J KAU: Earth Sci., vol. 6, pp 113-133 (1413 A.H. / 1993 A.D.)

Regional Variations of Monthly Rainfall Amounts in the Kingdom of Saudi Arabia

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ABSTRACT. Sporadic and haphazard spatial as well as temporal occurrences of rainfall intensities in arid regions such as the Kingdom of Saudi Arabia require detailed interpretations of rainfall amounts which are necessary prerequisites for various activities such as agricultural planning, water resources management, groundwater recharge, etc. The monthly rainfall totals at 29 stations for more then 15 year records are used in order to detect rainfall regimes by temporal and spatial evaluation techniques. First of all some basic statistics, namely, the mean, standard deviation, kurtosis and skewness are presented in order to identify the nature of temporal rainfall patterns. Frequency distribution of rainfall at each station provides supplementary information in such a pattern recognition process. In addition, plots of skewness versus kurtosis provide basis for firm decision making processes about pattern recognition. On the other hand, spatial monthly rainfall patterns are sought on the basis of kriged mean and standard deviation values all over the Kingdom. The pattern recognition procedures as proposed in this paper can be applied in any other part of the world. Besides, these techniques are preliminary requirements of regional and/or temporal rainfall modelling.

Introduction

The Kingdom of Saudi Arabia extends over an area of some 2,250,000 km^2 within the Arabian Peninsula of which more than 90% is covered with deserts or steppes and hardly suitable for any sort of agricultural or industrial development. On the average the rainfall is low, these conditions make it necessary to conserve every single drop of water in Saudi Arabia. Moreover, there is no perennial streams in the proper sense. Therefore, Saudi Arabia is heavily dependent on the groundwater resources as well as on the desalination of sea water.

In arid regions, rainfall is very low, unpredictable as well as highly irregular but it can be very intensive during local storms. In such areas evapotranspiration considerably exceeds precipitation. High temperature and dry wind are among the basic climatic parameters which control principly the evapotranspiration. If rainfall is not sufficient this may lead to a serious limitation to meet the agricultural needs. This is the main reason why over the Arabian Peninsula climate limits the activity of man.

Moreover, severe isolation and scarcity of water resources hinder the growth of permanent settlements. The aridity is the result of climatic influences which include the general circulation of the air, distance from a moisture source, and local factors such as mountain barriers.

Generally, the Arabian Peninsula is characterised by a hot climate subject for the greater part of the year to northerly winds moving from the eastern Mediterranean Sea towards the Arabian Gulf. The equatorial circulation system influences the area on both sides of the equator to 30°N and 30°S including the Arabian Peninsula, (Maclaren 1979). Furthermore, the Arabian Peninsula lies between the two of the hottest regions, namely the Sahara in the African continent and the northwest Indian subcontinent which provide heat reservoirs, (Şen 1983). Moreover, it is considered as a part of the Asian continent which developes in winter time some of the lowest temperatures in the world. On the other hand, the north pole creates cold through over Europe and the Mediterranean Sea which penetrates the northern part of the peninsula in winter, and therefore, these exists potential cold reservoirs in the northeastern and northwestern direction.

The weather patterns influencing the study area can best be explained by considering the various air masses that move into the Middle East. The effects of these air masses over the Arabian Peninsula were discussed and mapped by several investigators (Alqurashi 1981; Maclaren 1979 and Şen 1983). Figure 1 shows such influences introduced and explained in detail by Şen (1983). To a greater or lesser degree these air currents influence the Arabian Peninsula for some short time by one of these reservoirs or their combinations as a result of which modifications in the Kingdom's climate take place as these air currents make their way out from their origin.

Since the water is a major factor for domestic and agriculture activities, the rational development of resources should be considered as one of the highest priorities in areas with arid conditions. For this reason, the assessment of rainfall is necessary to objectively deal with natural recharge leading to aquifer replenishment especially in the western and central provinces of Saudi Arabia. Therefore, the main emphasis in this work is given to the air mass movements effecting the Kingdom's weather and as result its rainfall pattern. On the basis of historical monthly rainfall sequence assessments by using statistical approach one might provide helpful information for understanding and giving a good account on the variability of the Saudi Arabian rainfall patterns and their impacts on human activities.

