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Spatial and Temporal Analysis of Recurrence Time of Rainfall in the Sultanate of Oman

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Abstract

The analysis of rainfall in space, time and amounts is vital in arid and semi-arid regions where the water resource is scare, and highly variable. In this study, we analyze the spatial and temporal of recurrence time of rainfall in the Sultanate of Oman using data recorded for a period of more than 25 years. The data is divided into seven physical geographical surfaces to represent the various topographic regions in Oman. The lognormal distribution and Anderson Darling tests were used to estimate the recurrence periods of annual rainfall for the periods 2, 5, 25 and 50 years. The study shows that a potential increase of rainfall in all geographic locations. The highest rainfall of 50 years is predicted to be 1048 and 565 mm in Al Hajar and Dhofar Mountains respectively, followed by an average annual maximum rainfall of 362, 338, and 304 mm in the interior, Salalah coastal plain and northwest coast regions respectively.

Keywords: Arid Region, Rainfall Data, Recurrence, Oman

1. Introduction

Rainfall is an important climatological parameter in arid and semi-arid areas such as the land of Sultanate of Oman where there is an urgent need for water management due to vast urbanization and economic growth. The rainfall in Sultanate of Oman is characterized by three categories distributed all over the country; hyper-arid (< 100 mm), arid (100 – 250 mm), and semi-arid (250-500 mm). Since water is very crucial in the country, several recharge dams have been constructed for retaining some of surface water runoff during heavy rainfall storms in order to recharge the groundwater level (Ministry of Regional Municipality and Water Resources, 1998).

Rainfall in the Sultanate of Oman is affected by four main air masses from four different directions; the Mediterranean, Central Asia, Tropical Maritime of the Indian Ocean and Tropical Africa (Fisher and Membery, 1998). This atmospheric influence largely operate at different times of the year, bringing a variable degree of seasonal climate, and hence rainfall, to Oman (Charabi and Al-Hatrushi).

This study, is aiming to analyze the temporal and spatial variations of rainfall amount at seven selected meteorological stations in the Sultanate of Oman representing variety of topography and large latitudinal extent, using data recorded for a period of more than 25 years. The Lognormal distribution is used to estimate the recurrence of annual rainfall for several periods (2, 5, 25, and 50 years). The Sultanate of Oman is diversified in terms of its topographical features; therefore, the analysis of the rainfall data was divided into seven regions that are representative of different physical geographical surfaces. To the best of our knowledge, this study is the first to use such mathematical methodology in Oman and long records of rainfall data varying from 21 to 68 years of available records at selected meteorological stations.

2. Materials and Methods

2.1. Study Area

The sultanate of Oman is located in the southeastern corner of the Arabian Peninsula between 16 39' and 26 30' north of the equator, with an area of 309, 500 km2. The Sultanate is bordered in the west, northwest and southwest by the Kingdom of Saudi Arabia, United Arab Emirates and Republic of Yemen, respectively. Oman is surrounded by three bodies of water; the Gulf Sea, Oman Sea and the Arabian Sea, respectively. Oman has a coastal line extended to more than 3000 km from the north at Strait of Hormuz to the borders of Yemen in the southwest.

Seven meteorological stations have been chosen for the study to represent the major three topographical regions of the country (Fig. 1):

