Spatial and statistical analysis of rainfall in the Kingdom of Saudi Arabia from 1979 to 2008

Weather – October 2016, Vol. 71, No. 10

Sulafa Hag-elsafi[1] and Manahil El-Tayib[2]

[1]*Department of Geography, King Saud University, Riyadh, Saudi Arabia*

[2]*Department of Quantitative Analysis, King Saud University, Riyadh, Saudi Arabia*

Introduction

Rainfall should sustain the increasing needs of agricultural irrigation, the growing population, and rapid industrialisation (Singh *et al*., 2002). Water scarcity, however, is a chronic problem in the arid and semi-arid countries of the Middle East. The Kingdom of Saudi Arabia (KSA) has an extremely dry climate with a large water supply deficit. The spatial and temporal distribution, quantity, and duration of rainfall in the arid and semi-arid zones of the country are highly variable (Noy-Meir, 1973; Subyani, 2004; Kwarteng *et al*., 2009; El-Nesr *et al*., 2010).

Rainfall is a main source of water in the KSA. The disparity in rainfall distribution is great, and some parts of the country receive heavy rainfall, while others receive little. Thus, this study was conducted to analyse the statistical and spatial distribution of rainfall in the KSA over a 30-yr period.

Methods

Study area

The KSA lies in the tropical and subtropical desert regions of the globe, between latitudes 16°21′58″N and 32°9′57″N, and longitudes 34°33′48″E and 55°41′29″E. It has a dry desert climate, with generally light winds and high temperatures in most regions. Almost all of the country is arid, with relatively cloudless skies, resulting in great temperature extremes and wide variation among seasons and regions. In the north, annual rainfall amounts range from 100 to 200mm. Farther to the south, except near the coast, annual rainfall amounts are <100mm. Higher elevations in the western and southern KSA receive sufficient rainfall, and 500mm yr^{-1} is not uncommon in some small areas (AQUASTAT, 2008).

The KSA receives large amounts of rainfall in the northern, central-northern, and southwestern regions, whereas the southeastern region is almost entirely dry. The southwestern region of the country receives rainfall in almost all months of the year (Almazroui, 2012). The Tropical Rainfall Measuring Mission (TRMM) data for the period 1998–2009, from which an estimate of rainfall over Saudi Arabia can be made, indicate that very little or no rain at all fell in the Rub Al-Khali (Almazroui, 2010).

Rain is associated with different weather features in each season. Winter rain is caused by disturbances from the Mediterranean Sea and the Sudan Trough, and westerly waves in the upper atmosphere. Summer rain is caused by the northward advance of the southwesterly monsoon and the Intertropical Convergence Zone (Sen and Al-Suba'i, 2002); their potential generally decreases from north to south, except in mountainous areas, where uplift is a regional factor (Abdullah and Al-Mazroui, 1998). Regional and local variations or changes in the character of rainfall depend a great deal on atmospheric circulation patterns determined by the North Atlantic Oscillation, El Niño Southern Oscillation and other patterns of variability (Hasanean and Almazroui, 2015).

The rainfall distribution is not uniform in time or space; geographic factors, such as temperature, pressure, distance from source moisture, and topography also play important roles. Seasonality is an important factor (Abdullah and Al-Mazroui, 1998; Hasanean and Almazroui, 2015).

Data and results

Daily climatic data from 28 meteorological stations representing all 13 districts of the KSA (Figure 1) were obtained from the Presidency of Meteorology and Environment, the national official climate agency. The KSA contains the world's largest continuous uninhabited sand desert, which is called the Rub Al-Khali ('Empty Quarter'; Almazroui *et al*., 2012). Thus, no rainfall station is located in this southeastern region of the country. Recording began in various years and continued through 2011. For