Rainfall Distribution in Saudi Arabia

Saudi Arabia lies approximately between 15° 00′ and 32° 10′N (Fig. 1). Since the

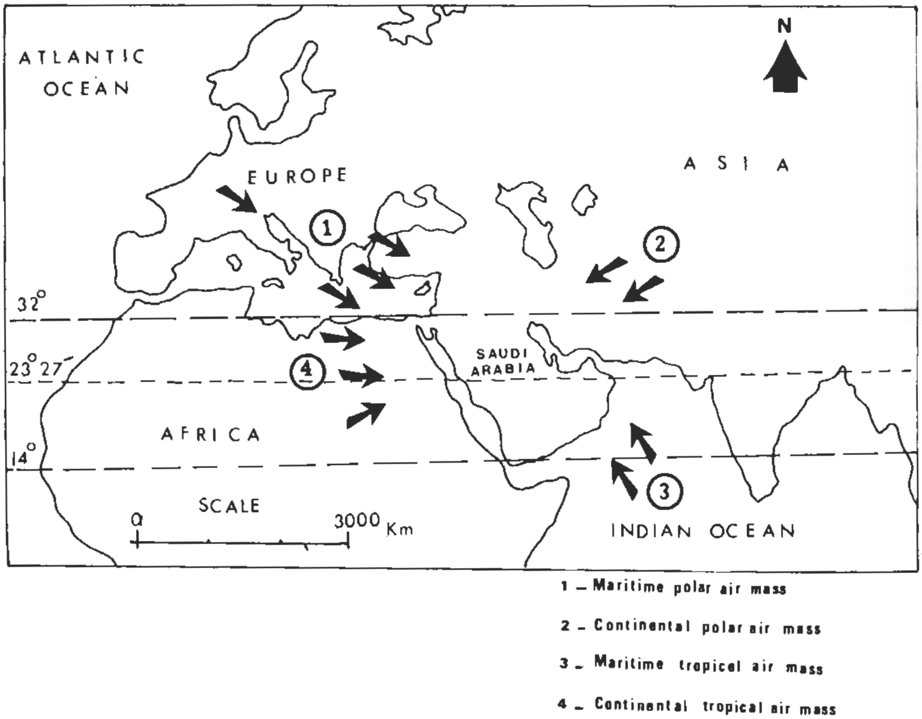

FIG. 1. Air mass movements.

northern tropic belt is bounded by latitude 23° 27′N which is also known as the Tropic of Cancer, the southern province of Saudi Arabia includes the intertropical front between the tropic and subtropic zones. However, most of the Kingdom falls within the subtropical zone. The subtropical belts of high pressures have a dominant influence on Saudi Arabian climate. Moreover, the local topography plays an important role particularly in the southwestern Arabia. In the remaining areas, the seasonal system of winds and rainfall depend mainly on the broad atmospheric circulation patterns with a few local deviations. In general, the rainfall in the upper two thirds of Saudi Arabia is scanty, unpredictable and irregular. Furthermore, variation among years has distinctive characteristics and long dry periods may exist. In most of the cases the rainfall occurs locally and sometimes in the form of violent thunderstroms of short duration. The intensity during such a storm may be so high that it exceeds the land capacity resulting in a high rate of runoff leading to flash floods causing erosion.

Generally, rainfall amounts decrease from north to south and from west to east. The main factors in such a decrease are topography and air mass movements. The relatively high zone of rainfall is in the southwest area which receives high amounts of rainfall, (>450 mm/year), with marked decreases towards the east which is extremely arid.

The monthly rainfall records are published by the Ministry of Agriculture and Water as annual hydrology reports. The rain guage density over an area has been fixed by WMO (1974) to be one station for every 600 km^2. However, the distribution over the Kingdom is rather non-uniform. Therefore, in this study 29 representative rainfall stations are considered which are more or less uniformly distributed over the Kingdom as shown in Fig. 2. These rain guages were selected with long record periods available more than 15 years. All relavant locational information about these stations are presented in Table 1.