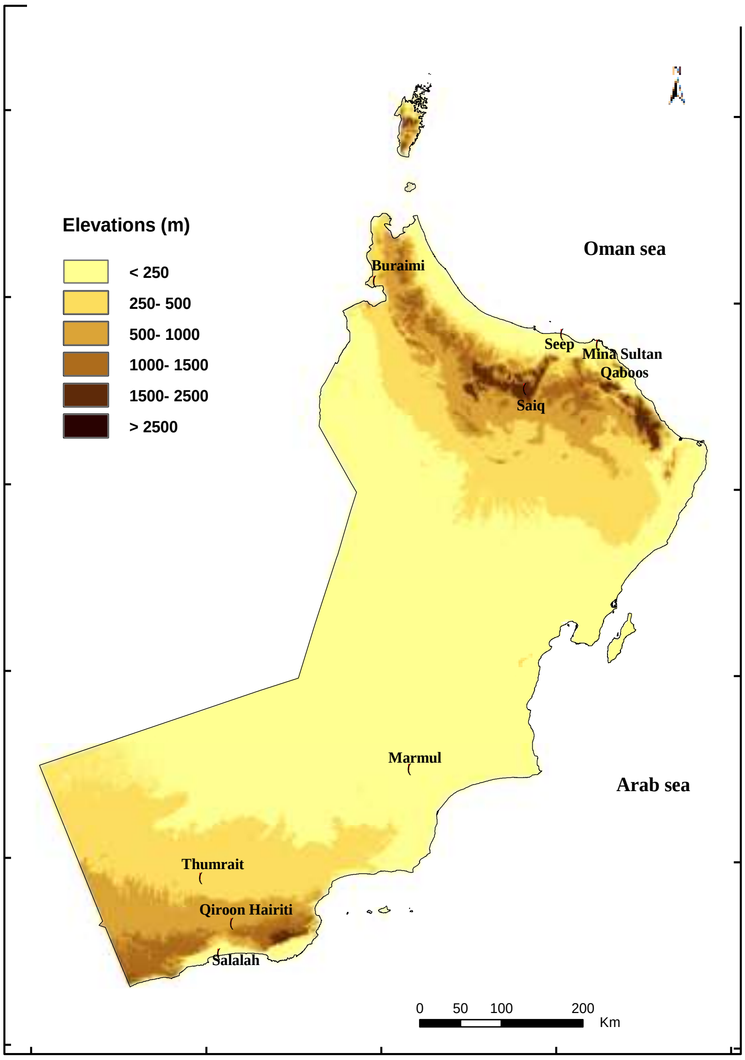

Figure 1: The location of the selected stations

1- The coastal plains including Al Batinah coastal plain in the north, and Salalah coastal plain in the south covering 3% of the total land mass. The coastal plains are heavily settled and considered to be the major agricultural areas and have elevations ranging from 0 to 500 m. This region represented by Seep station in Al Batinah coastal plain and Salalah station in Salalah coastal plain.

2- The interior region located between the mountains in the north and south of the country and dominated by the sandy land desert. The area of the region is 82% of the country and has elevations less than 500 m. This region is represented by Buraimi, Marmul and Thumrait stations.

3- The mountain ranges consist of the mountains stretching from the northern to the easternmost part of the country including Al Hajar Mountains in the north which has the highest peak of 3009 m above sea level in Jabal Shams. This mountain range is represented by Saiq station which is 2000m above mean sea level. Also the Dhofar Mountains dominated in the southwestern part of the country and have peaks ranging from 1000 to 2000 m above mean sea level. This mountain range is represented by Qairoon Hairiti station which is 878.30 m above mean sea level.

The amount of rainfall in the Sultanate of Oman is affected by four climatological systems (Robert and Wright, 1993):

1- Local strong convection cells during summer seasons which cause convective rainstorms.

2- The frequent cold fronts during the months of November to April moving from the Mediterranean Sea bringing rain to the northern parts of the Sultanate and even reaching the central and southern parts of the country.

3- Tropical storms and cyclones originate over the Arabian Sea are almost entirely confined to two cyclone seasons namely the pre-monsoonal period(May-June) and post-monsoonal period (October-November) bringing heavy rain to the Arabian Coast of Oman. The cyclones originating at the Arabian Sea are unpredictable and can occur any time of the year and give rise to intense storms bringing heavy rain and flash floods to the areas along the Arabian Coast of Oman. One of such storms reached the cost in June 2007 was the super cyclone Gonu. The cyclone is considered as the strongest in the last hundred years when 900 mm of rain was recorded in 24 hours (Al-Najar and Salvekar, 2009).

4- The southwesterly monsoon system is considered to be a very important climatological condition such as drizzle, fog, mist and rain affecting Dhofar Mountains and the southern region and the central region in general. This system occurs during the summer season from June to September.

In Oman the spectrum of plant life and seasonality of flowering are more influenced by the amount and distribution of rainfall than variations in temperature (Ghazanfar, 1997).

A study by Kwarteng et. al., 2009 showed that yearly rainfall over the country is quite variable and irregular, and depends on the geographical locations. The yearly rainfall recorded in the study in the Sultanate between 1977 and 2003 is 117.0 mm. The highest average of 338 mm was recorded in 1977. The years 1982, 1983 and 1995 to 1998 recorded high averages. Subsequently, the averages dropped off considerably. The lowest average of only 28.6 mm was recorded in 1984. Other low yearly rainfall averages of 50.9, 52.9 and 37.2 mm were recorded in 1986, 1991 and 2001, respectively. The study showed yearly averages of rainfall for different regions: the Dhofar Mountains have the highest yearly average of 184.6 mm. The yearly averages for the other regions are the northern Oman Mountains, 141.4 mm; Al Batinah coastal plain, 100.8 mm; northeast coast, 89.8 mm; interior region (mainly dry sandy desert), 76.6 mm; and Salalah plain, 112 mm. For all the regions, there is a lot of variation in the yearly averages as the study indicated by the coefficient of variation which is over 50% for most of the years.