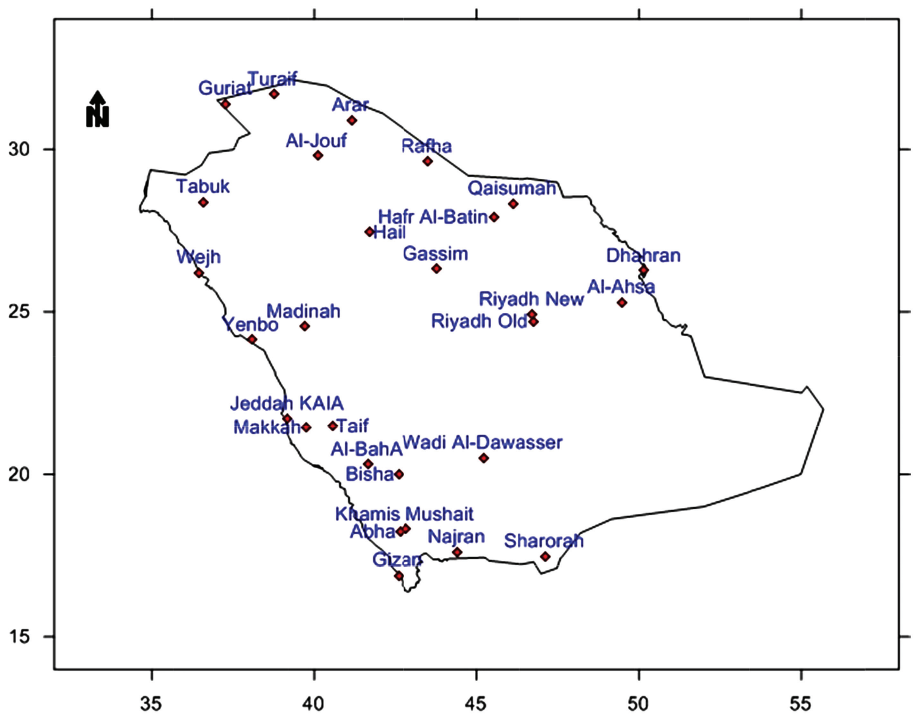

Figure 1. Meteorological stations in Saudi Arabia.

RMetS
Royal Meteorological Society

Table 1								
Descriptive statistics for annual rainfall amounts at 20 stations in Saudi Arabia, 1979–2008.								
Station name	*Maximum rainfall (mm)*	*Minimum rainfall (mm)*	*Range (mm)*	*Mean (mm)*	*SD*	*CV*	*Skewness*	*Elevation (m)*
Wejh	143.3	1.4	141.9	25.7	29.95	116.61	2.81	20
Yenbo	90.1	1.1	89.0	28.1	23.91	85.17	1.18	8
Tabuk	80.6	1.1	79.5	29.3	23.36	79.72	0.83	778
Jeddah KAIA	284.6	0.0	284.6	51.0	59.16	116.07	2.31	15
AlJouf	98.1	8.4	89.7	55.0	24.21	44.07	0.08	689
Arar	130.9	6.3	124.6	58.1	30.04	51.69	0.50	555
Najran	274.2	0.0	274.2	61.4	62.57	101.90	1.73	1212
Madinah	171.3	4.5	166.8	64.1	42.26	65.90	0.75	654
Bisha	285.2	22.4	262.8	87.9	59.16	67.32	1.69	1167
Turaif	299.3	29.6	269.7	88.3	61.35	69.47	2.17	813
Rafha	176.2	14.6	161.6	90.1	44.84	49.79	0.05	449
Old Riyadh	252.1	17.5	234.6	90.5	60.41	66.78	1.21	635
Dhahran	329.9	18.7	311.2	93.9	65.82	70.12	2.09	26
Hail	278.1	10.3	267.8	112.4	64.70	57.58	1.37	1015
Qaisumah	254.8	46.2	208.6	128.1	51.35	40.10	0.51	358
Gizan	307.8	5.2	302.6	133.2	77.39	58.09	0.79	6
Gassim	475.9	55.0	420.9	148.6	81.36	54.77	2.49	648
Taif	360.3	65.9	294.4	172.2	80.89	46.97	0.71	1478
Khamis Mushait	355.9	33.7	322.2	187.1	76.89	41.10	0.18	2066
Abha	567.1	87.4	479.7	233.5	120.19	51.46	1.09	2090

this study, complete rainfall data from the period 1979–2008 were used (Table 1). The data were inspected carefully to identify missing values and errors.