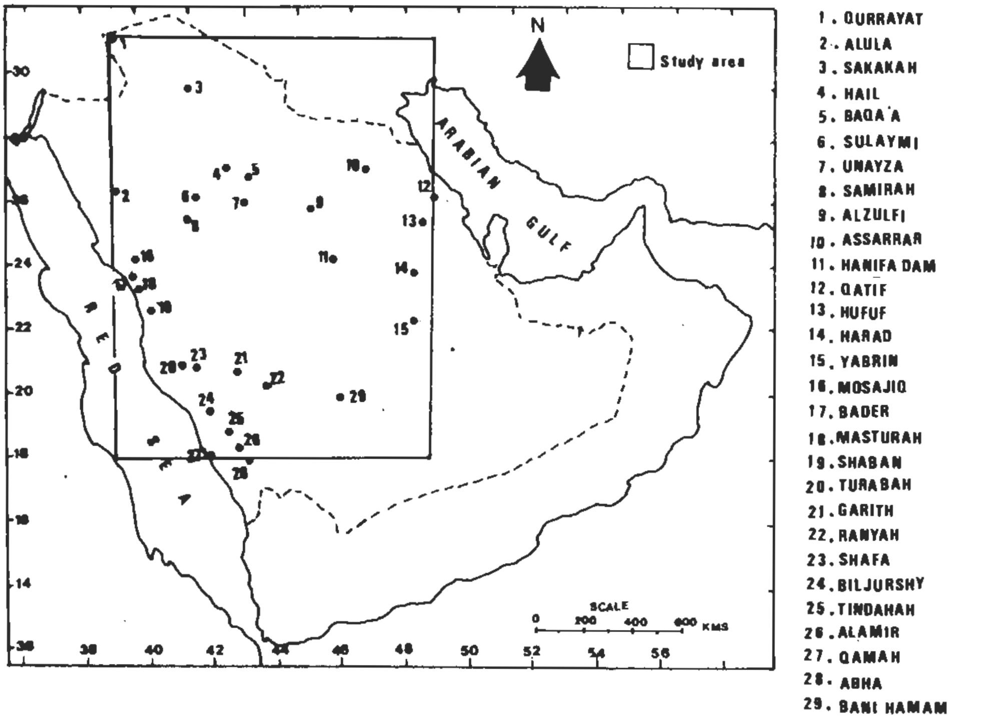

FIG. 2. Location map of the study area.

The relative frequency distributions together with the fitted probability distribution functions for each station are presented in Figure 3. It is to be noted that the logarithms of rainfall amounts are used on the horizontal axis. It is obvious that Turabah, Abha, Hanifa Dam, Shafa, Unayza, Alula, Mosajid and Alamir stations have slight negative skewness to the right which implies that high intensity rainfalls occur more frequently than low intensity rainfalls.

Figure 4 provides a general theoritical chart based on the skewness and kurtosis values and it is useful in depicting the suitable statistical distribution function. On the other hand, Figure 5 presents the plot of Saudi Arabian monthly rainfall amounts based on the same variables namely skewness and kurtosis. In this figure five diffe-

TABLE 1. Summary of station locations.

Station	Latitude		Longitude		Elevation (m)
Qurrayat	31°	26′	37°	21′	549
Alula	26°	37′	37°	51′	650
Sakakah	29°	58′	40°	12′	574
Hail	27°	32′	42°	43′	1001
Baqa'a	27°	04′	43°	51′	755
Sulaymi	26°	17′	41°	21′	950
Unayza	26°	04′	43°	59′	742
Samirah	26°	29′	42°	07′	–
Alzulfi	26°	18′	44°	48′	605
Assarrar	26°	59′	48°	23′	75
Hanifa Dam	24°	40′	46°	37′	625
Qatif	26°	30′	50°	00′	5
Hufuf	25°	25′	49°	34′	160
Harad	24°	10′	49°	01′	300
Yabrin	23°	14′	49°	00′	200
Mosajid	24°	05′	39°	05′	471
Bader	23°	44′	38°	46′	119
Masturah	23°	06′	38°	50′	55
Shaban	22°	35′	39°	38′	–
Bani Hamam	20°	49′	45°	49′	640
Turabah	21°	13′	41°	40′	1126
Garith	21°	37′	41°	53′	1100
Ranyah	21°	15′	42°	51′	810
Shafa	21°	04′	40°	22′	2190
Biljurshy	19°	52′	41°	33′	2400
Tindahah	18°	19′	42°	52′	1900
Alamir	18°	06′	42°	47′	2100
Qamah	18°	00′	41°	40′	20
Abha	18°	12′	42°	29′	2200

rent charts are exposed each for different region. The following significant observations and interpretations can be derived from this figure.

(i) It is a striking fact that the skewness-kurtosis relationships for each region appear as a straight line.

(ii) The best fitted straight lines in each region are parallel to each other. This fact shows that there is a universally valid skewness-kurtosis relationship at least for Saudi Arabia.

(iii) Overlapping of Figures 4 and 5 indicates the validity domains of different distribution functions for the Saudi Arabian rainfall. This point has been shown in Figure 5 by horizontal lines. In this context, LN, EX, NG, JF, UF mean lognormal, exponential, negative gama, J-form and U-form distributions.

