Alex. Eng. J., Alex. Univ., Volum 27 No. 2, pp.197-218 (1988)

COMPREHENSIVE ANALYSIS OF MUSCAT RAINFALL

ALAA AHMED YASSIN
Irrigation and Hydraulics Department
Faculty of Engineering, Alexandria University,
Alexandria, Egypt.

ABSTRACT

Precipitation in Oman, as the case in other arid areas, is characterized by short duration of relatively high intensity and with great variation in both space and time and mostly of limited areal extent. Prolonged period may be completely dry and good rains are often falling during single months.

The main objective of the present paper is to carry out a comprehensive analysis of Muscat rainfall; the capital of the Sultanate of Oman and which is located on the gulf of Oman. The avilable recorded rainfall data for the period 1893-1983 inclusive were analyzed considering monthly and annual series. Different statistical parameters were estimated and frequency analysis was carried out; considering different frequency distribution functions, for the daily, monthly and annual records. Moreover, moving mean values for the annual rainfall series were determined for different number of years and a successful search for a

trend for the moving mean curve was obtained and which is thought to be useful for future studies towards the forecasting of annual rainfall for Muscat.

1. INTRODUCTION

Muscat is the only area in the Sultanate of Oman where relatively long monthly and annual rainfall records are available. Regular records commenced in 1893 till date with some gaps where records are not traced. Those gaps are during the periods 1931-1935, 1943-1950, 1966-1967 and 1980. However annual rainfall values for years 1930-1935 inclusive, 1947, 1948, 1950 and daily rainfalls for 1952-1955 inclusive were recently found and recorded (1) but those were not used here in except for the study of the moving mean values for the annual series. Autographic data are available from 11 gauges installed from 1973 and these data have been subjected to rigorous quality control for the period 1973-1978 by Horn (2).

The present paper is primarily based on the available data of 75 years recorded at Muscat for the period between 1893-1983 and which was published by FAW report (1) and the Omani Ministry of Agriculture. The findings of the present paper will assist hydrologist in preparing successful water master plan for Oman and will allow for the proper and economical design of attenuation dams to be constructed across several major wadis in the Muscat area.

2. ANALYSIS OF MONTHLY RAINFALL

The available monthly data were carefully studied and different statistical parameters were estimated. Those included the values of the mean, standard deviation and skewness. Table (1) shows the values of these parameters for the 12 months and for the annual series. Also maximum recorded rainfall along with number of months in which rainfall exceeded 20, 50, 100 mm, number of dry months and number of months of annual maximum monthly rainfall are also shown in table (1).

The analysis of Muscat records summarized in Table (1) shows that only 3 months of December, January and February may be considered relatively wet while the rest of the year is generally dry. January was the wetest month as its mean rainfall value of 29.03 mm was the largest among other months. Twenty January months out of the 75 recorded values occupied the annual maximum of monthly rainfall; during 6 of them rainfall exceeded 100 mm. The maximum value of 143 mm was recorded in 1936. February comes in the second place after January as its mean monthly rainfall was 18.35 mm and 18 February months scored the annual maximum of monthly rainfall. Rainfall during that month exceeded 50 mm only 10 times while 25 months were dry. Also the maximum March rainfall was reported in 1955 where 70 mm was recorded. The mean value was 11.85 mm and this month was dry 33 times. It was noticed that for the three months of January, February and March the skewness coefficient was larger than 1.5 and the mean was larger than 10 mm.