Statistical analysis

The statistical analysis included data from 20 of the 28 meteorological stations, selected based on their locations throughout the country and the availability of data from the same period (Rahimzadeh *et al*., 2009). Table 1 shows statistics for annual rainfall amounts recorded at the 20 stations. Station elevation and the following parameters of average annual rainfall values were determined: minimum, maximum, range, 30-yr mean and standard deviation, coefficient of variation (CV), and skewness (McClave and Sincich, 2003). The following equations were used in the analysis.

Standard deviation

The standard deviation measures the degree to which data are concentrated around the mean. A small standard deviation means that the values in a statistical dataset are close to the mean of that dataset, on average, and vice versa.

$$S = \sqrt{\frac{\sum_{i=1}^{5}\left(X_i - \bar{X}\right)^2}{n-1}}$$

where $\bar{X}$ is the mean.

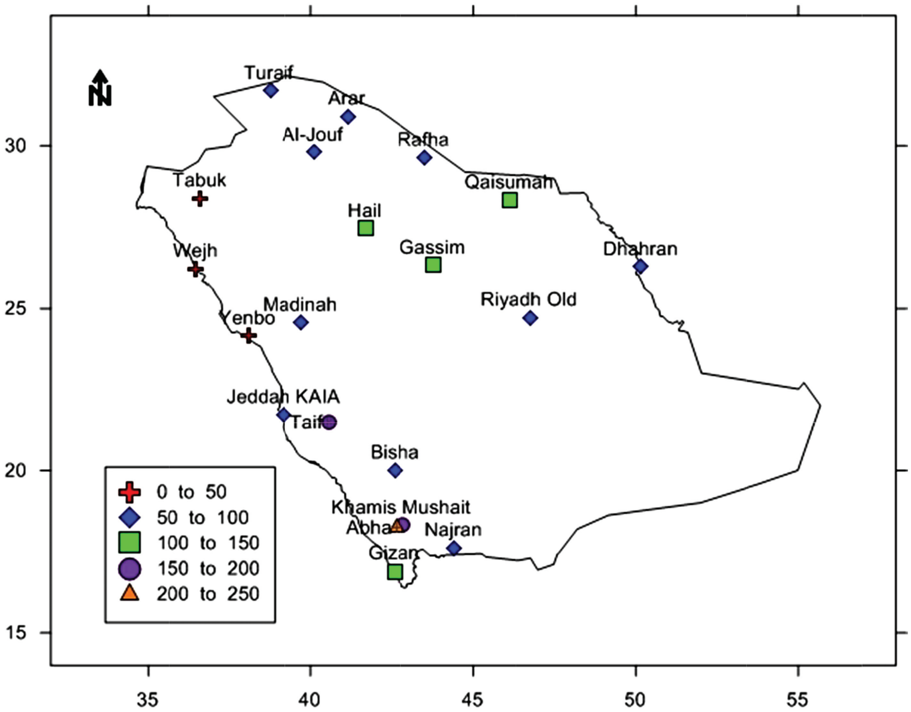

Figure 2. Average rainfall amounts at the meteorological stations.

Skewness

When the bulk of data in a dataset fall to the left, and the right tail is longer, the distribution is positively skewed; when the peak is towards the right, and the left tail is longer, the distribution is negatively skewed. Skewness is measured using the Pearson coefficient:

$$\text{Pearson's coefficient of skewness: } SK = \frac{3(\bar{X} - \text{median})}{\text{Standard deviation (SD)}}$$

The coefficient of skewness ranges from −3 to 3.