Regional Treatment of Rainfall Data

The average monthly rainfall, $\bar{x}$, as well as standard deviation, σ, skewness and kurtosis coefficients are calculated for the 29 rainfall stations in order to give a com-

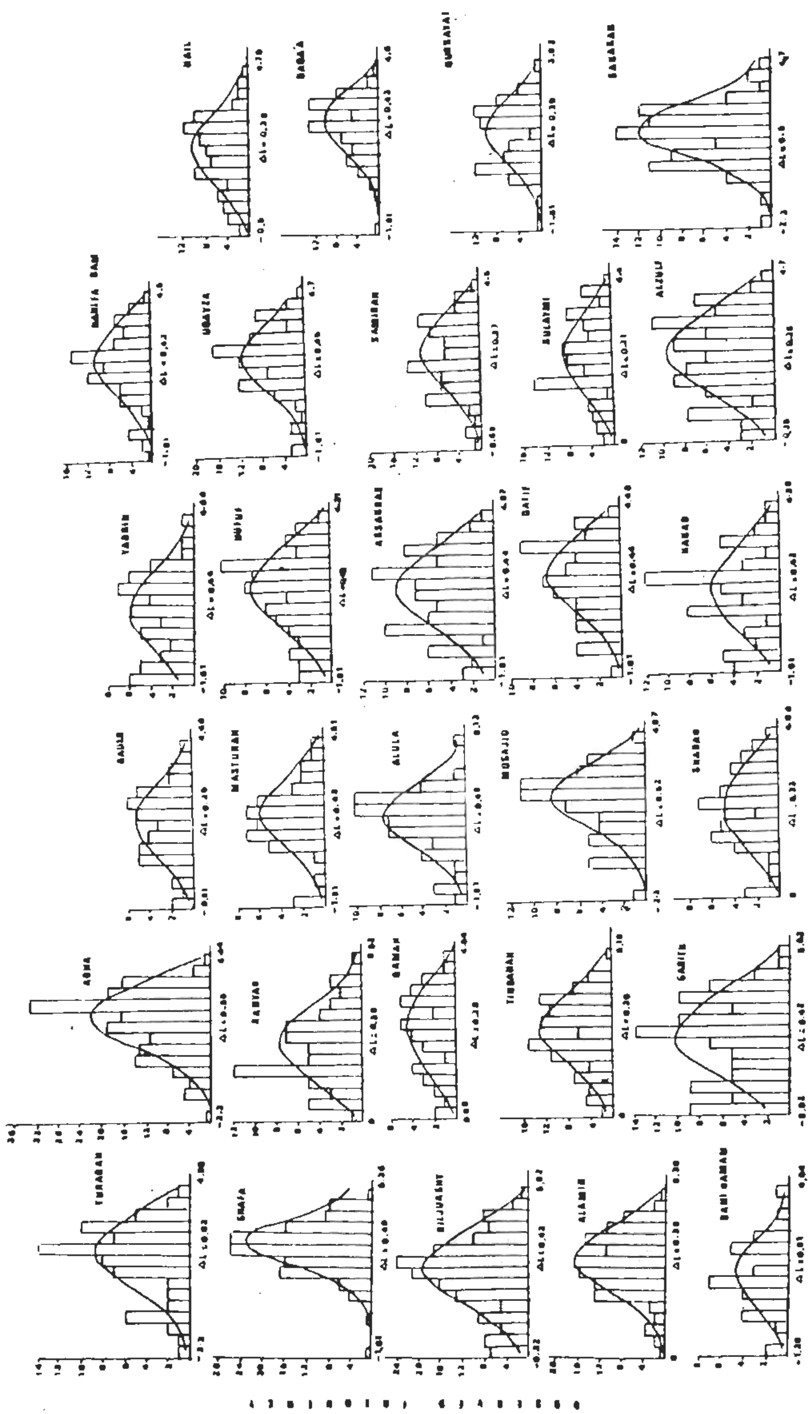

FIG. 3. Monthly rainfall frequency distribution.