The max monthly rainfall for April series was 98 mm recorded in 1916, while the mean April rainfall was as low as 8.76 mm. Also 46 months of April were dry and during only 4 months rainfall excessed 50 mm. Both months of March and April occupied maximum annual monthly rainfall 6 times. May is generally a dry month as 67 months out of the 75 recorded months were dry and the mean May rainfall was only 3.59 mm. However there were three years of 1960, 1963, and 1981 where 37 mm, 94 mm, and 103 mm of rainfall were recorded. The last one was during a violence storm which hit Muscat on the 3rd of may 1981 causing severe damage to roads and properties. During those three events the rainfall of May were the annual maxima of monthly rainfall. June is also a dry month with very few exceptions during the years 1898, 1903, 1914, 1977 where 64 mm, 1 mm, 9 mm, 7 mm where recorded. In 1898 the June rainfall was the maximum monthly rainfall of that year. Practically speaking since 1898 June is generaly a dry month. In July, rainfall exceeded 10 mm three times in the years 1956, 1962 1972 where 37 mm, 72 mm, and 18 mm were recorded. This 72 mm value was the maximum of monthly rainfall of 1962. The mean rainfall for July was 2.11 mm and 66 months were dry. Also During the month of August rainfall exceeded 10 mm only two times in 1916 and 1970 where 15 mm and 110 mm were recorded. The 110 mm of August 1970 was certainly an exeption and was the maximum of monthly rainfall of that year where the annual rainfall was 142 mm. As for September, no rainfall at all was recorded during the record of 75 years. October can also be considerd a dry month. Rainfall exceeded 10 mm only four times in 1902, 1914, 1916, and 1925 where 25 mm, 14 mm, 20 mm, 44 mm, were

The max monthly rainfall for April series was 98 mm recorded in 1916, while the mean April rainfall was as low as 8.76 mm. Also 46 months of April were dry and during only 4 months rainfall excessed 50 mm. Both months of March and April occupied maximum annual monthly rainfall 6 times. May is generally a dry month as 67 months out of the 75 recorded months were dry and the mean May rainfall was only 3.59 mm. However there were three years of 1960, 1963, and 1981 where 37 mm, 94 mm, and 103 mm of rainfall were recorded. The last one was during a violence storm which hit Muscat on the 3rd of may 1981 causing severe damage to roads and properties. During those three events the rainfall of May were the annual maxima of monthly rainfall. June is also a dry month with very few exceptions during the years 1898, 1903, 1914, 1977 where 64 mm, 1 mm, 9 mm, 7 mm where recorded. In 1898 the June rainfall was the maximum monthly rainfall of that year. Practically speaking since 1898 June is generaly a dry month. In July, rainfall exceeded 10 mm three times in the years 1956, 1962 1972 where 37 mm, 72 mm, and 18 mm were recorded. This 72 mm value was the maximum of monthly rainfall of 1962. The mean rainfall for July was 2.11 mm and 66 months were dry. Also During the month of August rainfall exceeded 10 mm only two times in 1916 and 1970 where 15 mm and 110 mm were recorded. The 110 mm of August 1970 was certainly an exeption and was the maximum of monthly rainfall of that year where the annual rainfall was 142 mm. As for September, no rainfall at all was recorded during the record of 75 years. October can also be considerd a dry month. Rainfall exceeded 10 mm only four times in 1902, 1914, 1916, and 1925 where 25 mm, 14 mm, 20 mm, 44 mm, were recorded respectively. In recent years and since 1926 October did not enjoy rainfall with the exception of 10 mm in 1938. November scored the annual maximum of monthly rainfall five times in years 1896, 1904, 1914, 1921 and 1959 where rainfall of 77 mm, 18 mm, 45 mm, 25 mm, and 69 mm were recorded respectively. The mean monthly rainfall of November was only 8.11 mm with 46 months of no rainfall. It was also noticed that the mean monthly rainfall for the months from April to November inclusive were very low and less than 10 mm while the coefficient of skewness were larger than 3.00 except the value of 2.586 for November. Those high values for the skewess reflect that there were more monthly rainfall below the mean value than above it.

As for the rainfall amounts, December comes in the third place after January and February. The mean monthly rainfall was 17.99 mm while 12 months of December occupied the annual maximum monthly rainfall. During December monthly rainfall exceeded 100 mm twice while 20 months were dry.

It was also found, as listed in table (1) that for each of the twelve months the standard deviation was larger than the mean; a characteristic which is not uncommon for arid regions, and which indicates the large variablity in the rainfall series. Figure (1) shows a plot for the values of the mean rainfall and standard deviation for different months.