Coefficient of variation (CV)

The CV represents the ratio of the standard deviation to the mean and is a useful statistic for comparing the degree of variation from one data series to another. It is calculated as follows:

$$\text{Coefficient of variation} = \frac{\text{Standard deviation (SD)}}{\text{Mean } (\bar{X})} \times 100$$

The largest and smallest mean annual rainfall amounts during the study period were recorded at Abha (233.5mm) and Wejh (25.7mm), respectively (Table 1). Most CVs exceeded 50%, indicating significant variability in mean annual rainfall among stations. Skewness values for all stations were positive, meaning that annual rainfall exceeded the 30-yr average in most cases.

Standard deviations were large for areas with high average rainfall amounts (e.g. Abha, Gassim, Taif and Gizan) and small for areas with medium to low rainfall amounts

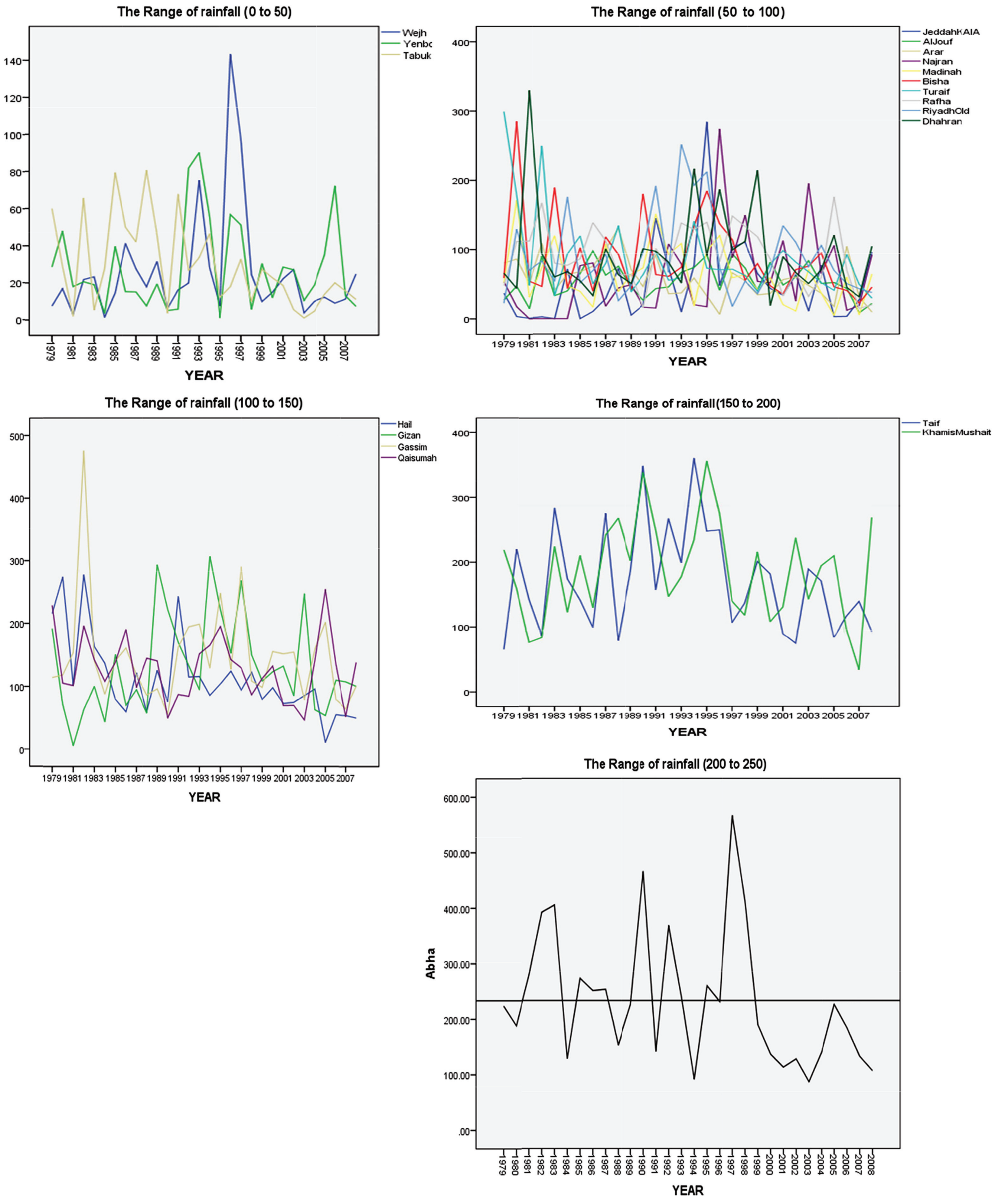

Figure 3. Annual rainfall totals according to classification, based on rainfall averages.