2.2. Data Description

The data used in this study were obtained from the Ministry of Environment and Climatological Affairs. In this study, seven monitoring stations, with more than 21 years of continuous rainfall data coverage from 1943 to 2011 were used (Table 1). Taking into considerations all the facts about the location of the country, the different types of topographical features of the land, climatological systems and seasonal rainfall (see Section 2.1), the stations have been selected to be representative, and they consist of (1) north coastal plain (Seep Station), (2) south coastal plain (Salalah Station), (3) interior region (Buraimi Station), (4) northern mountains (Saiq Station), (5) southwestern mountains (Qairoon Hairiti Station), (6) the desert (Marmul Station), (7) the desert in the south-rain shadow of the Monsoon (Thumrait Station). Table 1 shows the characteristics of the stations including Universal Transverse Mercator coordinates (longitudes and latitudes), the World Meteorological Organization (WMO) index number, and elevation.

Table 1: Geographic Location Details of Stations

STATION	W.M.O Index No.	Latitude "N"			Longitude "E"			Elevation (M)
		Deg.	Min.	Sec.	Deg.	Min.	Sec.	above M.S.I
Buraimi	41244	24	14	29.10	55	47	13.80	298.89
Seeb	41256	23	35		58	17		8.40
Saiq	41251	23	04	26.30	57	36	59.50	2001
Marmul	41304	18	08	23	55	10	39	269.00
Thumrait	41314	17	40	22.80	54	01	35.70	466.90
Qairoon Hairiti	41315	17	15	17.60	54	05	6.70	878.30
Salalah	41316	17	02		54	05		20.00

2.3. Data Analyses

The recurrence periods of the average yearly rainfall were calculated for all the stations. The following parameters were analyzed for the stations: (1) the Anderson-Darling Normality Test, (2) mean, (3) median, (4) maximum, (5) standard deviation, (6) coefficient. Variation, and (7) 95% confidence interval.

The estimation of recurrence periods of rainfall requires the choice of a statistical distribution, its estimation method and goodness of fit test. The choice of the three parameter lognormal probability distribution was made by looking at the empirical shape of the distribution, the estimates of skewness and kurtosis. However, for some stations the performance of the distribution was also compared with Gamma and Weibull distributions. Anderson-Darling test was used because it is well established powerful test.

The lognormal distribution and Anderson Darling tests of goodness of fit were used to calculate the retention periods. The probability density function (pdf) of three parameter lognormal distribution is given as below:

$$f(x) = \frac{\exp(-\frac{\log(x-\theta)-\xi)^2}{2\sigma^2})}{(x-\theta)\sqrt{2\pi\sigma}}$$

The random variable x has a lognormal distribution if $\log(x - \theta)$ has a normal distribution where $x > \theta$ and θ is threshold parameter , $\sigma > 0$ and σ is location and ξ is the scale parameter.

The quintile function of this distribution can be written in terms of a standard normal variable $\phi^{-1}(F)$ as:

$X(F) = \theta + \exp(\xi + \sigma\phi^{-1}(F))$

Where F is the probability of exceedance and its reciprocal is termed as Return Period T. Thus $T = F^{-1}$.

The unknown parameters of this distribution were estimated using MIMITAB which calculates unbiased parameter estimates and uses Anderson-Darling statistics to perform Goodness-of-fit test. The Anderson-Darling Statistic (AD) is calculated as follows:

$AD = -n - (1/n) \Sigma_i [(2i - 1) \log Z_{(i)} + (2n + 1 - 2i) \log (1 - Z_{(i)})]$

Where $Z_{(i)}$ are ascending order standard normal varieties.

3. Results

Yearly rainfall over Oman is quite variable and irregular, and depends on the geographic location as depicted in Table 2 of the regions, the Al Hajar Mountains (Saiq Station) have the highest mean average followed by the Dhofar Mountains (Qairoon Hairiti Station) and south coast plain (Salalah Station). The lowest mean averages are the desert in the South-rain shadow of the Monsoon (Marmul and Thumrait Stations). For all the regions, there are a lot of variations in the yearly averages as indicated by the coefficient of variation. The highest more consistent of rainfall is in the Mountain regions and the lowest less consistent is in the desert regions as indicated by the low and high values coefficient of variation respectively. The data show that in the years that the maximum rainfall is high, this applied to all regions. In general the yearly rainfall distributions appear similar in all the regions as indicated by the skewness and kurtosis calculations. Table 3 shows that similar pattern of rainfall as shown by the AD (Anderson goodness of fit values) and the threshold values. Table 4 shows the rainfall threshold values along with their standard errors for various recurrence periods. The model predicts the expected annual maximum rainfall averages from 2 years to the next 50 years with the highest expected average rainfall in Al Hajar Mountains region with non exceedance of about 1000 mm. The interior region (Buraimi Station) and northeast coast (Seep Station) are also shown to have on average 50 yearly rainfall of more than 300 mm. The high standard errors for the desert regions (Marmul and Thumrait Stations) are expected since the coefficient of variation are high for these regions. Therefore, the model could not give us a good prediction of the recurrence periods for these regions for more than the next 25 years.