3. ANALYSIS OF ANNUAL RAINFALL

As for the annual rainfall series, the mean value for the 75 years of record was 103.89 mm. Maximum value of 266 mm was recorded twice in 1916 and 1972. While the minimum value was during 1922 where only 12 mm was recorded. This indicates the big value of 22.17 for the ratio of maximum to minimum annual rainfall. Also for the 75 years of Muscat record the annual rainfall ranges from 11.50 % to 255 % of the annual mean. The above figures reflects the wide variability of annual rainfall. This fact was also supported by the high value of 65.05 mm for the standard deviation for annual rainfall. Moreover, the postive value of 0.661 for the skewness cofficient reflects that there were more annual values below the mean than above it. It was also noticed that relatively high values for annual rainfall was often due to rainfall in single months separated by prolonged rainless periods.

The aforementioned findings are typical features of rainfall pattern in arid areas. In such areas, the designer of water resources schemes usually recommends the use of the sample mode as an index instead of using either the arithmatic mean or the median. Although the median is not greatly affected by extreme values, it is not used if the data is appreciably skewed. The mode for Muscat record was 85 mm while the median was 98 mm. Figure (2) shows the annual rainfall series for Muscat.

4. FREQUENCY ANALYSIS

Frequency analysis is widely recommended and used to estimate extremes of precipitation and floods for design

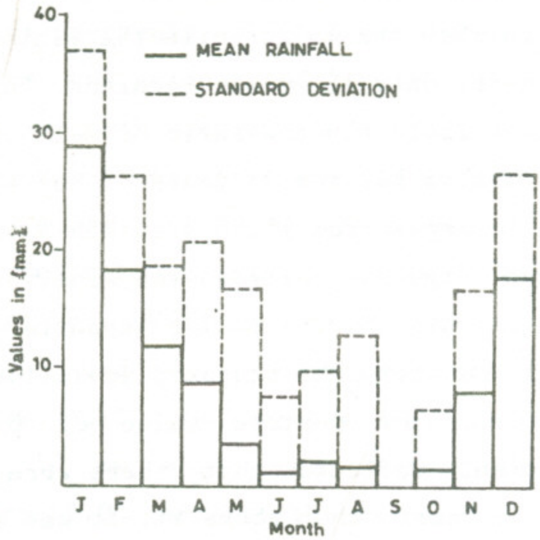

Fig.(1) MEAN RAINFALL AND STANDARD DEVIATION FOR DIFFERENT MONTHS.

