has been carried out. Only one significant difference was noticed between the annual averages of 1967 and 1957. The other four years showed no significant difference. Having five peaks throughout the studied time series means having troughs located before those peaks midway between each two peaks. Thus, Table 7 shows the following:

1957 The annual rainfall average in this year was a peak and it is significantly greater than 1955's annual rainfall average which was located about midway between 1952 and 1957.

1962 The annual rainfall average in this year was also a peak and it significantly exceeded the annual rainfall average in 1959 and 1960.

These two years were also located at the midpoint of the cycle. Their mean could be considered a trough.

1967 The annual rainfall average in this year as a peak and significantly exceeded the annual rainfall average in 1964 and 1965. Since these two years were located at the middle of the cycle, their rainfall mean could be considered a good estimator for the fourth trough. Likewise, for 1972 and for the upper peaks similar comparisons can be made.

Figure 2 shows a graph for systematic rainfall cycles.

3. <u>Rainfall averages estimations for cycle years</u>

To set up a proper model for estimating the rainfall averages of the cycle years, it was necessary to establish a test to verify the slope position of the two lines touching the peaks and troughs of the successive cycles. Furthermore, a test has been conducted for the distance between those lines (intersections).

Assuming the following equation for the two lines:

$$Y_{ij} = \alpha_i + \beta_i (X_{ij} - \bar{X}_i) + \epsilon_{ij}$$

where: $i = 1, 2$
$j = 1, 2 \ldots 5$

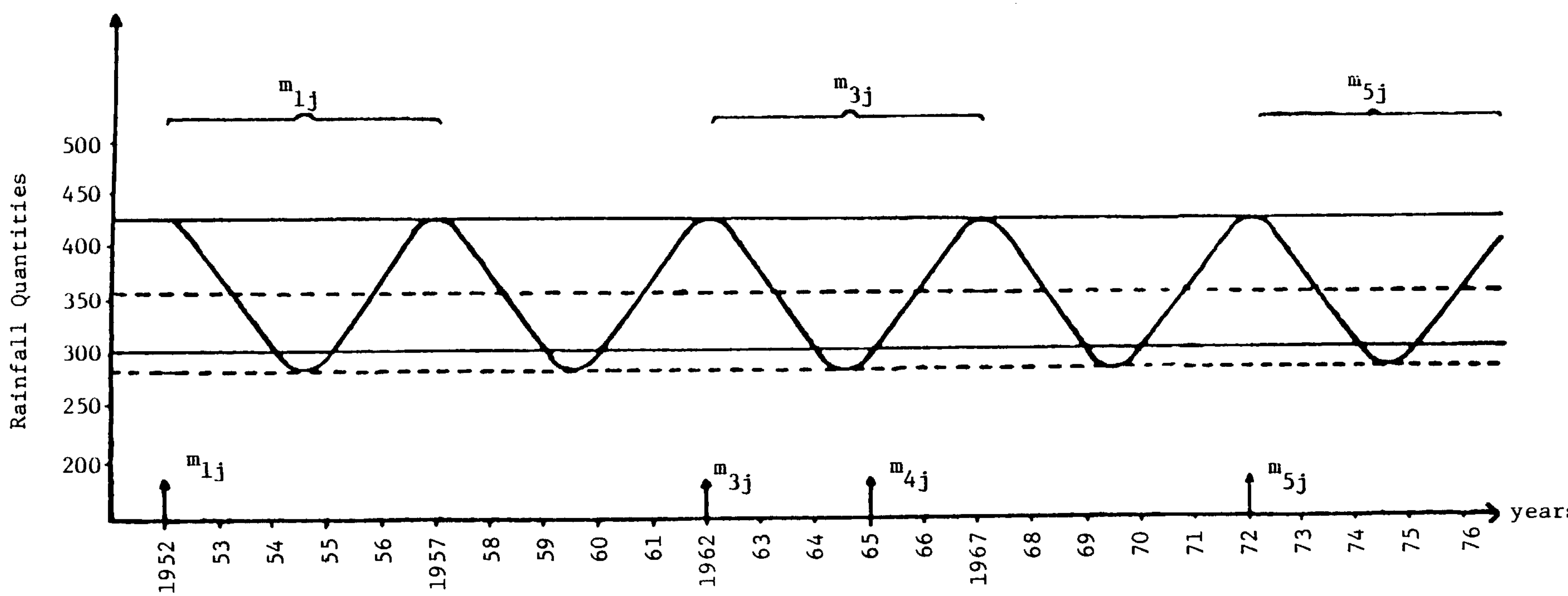

Figure 2. Systematic rainfall cycle in S.A.R. during the median period (1952-1976).

such that the first line touches the peaks of the five-year cycles, while the second one goes through the points located directly around the trough's points. Those years are 1955, 1960, 1965, 1970, and 1975.