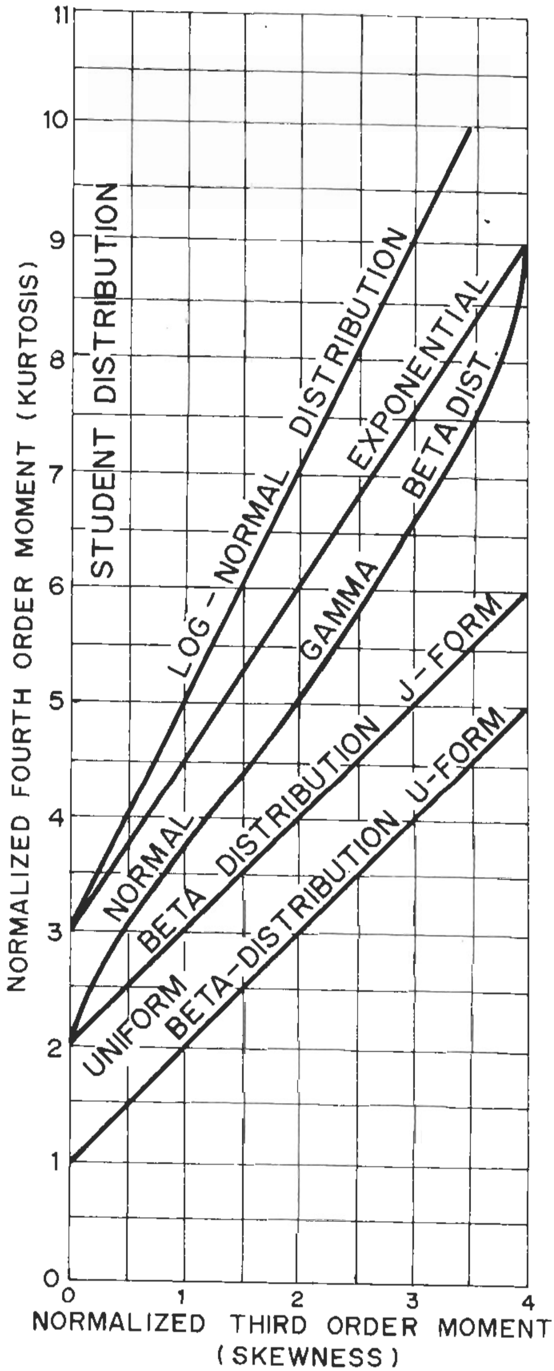

FIG. 4. Theoritical skewness-kurtosis relationship.