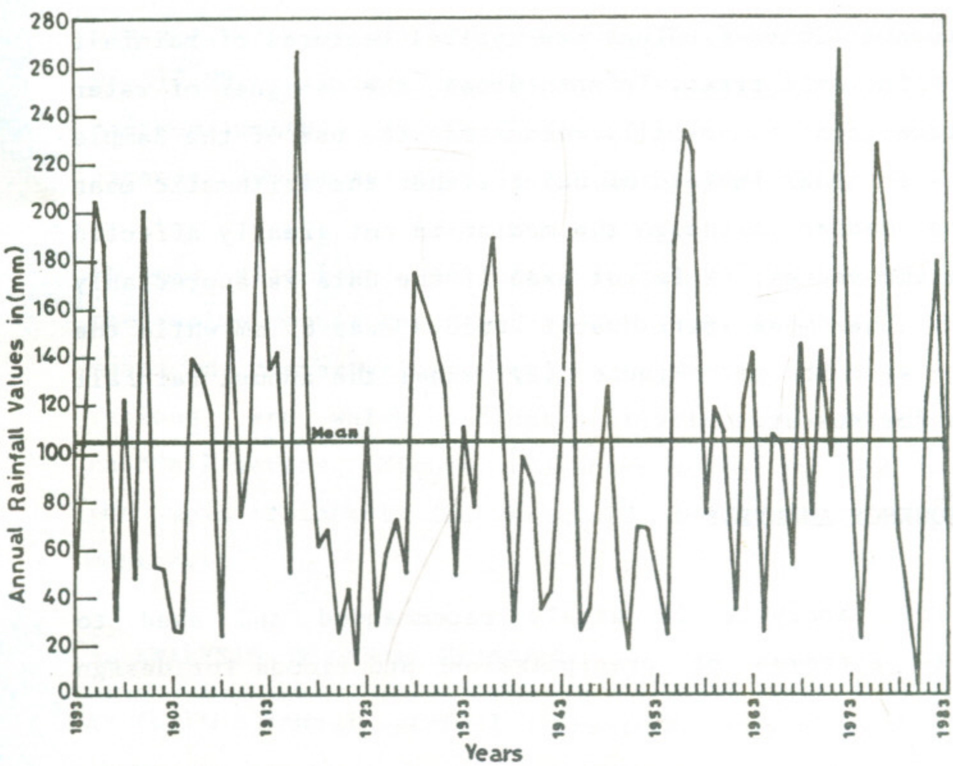

FIG.(2) ANNUAL RAINFALL SERIES FOR MUSCAT.

needs. However there are several frequency distribution methods which are presently in use to predict precipitation and flow corresponding to different return periods, but the merits of their applicability and accuracy for different purposes have not been clearly identified. In a recent inquiry of the World Meteorological Organization in 1983 (3) showed that the Type I-Extremal and the Log-Normal frequency distribution types are the most widely used or recommended frequency distribution types for extremes of both precipitation and floods at present. Almost one half of the 55 agencies from 27 countries participated in that inquiry are using those distribution types. The results of the inquery also revealed that the type II-Extremal, the Pearson type 3 and the Log-Pearson type 3 distributions are also in use, but mainly for floods. Moreover, to provide for a uniformity in fedral water resourses planning, the Water Resourses Council in U.S.A. has recommended that all government agencies use the Log-Pearson Type 3 as a base method (4).

In the present study the Type I-Extremal (TIE), the 2 Parameter Log Normal (2PLN), the 3 Parameter Log-Normal (3PLN), the Pearson type 3 (PT3) and the Log-Pearson Type 3 (LPT3) were used for the analysis of extreme events.

4.1 Frequency Analysis of Annual Series

The annual series of Muscat was analysed by applying the five different frequency distribution functions mentioned above. The standard error (SE) of each of the five

Table (2) Frequency Anylysis of Annual Rainfall by 3 different frequency distribution functions.

RP*	TIE mm	PT3 mm	LPT3 mm
5	151	143	154
10	189	189	201
25	237	246	261
50	273	290	306
100	308	332	351

* RP is the return period in years.