To meet the previous conditions, the following hypotheses have been tested:

H_{01}: $\alpha_1 = \alpha_2 = \alpha = 0$	The two lines are congruent and they pass the original point.
H_{02}: $\alpha_1 = \alpha_2 = \alpha \# 0$	The two lines are congruent and they don't pass the original point.
H_{03}: $\beta_1 = \beta_2 = \beta = 0$	The two lines are parallel to the X axis.
H_{04}: $\beta_1 = \beta_2 = \beta \# 0$.	The two lines are parallel but not parallel to the X axis.

By setting up the following variance analysis table, two major results can be shown.

a. There is a significant distance between these two lines.

b. The two lines are parallel.

Table 8. Analysis of variance for comparision between the two lines crossing the five peaks' points and around the five troughs' points

S.O.V.	C.S.O.S	df	E.O.V.	F	$F_{0.05}$
H_{01}: $\alpha_1 = \alpha_2 = \alpha = 0$	1339560.00	1	1339560.00	446.17	F(1,6) 5.89
H_{02}: $\alpha_1 = \alpha_2 = \alpha \# 0$	36723.60	1	36723.60	12.23	
H_{03}: $\beta_1 = \beta_2 = \beta = 0$	7880.45	1	7880.45	2.62	
H_{04}: $\beta_1 = \beta_2 = \beta \# 0$	1264.05	1	1264.05	2.38	F(6.1) 234
Residual	18013.90	6	3002.32		
Total	1403442.00				

So the mean of the peaks' values becomes a good estimator for α_1, and the mean of the points located around troughs are a good estimator for α_2, so:

$$\hat{\alpha}_1 = \bar{Y}_2 = 426.6$$
$$\hat{\alpha}_2 = \bar{Y}_2 = 305.4$$

The difference between these two interesections gives the distance between the two lines, "d".

$$d = \hat{\alpha}_1 - \hat{\alpha}_2 = 121$$

assuming the following form for the cyclical component:

$$Z_{ij} = A \cos \frac{ZM_{ij}\ \pi}{S} + \epsilon_{ij} \qquad (1)$$

where M_{ij} indicates the cycle order

$i = 1, 2...5$ cycle number
$j = 1, 2, 3...5$ years within the cycle

and S indicates the cycle length that equals five years.

Looking at the two lines in Figure 3, another definition for "d" can be determined by using the previous sinusoidal formula.

$$d = A + A \mid \cos \frac{4\pi}{5} \mid \qquad (2)$$

where d = the distance between the two lines
a = the length of cycle depth
s = the cycle length