Table 2: Descriptive Rainfall Statistics for the stations

Station	Years	Mean	StDev	CoefVar	Median	Maximum	Skewness	Kurtosis
Buraimi	32	82.5	88.9	107.81	62.3	423.0	2.44	6.85
Seep	37	83.6	70.4	84.23	70.2	307.6	1.41	1.99
Qairoon H	21	213.9	124.4	58.15	176.2	588.4	1.69	3.28
Salalah	68	104.7	88.2	84.22	73.4	509.4	2.63	7.92
Marmul	24	27.53	45.84	166.49	9.75	203.00	2.87	9.20
Thumrait	28	31.6	53.1	167.87	8.60	227.0	2.57	6.70
Saiq	32	300.3	172.53	55.57	254.3	900.9	1.56	3.47

Table 3: Parameter Estimates of 3-Parameter Lognormal with Anderson (AD) goodness of fit values**.**

Parameters

Station	Location	Scale	Threshold	AD
Buraimi	4.14900	0.85953	-8.40111	0.295
Seep	4.46797	0.64323	-22.86369	0.234
Qairoon H.	5.10268	0.58430	18.99005	0.264
Salalah	4.17295	0.78141	14.99663	0.524
Marmul	2.11094	1.86971	-0.13239	0.668
Thumrait	2.04660	2.10615	-0.03909	0.684
Saiq	4.97150	0.92105	92.48041	0.615

Table 4: Rainfall Threshold values (mm) along with their Standard Errors (S.E) for various Return Periods in years.

	Return Periods in Years			
Station	**50**	**25**	**5**	**2**
Buraimi	361.876	276.961	122.232	54.9695
S.E	115.149	76.7299	23.1375	10.2508
Seep	303.820	245.960	26.939	64.3156
S.E	76.5647	53.0164	18.4422	10.1837
Qairoon H.	565.024	476.411	287.917	183.453
S.E	148.019	105.310	9.9071	22.6749
Salalah	338.032	269.916	140.282	79.9030
S.E	58.2420	40.5014	13.8230	6.3352
Marmul	383.948	217.806	39.6939	8.12363
S.E	370.813	179.286	18.6284	3.5939
Thumrait	585.249	309.106	45.5279	7.70246
S.E	515.423	236.678	21.8681	3.28645
Saiq	1048.80	815.878	405.626	236.723
S.E	405.668	252.595	59.7692	28.4715

4. Discussion

The average yearly rainfall distribution indicates that Oman experiences arid, semi-arid and hyper-arid conditions. The rainfall patterns appear stable and predictable over the next 50 years. The ability to observe trends in average rainfall is quite important that might be useful in predicting potential periods of droughts or intense rainfall. This study is the first study to use long records of rainfall data which is an essential to detect any significant trends in rainfall in arid and semi-arid regions, because due to the irregular and unpredictability of rain, arid and semi-arid terrains require long period data for any trends to be observed. Fisher (1994) observed that data records of 10 years or more were sufficient to estimate mean total rainfall and other climatological parameters.

This study utilized rainfall records ranging from 21 to 68 years of data. Such predictive potential of rainfall of more than 300 mm for a recurrence period of 50 years could have a significant impact on the management of crops, livestock, urbanization and sustainable development in the Sultanate of Oman. The locations of high average rainfall as predicted in this study are essential to the recharging of the underground water. Since several dams have been built in Oman to store and recharge the water tables, the prediction of the rainfall for the recurrence periods in 25 and 50 years could encourage in continuity of building more dams and establish maintenance programs for the dams.

5. Conclusion

The sultanate of Oman is quite diversified in terms of its northeast-southwest extent, geomorphology and climatic conditions. This variations used in the analysis of available rainfall data recorded at 7 stations. This led to divide the data set into six regions that are representative of the different geomorphic sectors. Rainfall in Oman is highly variable, irregular and diversified. The yearly mean rainfall varies from a low of 27.53 mm in the hot, dry desert to a high of 300.31 mm in the Al Hajar Mountains. In general the yearly patterns of variation are similar in all regions over the study period. The majority of rainfall in northeast coast region occurs in winter season from November to April due to mid-latitude westerly depression by polar front jet stream. The rainfall in Dhofar Mountains and south coast plain (Salalah Plain) are dominated by the fall season in July and August due to southwest monsoon. The rainfall months in the interior region are February and March.

The recurrence periods of 2, 5, 25 and 50 average yearly rainfall indicate that the prediction shows a potential increase of rainfall in all geographic locations. The highest rainfall of 50 years of return period is predicted to be 1048 and 565 mm in Al Hajar and Dhofar Mountains respectively, followed by an average annual maximum rainfall of 362, 338, and 304 mm in interior, Salalah coastal plain and northeast coast regions respectively, while the lowest rainfall in the desert region but with high standard errors due to the high values of coefficient variations.

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