RMetS
Royal Meteorological Society

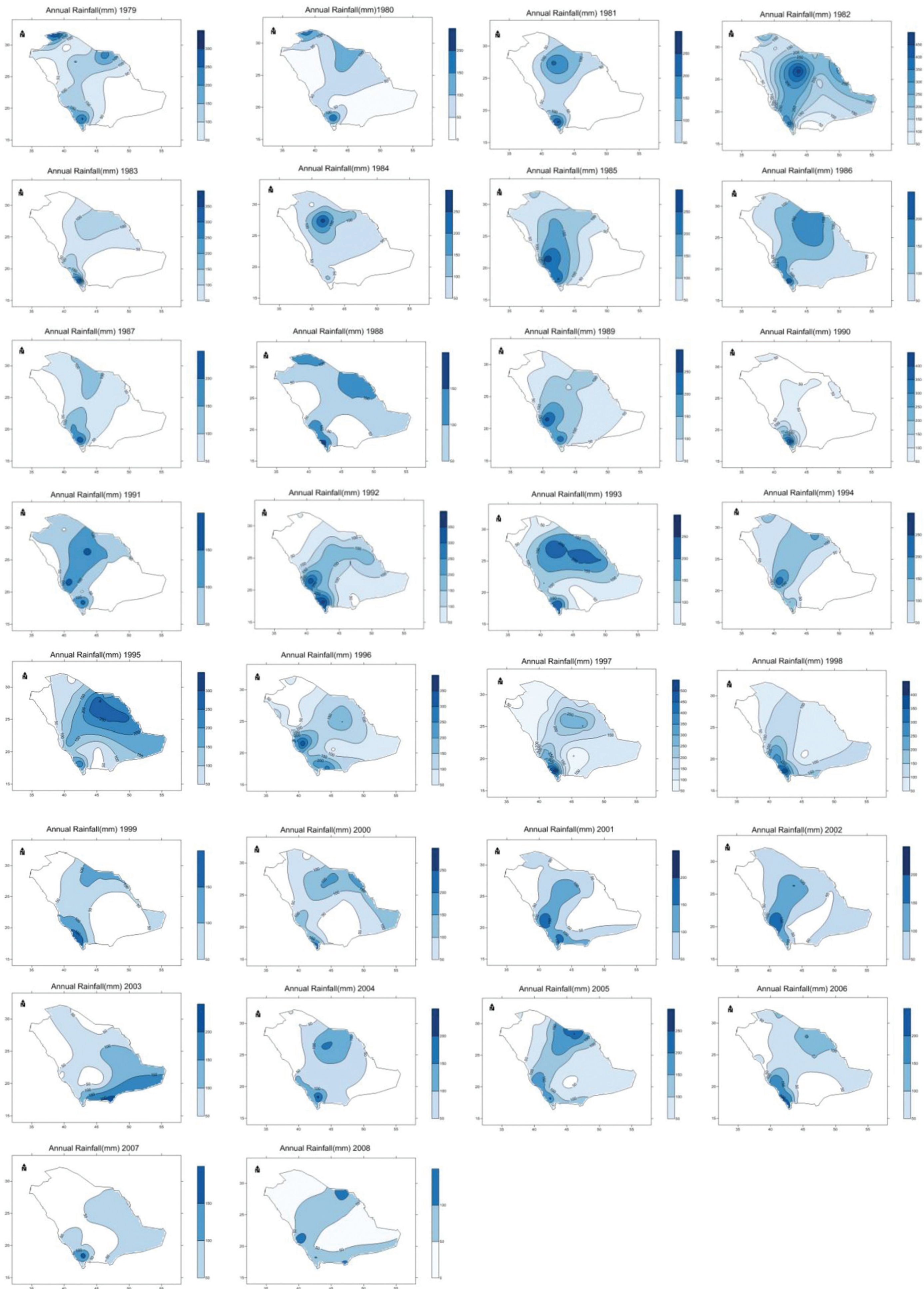

Figure 4. Spatial distribution of annual rainfall, 1979–2008.

RMetS
Royal Meteorological Society

(e.g. Al-Jouf, Yenbo, Tabuk and Arar). This difference reflects a large degree of variation in rainfall amounts in high-rainfall areas for long periods during the year, and much less variation in low-rainfall areas.

Based on the lowest and highest average annual rainfall amounts recorded during the study period (25.7 and 233.5mm, respectively), the stations were divided into five categories (Figure 2).

Examination of variation in averages among stations

The Levene test, with a significance level $\alpha = 0.05$, was used to examine the degree of homogeneity in annual rainfall patterns among all stations. The result of the Levene test was 6.443 ($\alpha = 0.000$); thus, the null hypothesis of homogeneity of variance was rejected.

The *F* test, with a significance level $\alpha = 0.05$, was used to compare average annual rainfall amounts among stations. The *F* value was 24.844 ($\alpha = 0.000$), indicating the presence of significant differences in average rainfall among stations.

Fluctuations in annual rainfall

Annual averages exceeded the overall station averages at 12 stations (Figure 3), compatible with the skewness results presented in Table 1.

To examine the relationship between elevation and average annual rainfall, a simple correlation coefficient (Lind *et al*., 2008) was used. The correlation coefficient (*r*) is a measure of the strength of the relationship between two variables. It requires interval or ratio-scaled data, and ranges from −1.00 to 1.00 ($-1 \le r \le 1$). Values of −1.00 and 1.00 indicate perfect correlation, and values close to 0.00 indicate weak correlation. Negative values indicate an inverse relationship and positive values indicate a direct relationship.

$$r = \frac{\sum (X-\bar{X})(Y-\bar{Y})}{(n-1)S_X S_Y}$$

The *r* value was 0.67, reflecting a moderate positive relationship between elevation and average annual rainfall. The result ($\alpha = 0.001$) compared with the 0.05 level of significance (α) of the results indicate the presence of a significant relationship between the two variables.