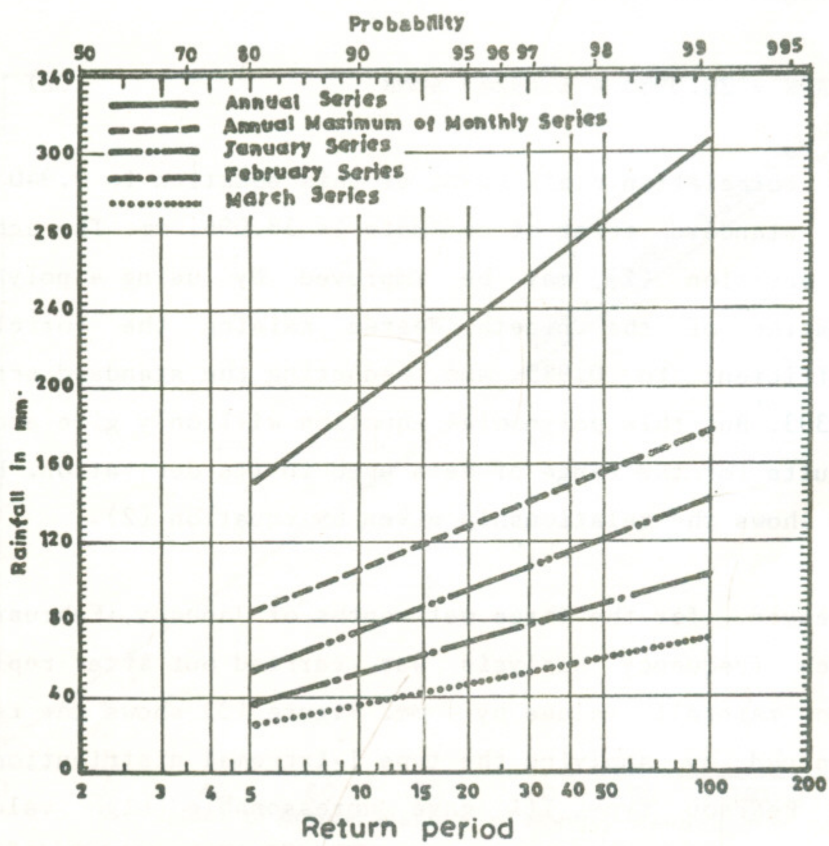

FIG.(3) FREQUENCY ANALYSIS OF MONTHLY AND ANNUAL SERIES BY TIE FUNCTION.

of monthly maxima, and the standard error for each was computed. It was found that the TIE distribution gave the minimum value of 4.777 for the standard error. Table (3) shows the values of monthly maxima corresponding to different return periods predicted by the TIE, PT3 and LPT3. The 2PLN and 3PLN functions predicted unreasonable monthly maxima for return periods of 25 years and up. Figure (3) shows the results obtained by the type I-Extremal distribution and which is adopted by the present study.

Moreover, the annual maxima of monthly rainfall (AMMR) was correlated to the annual rainfall (ANN) by the following straight line equation:

$$ANN = 20.0966 + 1.45245\ AMMR \quad (2)$$

The correlation coefficient of this equation is 0.940 while the standard error of estimate is 38.096. mm. The accuracy of equation (2) may be improved by using a polynomial equation of the nineth degree raising the correlation coefficient to 0.985 and reducting the standard error to 35.303. But this polynomial equation will only give accurate results for the range of data used in its derivation. Figure (4) shows the relationship given by equation (2).

Moreover, for the three wet months of January, February and March frequency analysis was carried out after replacing zero rainfall values by 1 mm. Figure (3) shows the results obtained by applying the type I-Extremal distribution. The Log Pearson type III gave unreasonable high values of

Table (3) Frequency Analysis of Monthly Maxima Rainfall by 3 different frequency distribution functions.

RP years	TIE mm	PT3 mm	LPT3 mm
5	84	81	86
10	105	106	111
25	132	138	142
50	152	161	164
100	171	184	185