Therefore,

$$\hat{A} = \frac{d}{(1 + /\cos \frac{4\pi}{5}|)} \qquad (3)$$

$\hat{A} = 67.00$

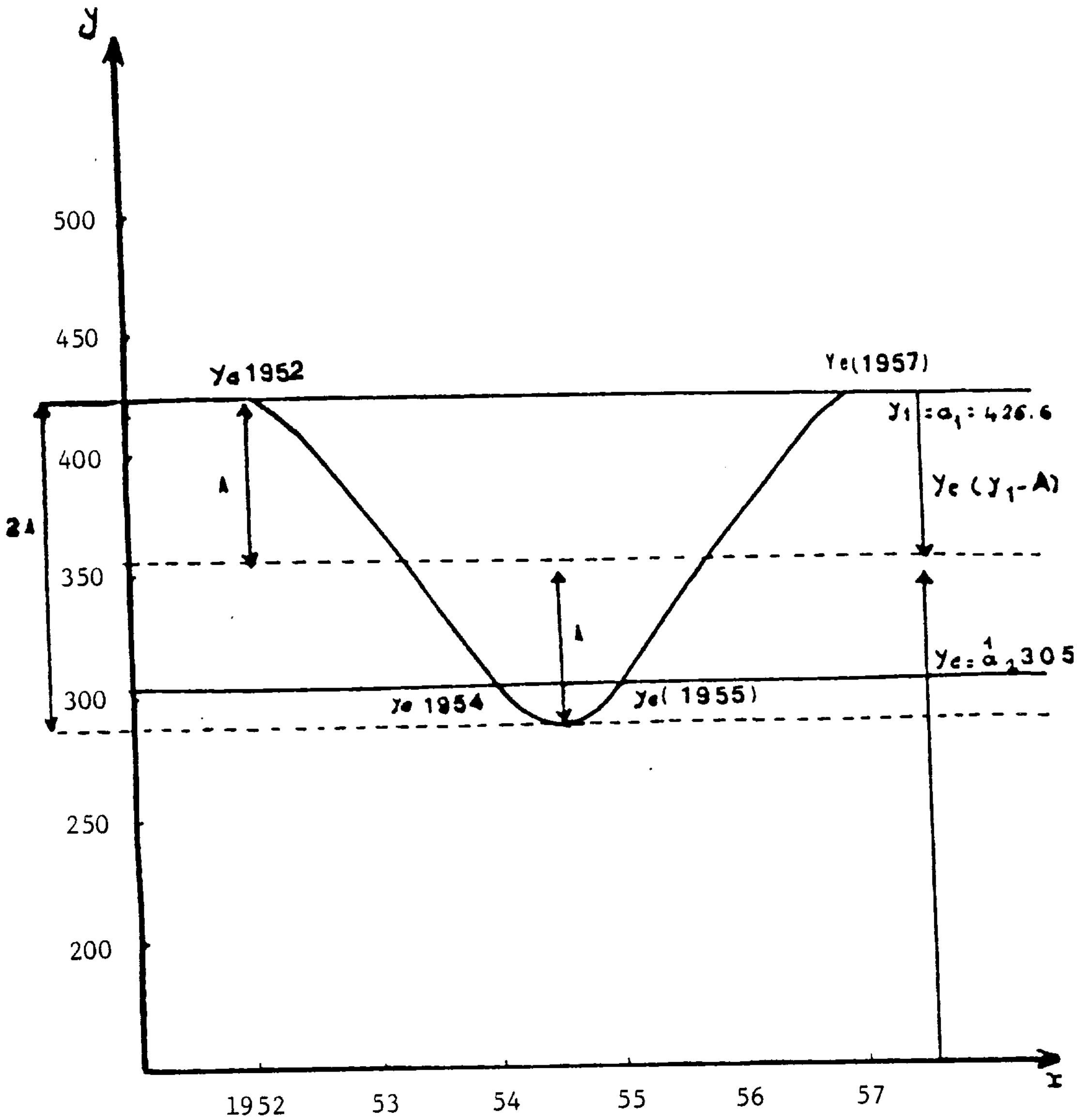

Figure 3. Graphical representation for rainfall cycle years

After estimating these two basic parameters, it becomes possible to set up a model to estimate the annual rainfall average for each year in the cycle.

The estimations have been carried out by using the mean of the rainfall quantities in the peaks' years.

$$Y_e = (Y_1 - A) + Z_{ij} + \epsilon_{ij} \qquad (4)$$

$$Y_e = (Y_1 - A) + A\cos \frac{2M_{ij}\pi}{S} + \epsilon \qquad (5)$$

where Y_e is the expected value of the rainfall average and Y_1 is the mean of the annual rainfall quantities in the peak years. By substituting the following formula can be derived:

$$\hat{Y}_e = 359.6 + 67\cos \frac{2M_{ij}\pi}{5} \qquad (6)$$

Table 9 shows the estimated rainfall averages within the five-year rainfall cycle.