Spatial analysis

The ability to observe trends in rainfall records is important, as the underlying mechanism may aid the prediction of potential periods of drought or intense rainfall (Subyani, 2004). Several spatial interpolation techniques, such as Thiessen polygons, inverse distance, polynomial fitting, and kriging, are available. Kriging has been found to be the best interpolation technique for rainfall mapping. (Tabios and Salas, 1985; Subyani, 2004).

To ensure accurate spatial representation, all available station data were included in the analysis. Data from all 28 stations were collected in a single file for each year in a three-column format (longitude, latitude and rainfall). Each set of yearly data was gridded separately using the ordinary kriging method, which estimates the values of the points at the grid nodes. SURFER software was used to perform these calculations (Subyani, 2004). The resulting grid was blanked outside the political borders of the KSA.

As the maps were designed to show the spatial distribution according to range of rainfall (Figure 2), the isoline interval (50mm) was used. The spatial distributions of rainfall in all years of the study period were used to graphically represent the trend of annual rainfall distribution (Figure 4). The maps indicate that the majority of the KSA received rainfall of less than 150mm yr^{-1} during the study (Figure 4).

Conclusion

The purpose of this study was to examine the statistical and spatial characteristics of annual rainfall in the KSA over a long time period. Continuously recorded longitudinal data from 20 of 28 meteorological stations throughout the country were included in the statistical analysis. Annual rainfall amounts for a 30-yr period (1979–2008) were analysed to determine the extent of variation and fluctuation. The maximum annual rainfall during the 30-yr period and highest 30-yr mean were recorded at the Abha station (567.1 and 233.54mm, respectively). The annual rainfall amount showed extreme variation among stations (range: 79.5–479.7mm) and among years. A significant positive relationship was observed between elevation and average annual rainfall.