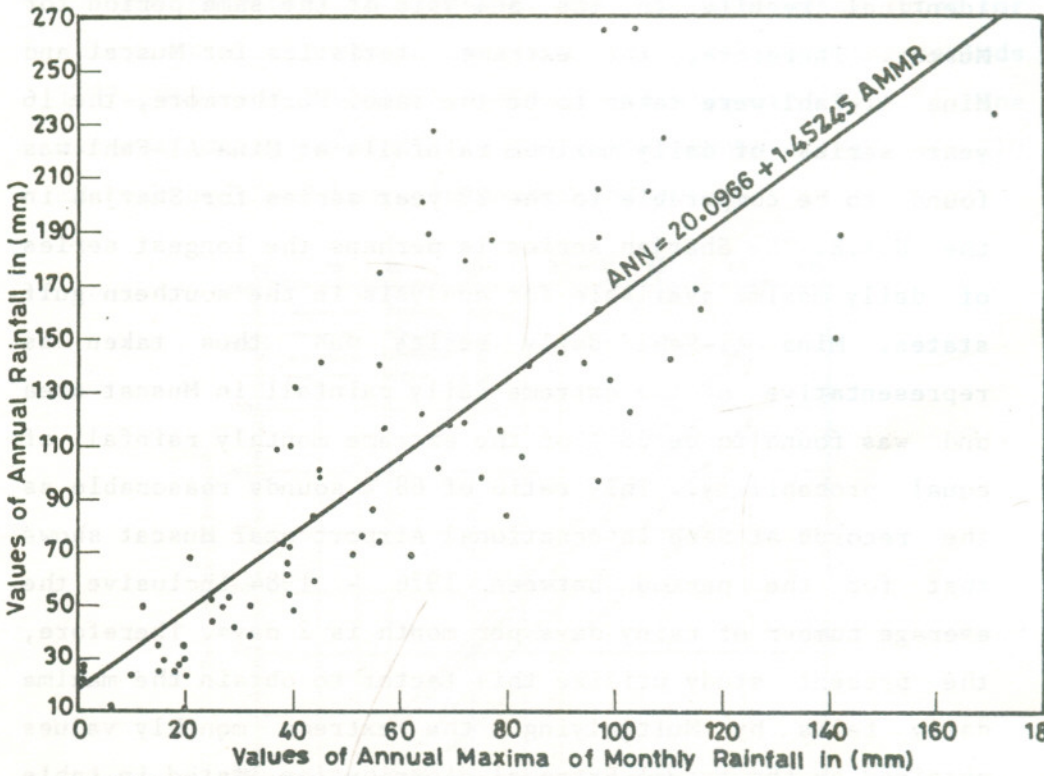

FIG.(4) RELATIONSHIP BETWEEN ANNUAL RAINFALL AND ANNUAL MAXIMA OF MONTHLY RAINFALL.

rainfall corresponding to return periods bigger than 10 years.

4.3 Frequency Analysis of Dialy Rainfall

The longest available daily rainfall record in Oman is that for Mina AL-Fahl; the oil port in Muscat, and which commenced in 1976. Also the heaviest daily rainfall on Muscat was 300 mm recorded during a cyclone on June 1890(5).

In a study reported by Gibb, Petermuller & Partners (6) the data of the available 16 year series of monthly maxima at Mina Al-Fahl were analysed and were found to give almost identical results to the analysis of the same period for Muscat. Therefore, the extreme statistics for Muscat and Mina Al-Fahl were taken to be the same. Furthermore, the 16 year series of daily maximum rainfalls at Mina Al-Fahl was found to be comparable to the 29 year series for Sharjah in the U.A.E. The Sharjah series is perhaps the longest series of daily maxima available for analysis in the southern gulf states. Mina Al-Fahl daily series was thus taken as representative of the extreme daily rainfall in Muscat area and was found to be 68 % of the extreme monthly rainfall of equal probability. This ratio of 68 % sounds reasonable as the records at Seeb International Airport near Muscat shows that for the period between 1976 - 1984 inclusive the average number of rainy days per month is 2 days. Therefore, the present study utilize this factor to obtain the maxima daily falls by Multiplying the extreme monthly values obtained by the type I-Extremal distribution listed in table

(3) by this factor.

In another study Wheater and Bell (7) analyzed 12 annual maxima daily falls abstracted from the Pakistan Wheather Review and which covered the period from August 1947 to May 1959. The findings given by Wheater are lower than those reported by Gibb and those of Sharjah. Figure (5) shows the findings of the presènt study, Wheater and Bell and those of sharjah.

Moreover, Horn (2) mentioned the existance of a summary table indicating the greatest daily rainfall values that have occured during different months for a period of 38 years during 1893-1929 and 1935-1944. The maximum value was 79 mm recorded in January. Also Horn frequency curve for daily rainfall based on data of 15 years for the periods 1952-1955 and 1968-1978 inclusive is shown in Fig. (5). The largest daily rainfall for the latter group of data was 110 mm recorded in 9 hours in August 1970.