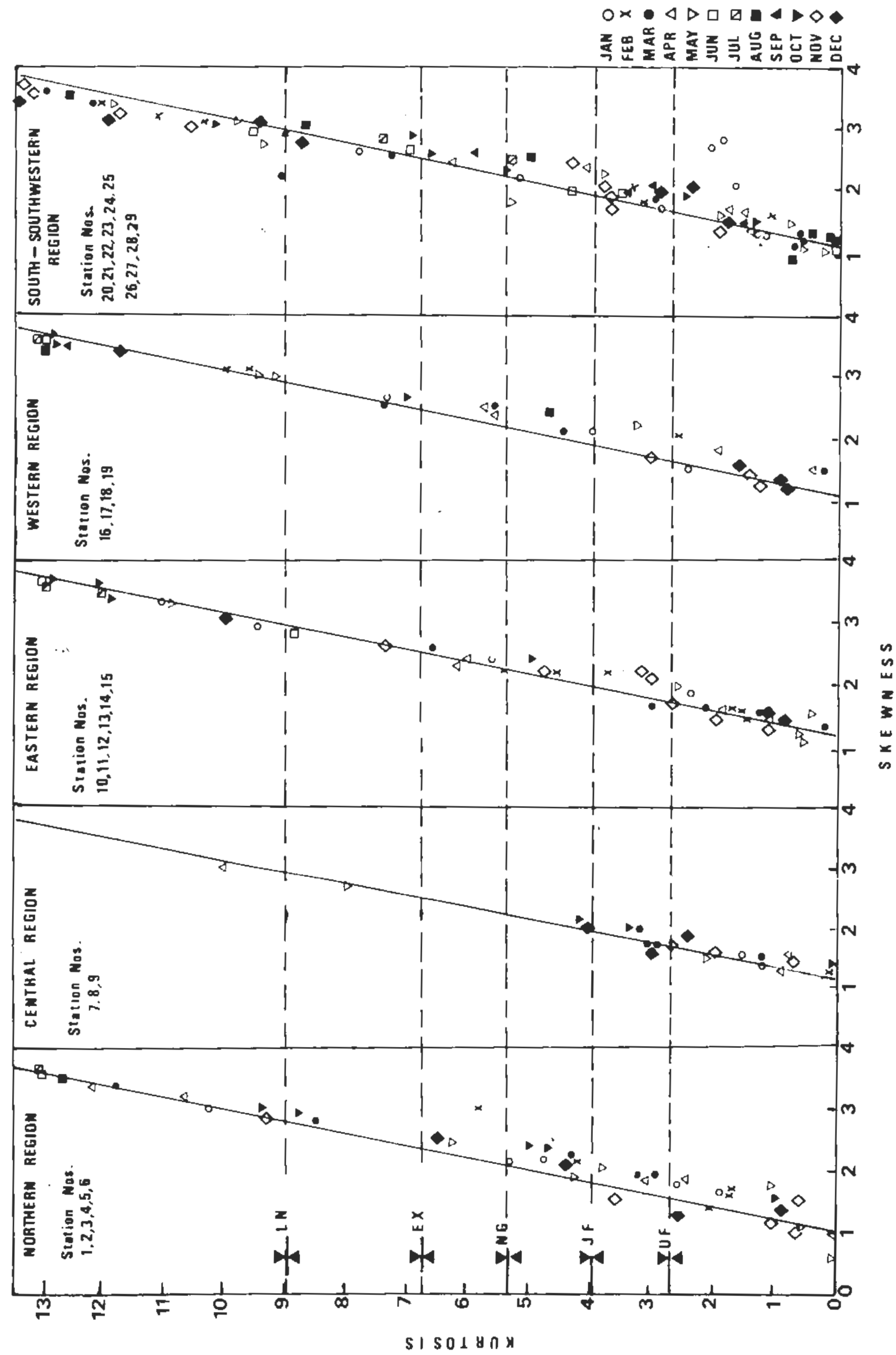

FIG. 5. Saudi Arabian skewness-kurtosis variations.

plete idea about the temporal and spatial variation in the rainfall pattern, (see Table 2). From the average monthly rainfall it can be predicted that the rainfall variability over the Kingdom is extremely high which might be attributed to the two dominant factors mentioned above.

In addition to that, if the annual value of the coefficient of variation, $C_v = \sigma/\bar{x}$ for each station in the southwest are plotted as shown in Figure 6, it will be clearly noticed that three of those stations which have the highest elevations such as Alamir (2100 m), Abha (2200 m), and Biljurshy (2400 m) will give the minimum value. On

TABLE 2. Statistical summary of rainfall stations.

STATION		J	F	M	A	M	J	J	A	S	O	N	D
Baqa'a	$\bar{x}$	40.0	6.7	22.0	14.0	7.4	0.0	0.0	0.0	0.0	2.7	20.3	14.0
	σ	55.5	18.0	30.5	19.5	9.0	1.0	0.5	0.0	0.0	6.5	22.0	14.5
Sulaymi	$\bar{x}$	17.6	5.8	12.1	17.5	7.8	0.0	0.0	0.0	0.0	4.3	21.7	7.5
	σ	24.5	9.5	19.0	21.0	13.0	0.0	0.0	0.0	0.0	10.5	25.5	7.5
Unayza	$\bar{x}$	22.0	11.5	22.0	13.5	10.5	0.0	0.0	0.0	0.0	0.7	20.0	15.0
	σ	22.0	12.0	32.5	19.0	14.0	0.5	0.0	0.0	0.0	2.0	28.5	18.0
Samirah	$\bar{x}$	23.1	9.1	13.3	15.7	6.7	0.0	0.0	0.0	0.0	10.0	21.0	7.6
	σ	28.5	10.0	17.5	20.0	12.0	0.0	0.0	0.0	0.0	18.5	26.5	11.5
Alzulfi	$\bar{x}$	22.0	12.0	27.0	24.0	7.0	0.4	0.0	0.0	0.0	0.5	13.0	10.2
	σ	23.0	14.5	25.0	30.0	10.0	1.5	0.0	0.0	0.0	2.0	27.5	19.5
Assarrar	$\bar{x}$	13.0	12.0	18.0	18.0	4.0	0.0	0.0	0.0	0.0	4.4	12.8	15.0
	σ	21.5	17.0	24.0	27.5	5.5	0.5	1.5	0.0	0.0	14.0	18.0	7.0
Hanifa Dam	$\bar{x}$	14.0	8.0	20.0	30.0	7.6	0.0	0.7	0.0	0.0	0.5	3.5	7.2
	σ	23.0	9.5	25.0	31.0	8.0	1.5	2.5	0.0	0.0	1.5	6.5	10.5
Qatif	$\bar{x}$	17.5	14.0	13.6	13.4	0.0	0.0	0.0	0.0	0.0	0.0	10.0	11.0
	σ	17.5	29.0	20.5	18.5	1.5	0.0	0.0	0.0	0.0	0.5	11.5	23.5
Hufuf	$\bar{x}$	16.2	11.3	15.0	15.0	1.2	0.0	0.0	0.0	0.0	0.0	2.5	4.6
	σ	26.0	15.0	19.0	19.5	2.0	0.0	0.0	0.0	0.0	1.0	5.5	5.5
Harad	$\bar{x}$	13.0	10.1	8.3	10.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	1.8
	σ	23.5	16.0	12.0	12.5	3.5	0.0	1.5	0.0	0.5	0.5	0.5	2.5
Yabrin	$\bar{x}$	11.5	5.8	10.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	2.0
	σ	29.5	7.5	12.5	10.0	1.0	0.0	0.5	0.0	0.0	0.0	4.0	3.0
Mosajid	$\bar{x}$	20.0	9.3	12.0	15.2	3.3	0.0	0.0	2.1	3.2	0.0	16.0	16.0
	σ	22.5	12.0	22.0	27.5	9.0	1.5	1.5	5.5	4.5	1.0	17.5	39.0
Qurrayat	$\bar{x}$	8.7	5.6	10.0	3.5	2.9	0.0	0.0	0.0	0.0	3.3	7.5	4.5
	σ	7.5	8.0	15.0	6.0	5.5	0.0	0.0	0.0	1.0	5.0	8.3	5.5
Alula	$\bar{x}$	6.4	4.9	8.8	16.5	2.8	0.0	0.0	1.3	0.0	1.5	8.9	5.4
	σ	9.0	5.5	17.5	20.0	5.5	0.0	0.0	4.0	0.0	5.0	10.0	9.0
Sakakah	$\bar{x}$	11.0	5.7	7.9	8.0	5.2	0.0	0.0	0.0	0.0	3.6	19.0	3.9
	σ	16.5	8.0	17.5	18.0	9.0	0.0	0.0	0.0	0.0	9.0	28.5	5.5
Hail	$\bar{x}$	19.0	5.8	16.8	20.0	2.9	0.0	0.0	0.0	0.0	4.9	28.0	7.1
	σ	31.0	6.5	27.0	23.5	9.5	0.0	0.0	0.0	0.0	11.0	23.5	7.0