Table 9. The annual rainfall average estimations within the five-year cycle.

n	$2n \frac{\pi}{5}$	$\cos 2n \frac{\pi}{5}$	$\hat{y}_e$
0	0	1	426.60
1	$2 \frac{\pi}{5}$	0.3090	380.30
2	$4 \frac{\pi}{5}$	-0.8090	305.40
3	$6 \frac{\pi}{5}$	-0.8090	305.40
4	$8 \frac{\pi}{5}$	0.3090	380.30
5	$10 \frac{\pi}{5}$	1	426.60

4. <u>Testing the significance of estimated rainfall averages</u>

It is quite possible to set up the confidence interval that includes the expected values of the rainfall averages. This can be done by calculating the confidence limits depending on the estimated values. Both 95 percent and 99 percent of probability were considered. The following statement also has been taken into account:

$$\frac{(Y_o - Y_e)}{s} \sim N(0,1) \qquad (7)$$

where Y_o indicates the observed values, and Y_e the expected values, while S is the standard error.

a. <u>Estimating the standard error</u>

Depending on Table 10, and writing:

$$Z_i = (Y_o - Y_e) \qquad (8)$$

$$\Sigma (Z_i - \bar{Z})^2 = \Sigma Z_i^2 - \frac{(\Sigma Z)^2}{n} \qquad (9)$$

substituting the values from Table 10:

$$\Sigma (Z_i - \bar{Z})^2 = 222684.9 - \frac{(270)^2}{25} = 219768.9$$

$$S^2 = \frac{\Sigma (Z_i - \bar{Z})^2}{24} \qquad (10)$$

$$= \frac{219768.9}{24} = 9157$$

$$S = 95.5$$

b. <u>The confidence interval</u>

The following well known equation determines the confidence interval that includes the expected value of the annual rainfall averages.

(1) At the 5 percent level of significance,

$$L\ (0.05) = Y_e \mp S \times t_{0.05} \qquad (11)$$

$$L\ (0.05) = Y_e \mp 197$$

(2) At the 1 percent level of significance,

$$L\ (0.01) = Y_e \mp S \times t_{0.01} \qquad (12)$$

$$L\ (0.01) = Y_e \mp 267$$

where $t_{0.05} = 2.064$, $t_{0.01} = 2.797$

Setting up a comparison between Z_i values and the two confidence limits, it was found that all the values were located within the confidence interval at 5 percent level of significance including the rainfall average in 1969 which fell within the confidence interval at the 1 percent level of significance.

Figure 4 shows the scattering of observed rainfall averages within the two confidence intervals. This result indicates that all the rainfall average estimations during the studied period estimated by the previous model were considered good estimates.

Finally, two important conclusions can be reached:

<u>First</u> - The variance analysis procedure proved to be an adequate methodology to find out the length of the cycles and it can be applied to other similar topics.

<u>Second</u> - Through the study of the special case, it was confirmed that the length of the rainfall cycle in the S.A.R. is five years and all the predictions of the rainfall averages during the cycle's years were significant.

Table 10. Differences between observed and estimated annual rainfall during the selected period

	m_{ij}	=	y_o (mm)	y_e (mm)	$(y_o - y_e)$ Z	Z^2
1952	m_{11}	0	422	426.60	-4.60	21.16
1953	m_{12}	1	491	380.30	110.70	12,254.49
1954	m_{13}	2	494	305.40	188.60	35,569.96
1955	m_{14}	3	278	305.40	-27.40	750.76
1956	m_{15}	4	423	380.30	42.70	1,823.29
1957	m_{21}	5	377	426.60	-49.60	2,460.16
1958	m_{22}	6	286	380.30	-94.30	8,892.49
1959	m_{23}	7	260	305.40	-45.40	2,861.16
1960	m_{24}	8	202	305.40	-103.40	10,691.56
1961	m_{25}	9	261	380.30	-119.30	14,232.49
1962	m_{31}	10	416	426.60	-10.60	112.36
1963	m_{32}	11	409	380.30	28.70	823.69
1964	m_{33}	12	365	305.40	59.60	3,552.16
1965	m_{34}	13	375	305.40	69.60	4,844.16
1966	m_{35}	14	270	380.30	-110.30	12,166.09
1967	m_{41}	15	496	426.60	69.40	4,816.36
1968	m_{42}	16	421	380.30	40.70	1,656.49
1969	m_{43}	17	541	305.40	235.60	55,507.36
1970	m_{44}	18	308	305.40	2.60	6.76
1971	m_{45}	19	377	380.30	-3.30	10.89
1972	m_{51}	20	422	426.60	-4.60	21.16
1973	m_{52}	21	197	380.30	-183.30	33,598.89
1974	m_{53}	22	421	305.40	115.60	11,363.36
1975	m_{54}	23	364	305.40	58.60	3,433.96
1976	m_{55}	24	384	380.30	3.70	13.69
					270.00	222,684.90