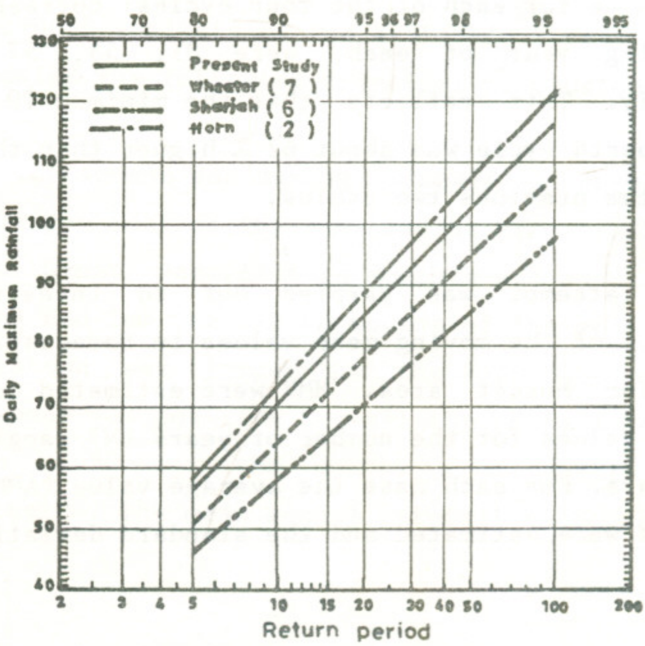

FIG.(5) FREQUENCY ANALYSIS OF DAILY MAXIMA SERIES BY TIE FUNCTION.

5. MOVING MEAN VALUES FOR ANNUAL RAINFALL SERIES

The fluctuation in annual rainfall series may be damped or smoothed out by plotting the moving mean values (MMV) for N years of the annual series. The value of N is chosen so that most of the random component of precipitation is damped out leaving the effects of longer wet and dry cycles in the record. MMV were estimated considering different number of years and table (4) shows the maximum and minimum MMV for N ranging from 5 to 25 years. Figure (6) shows the 10-year moving means for Muscat for the period 1893 to 1974. Values of MMV were plotted at the begining of the period. It is seen from that figure that there were four general cycles each lasted for about 10 years in which the 10 year MMV was increasing reaching almost a common maximum value of about 131 mm. Those four cycles started at years 1901, 1918, 1945 and 1958 reaching maximum mean values of 131, 130, 127 and 135 mm at years 1909, 1928, 1955 and 1968 respectively. The minimum value for each of the four cycles; corresponding to the begining year of each were 81, 53, 57 and 89 mm respectively. This reflects that the minimum 10 year MMV for the fourth cycle was about 62 % higher than the minimum value for the previous two cycles.

A further attempt was carried out to investigate the possible use of the moving mean values in forecasting annual rainfall for Muscat area. MMV were estimated considering different values for the number of years (N) ranging from 5 to 75 years. For each case the average value (AMMV) of the MMV values were estimated and the standard deviation of the

MMV values from their average value (AMMV) were determined. It was found that the MMV for N=63 gave the minimum value for the standard deviation. For this case MMV ranged between a maximum value of 100.71 mm and a minimum of 94.48 mm, and the AMMV was 97.53 mm.

Figure (7) shows the plot of the MMV for N=63. This figure shows that the MMV curve considering 63 years may be approximated by a sine curve along the AMMV line and which is shown dotted on the figure. This sine curve relationship may be used to predict future annual rainfall for Muscat. However, the above analysis is only a preliminary one and further investigation is needed to identify the best fit sine curve equation to be utilized for future forecasting of annual rainfall for Muscat.

6. CONCLUSIONS

The thorough analysis of the available Muscat rainfall data has revealed the following principal conclusions:

1. The wet season was during December to February inclusive while the rest of the year may be practically considered dry. Great variation in monthly and annual series were found and for the twelve months of the year the standard deviation were larger than the mean. The coefficient of skewness was positive for all the records and was larger than 2.50 for the months from April to November inclusive. The mean annual rainfall value was 104 mm.

Table (4) Maximum and Minimum MMV for Different Number of Years.

N Years	Maximum		Minimum	
	Value	Period	Value	Period
5	168	1955-1959	42	1918-1927
10	135	1968-1977	58	1917-1926
15	119	1905-1919	68	1940-1954
20	119	1954-1973	80	1935-1954
25	119	1955-1979	85	1918-1942

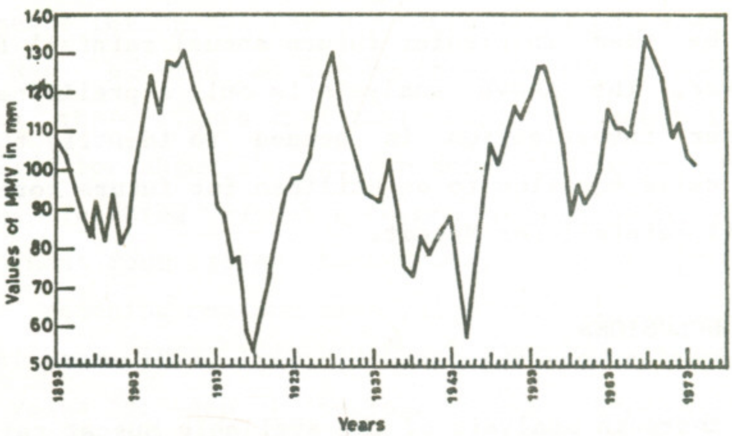

FIG.(6) THE 10 YEAR MOVING MEAN VALUES FOR MUSCAT.