TABLE 2. (Continued).

STATION		J	F	M	A	M	J	J	A	S	O	N	D
Bader	$\bar{x}$	10.0	5.5	3.5	12.3	1.2	0.0	0.0	0.0	0.0	0.5	6.1	9.0
	σ	10.5	14.0	6.5	26.0	2.5	0.0	0.0	0.0	0.0	2.0	7.5	12.5
Masturah	$\bar{x}$	12.0	5.1	1.0	11.5	1.2	0.0	0.0	0.0	0.0	0.0	8.1	7.8
	σ	16.0	12.0	3.0	27.5	3.0	0.0	2.5	1.0	0.0	2.0	10.0	7.0
Shaban	$\bar{x}$	21.0	9.8	7.5	18.0	0.0	0.0	0.0	0.0	0.8	1.8	13.0	5.6
	σ	31.0	15.0	15.0	33.5	1.5	0.0	0.0	0.0	2.5	4.5	17.5	7.0
Turabah	$\bar{x}$	12.0	8.0	22.6	33.0	13.0	0.0	1.9	4.9	1.3	0.0	8.1	8.7
	σ	17.5	17.0	25.0	51.0	16.0	1.5	5.0	9.0	3.5	2.5	15.4	17.5
Garith	$\bar{x}$	10.0	4.0	24.0	40.0	16.5	2.0	2.5	0.0	0.0	1.8	9.2	3.8
	σ	17.5	7.5	26.0	44.0	20.0	5.0	7.5	1.0	1.5	4.9	17.0	7.0
Ranyah	$\bar{x}$	6.1	4.5	39.0	46.0	10.0	0.0	1.5	0.0	0.0	1.6	4.6	2.4
	σ	8.5	11.5	27.0	49.0	22.5	0.0	5.5	0.0	0.0	6.5	13.0	5.5
Shafa	$\bar{x}$	44.0	22.0	12.0	42.0	54.4	14.0	15.0	35.0	25.0	37.0	24.0	20.0
	σ	63.0	30.0	13.5	60.0	64.0	23.0	17.0	40.0	17.0	43.0	32.0	19.0
Biljurshy	$\bar{x}$	71.6	29.1	31.0	56.0	25.0	12.0	22.0	28.0	8.7	22.0	50.0	44.0
	σ	77.5	41.5	37.0	89.5	25.0	12.0	27.5	32.0	12.0	20.0	50.0	61.0
Tindahah	$\bar{x}$	10.0	7.0	22.0	36.5	33.5	6.5	23.0	16.0	3.4	0.5	11.5	4.6
	σ	13.5	13.0	45.0	31.5	30.5	6.5	16.0	18.0	7.5	1.5	15.5	18.0
Alamir	$\bar{x}$	20.0	24.5	47.0	56.0	55.0	17.5	38.0	5.6	7.4	3.9	12.0	9.0
	σ	23.5	35.0	61.0	52.5	43.0	14.0	21.0	4.5	8.0	6.5	21.0	14.5
Qamah	$\bar{x}$	23.0	7.0	2.8	5.8	2.8	0.2	4.8	1.0	1.3	2.5	8.2	15.0
	σ	31.5	9.0	9.0	12.5	6.5	1.0	29.5	2.5	4.5	6.0	22.0	21.5
Abha	$\bar{x}$	33.4	27.0	49.0	56.0	44.0	15.0	44.0	40.0	7.3	10.6	16.5	8.0
	σ	26.3	57.8	67.0	43.9	35.5	12.0	19.4	16.0	8.0	18.0	38.0	18.0
Bani-Hamam	$\bar{x}$	3.0	1.6	10.9	7.5	0.7	0.0	6.3	1.8	0.0	0.0	4.1	0.3
	σ	6.0	4.0	27.5	8.0	2.0	0.0	0.0	0.0	0.0	0.0	14.5	1.0