The stations were classified according to average annual rainfall amounts over the 30-yr study period (0–50mm, $n = 3$; 50–100mm, $n = 10$; 100–150mm, $n = 4$; 150–200mm, $n = 2$; 200–250mm, $n = 1$).

Data from all 28 stations were used for the analysis of spatial distribution. Maps for each year of the study period (1979–2008) showed no clear pattern in the distribution of rainfall, although the majority of areas received <150mm yr^{-1}, and the highest values were recorded in the southwestern part of the country.

Acknowledgments

This research was supported by a grant from the Research Centre for the Humanities, Deanship of Scientific Research at King Saud University.

References

Abdullah MA, Al-Mazroui MA. 1998. Climatological study of the southwestern region of Saudi Arabia. I. Rainfall analysis. *Clim. Res.* **9**: 213–223.

Almazroui M. 2010. Calibration of TRMM rainfall climatology over Saudi Arabia during 1998–2009. *Atmos. Res.* **99:** 155–165.

Almazroui M. 2012. Temperature variability over Saudi Arabia and its association with global climate indices. *Met. Env. Arid Land Agric. Sci.* **23**(1): 85–108.

Almazroui M, Islam MN, Jones PD *et al.* 2012. Recent climate change in the Arabian Peninsula: seasonal rainfall and temperature climatology of Saudi Arabia for 1979–2009. *Atmos. Res.* **111**: 29–45.

AQUASTAT. 2008. FAO's information system on water and agriculture, and climate information tool. http://www.fao.org/nr/water/aquastat/countries/saudi_arabia/index.stm (accessed 22 March 2015).

El-Nesr M, Alazba A, Abu-Zreig M. 2010. Analysis of evapotranspiration variability and trends in the Arabian Peninsula. *Am. J. Environ. Sci.* **6**(6): 535–547.

Rahimzadeh F, Asgari A and Fattahi E. 2009. Variability of extreme temperature and precipitation in Iran during recent decades. *Int. J. Climatol.* **29**: 329–343.

Hasanean H, Almazroui M. 2015. Rainfall: features and variations over Saudi Arabia, a review. *Clim. J.* **3**: 578–626.

Kwarteng AY, Dorvlo AS, Kumar GTV. 2009. Analysis of a 27-year rainfall data (1977–2003) in the Sultanate of Oman. *Int. J. Climatol.* **29**: 605–617.

Lind DA, William G, Marchal SA *et al.* 2008 *Statistical Techniques in Business and Economics*, 13th Edition. McGraw-Hill/Irwin.

McClave JT, Sincich T. 2003. *Statistics*. 9th Edition. Prentice Hall.

Noy-Meir I. 1973. Desert ecosystems: environment and producers. *Annu. Rev. Ecol. Syst.* **4**: 25–51.

Sen Z, Al-Suba'i K. 2002. Hydrological consideration for dam siting in arid regions: a Saudi Arabia study. *Hydrol. Sci. J. Des Sci. Hydrol.* **47**: 173–186.

Singh CV, Adhikari RS, Garg HP. 2002. Analysis of the statistical behavior of daily maximum and monthly rainfall data at New Delhi during monsoon period. *Adv. Atmos. Sci. J.* **19**(3): 425–432.

Subyani AM. 2004. Geostatistical study of annual and seasonal mean rainfall patterns in southwest Saudi Arabia. *Hydrol. Sci.* **49**(5): 803–817.

Tabios GQ, Salas JD. 1985. A comparative analysis of techniques for spatial interpolation of precipitation. *Water Resour. Bull.* **21**(3): 365–380.

Correspondence to: Sulafa Hag-elsafi

sulafa007@gmail.com

doi:10.1002/wea.2783