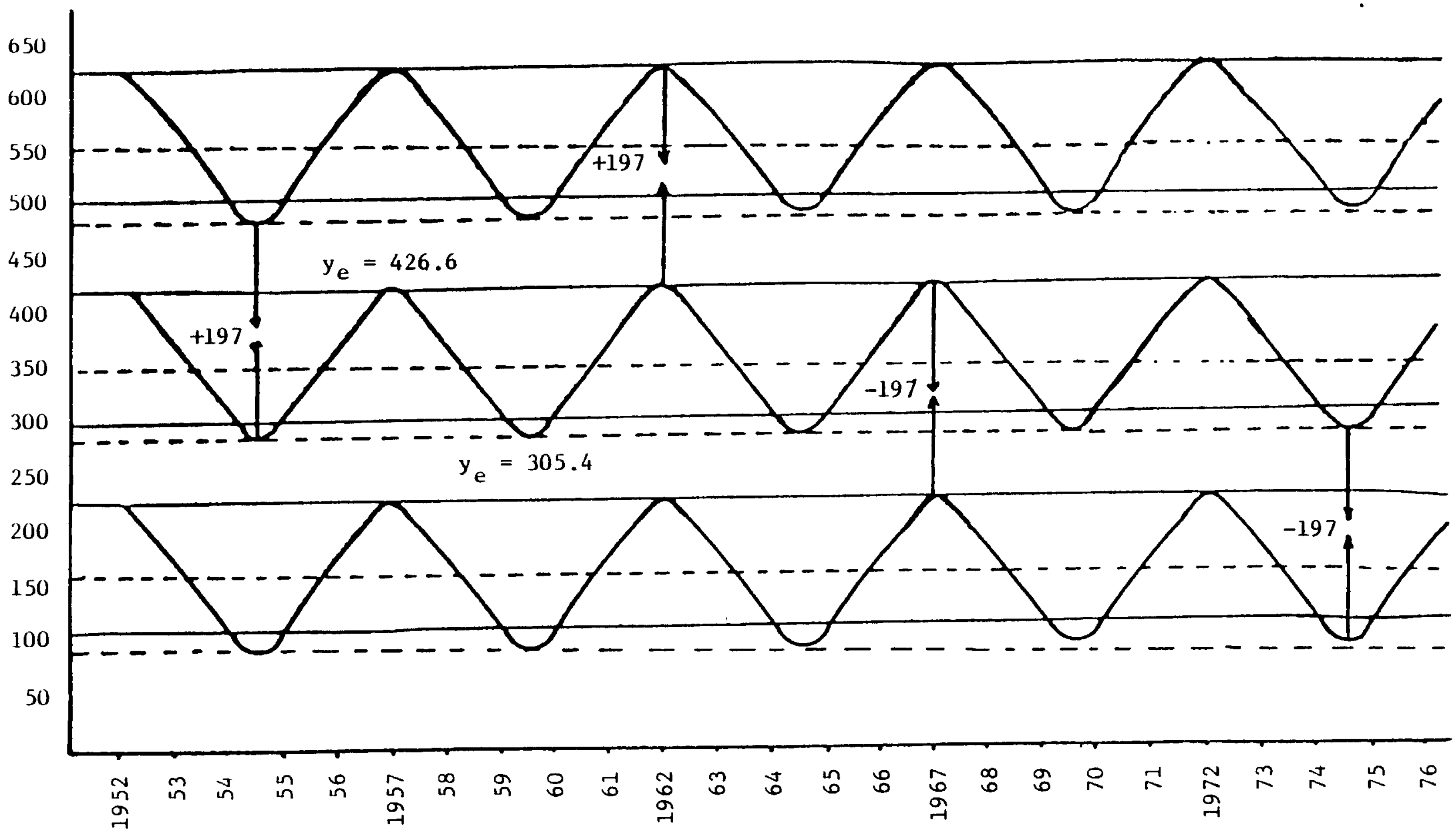

Figure 4. Graphical representation for systematic five-year rainfall cycles surrounded with the confidence interval for the estimated values at 95 percent probability