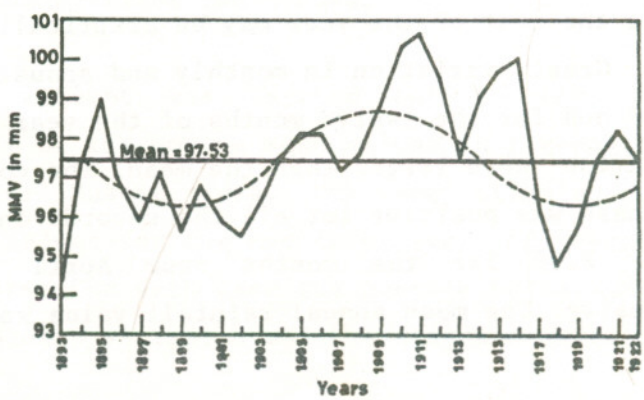

FIG.(7) THE 63 YEAR MOVING MEAN VALUES FOR MUSCAT.

2. The type I-extremal frequency distribution function was the best function among other four functions to fit daily, monthly and annual series. Rainfall corresponding to different return periods for daily, monthly and annual series were given.

3. Moving mean values for different years were studied and the ten year moving mean values showed four general cycles each lasted about ten years.

4. The 63 years moving mean values gave the least standard deviation of the MMV from their average. For this case the MMV curve was approximated by a sine curve which may be used in a future study for the forecasting of Muscat annual rainfall.

ACKNOWLEDGEMENT

This paper was prepared when the author was on sabbatical leave from Alexandria University and working as a hydraulic engineer for the Ministry of Communications, Sultanate of Oman. The author wishes to thank the officials of that Ministry for their cooperation in furnishing the data used in the present study.

NOTATIONS

AMMR = annual maxima of monthly rainfall

AMMV = average of moving mean values

ANN = annual rainfall

LPT3 = log Pearson type 3 frequency distribution function

MMR = maximum monthly rainfall

MMV = moving mean value

NMAM = number of months of annual maximum of monthly rainfall

NMR = number of months with rainfall as specified

PT3 = Pearson type 3 frequency distribution function

RP = return Period

SD = standard deviation

SE = standard error of estimate

TIE = type 1 extremal frequency distribution function

2PLN = 2 parameter log normal frequency distribution function

3PLN = 3 parameter log normal frequency distribution function

REFERENCES

[1] Horn, P.M., "Rainfall in the Muscat Area", FAW Field Document No. 1, Rome, 1976.

[2] Horn, P.M., "Rainfall Intensities in Oman", Appendix A to FAW Field Document No. 11, Rome, 1978.

[3] Sevruk, B. and Geiger, H., "Frequency Distributions prefared by Hydrologist", IAHR XXII Congress and Fourth International Conference on Urban Storm Drainage, Lausanne, Switzerland, 1987.

[4] Guidelines for Determining Flood Flow Frequency, Bulletin 17, Hydrology Communication Water Resources Council, Washington D.C., June 1977.

[5] Kite, G. W., "Frequency and Risk Analysis in Hydrology", Water Resources Publications, Fort Collins, Colorado, U.S.A., 1978.

[6] Gibb, Petermuller and Partners, "Nizwa-Thamrit Road-Drainage Design Review-Vol.1, Report Submitted to the Omani Ministry of Communications, Athens, Greece, 1983.

[7] Wheater, H.S. and Bell, N.C., "Northern Oman Flood Study", Proceeding of the Institution of Civil Engineers Part 2, Sept. 1983.