the other hand, station with low altitudes for example, Qamah (20 m) will get the highest value for the coefficient of variation.

In order to assess such a variation, distributions of rainfall over the study area were investigated in time and space. The simple representation of the state is a set of monthly rainfall maps. These maps would give a better view for the regional rainfall variation. The rainfall in the Kingdom may be considered as one of the most important factor in the water balance equation, varying more significantly in a random fashion from place to place than any other climatological parameter. Moreover, rainfall in monsoon Asia is strongly distinguished by its seasonality, interannual variability, torrential behaviour and sharp regionality (Yoshino 1971). Similar patterns are expected to occur especially in the southwestern part of the Kingdom of Saudi Arabia.

For regionalisation of the two parameters, namely, mean and standard deviation, monthly isohyetal maps were developed by using kriging method. The variability of

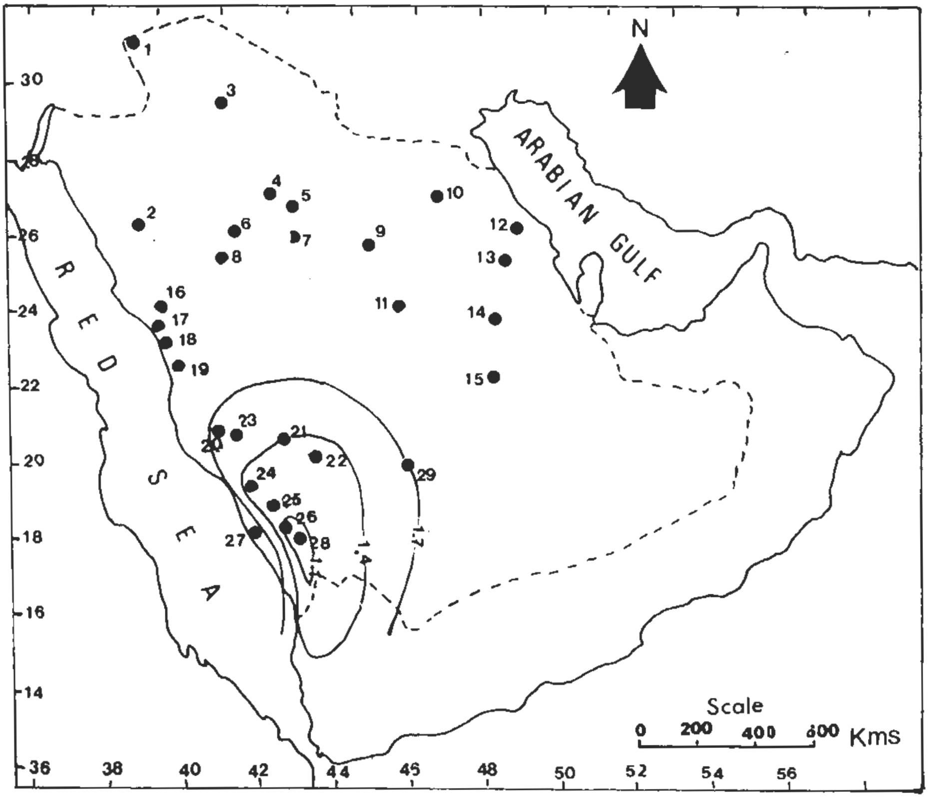

FIG. 6. Annual variation of C_v in the southwest region.

the rainfall over the Kingdom will be discussed according to the seasonal variation which is based on the categorizing of the months in four groups in accordance with the rainfall patterns as follows (Notice that in Figures 7-18 "a" and "b" imply the standard deviation and mean values, respectively):

(i) Winter Season, (December-February)

Isohyetal maps for winter months are shown on Figures 7 to 9. It can be noticed that the temporal and spatial distribution of the rainfall over the study area in winter season is due to the influence of the air masses movement coming from north direction. During the winter, cyclonic disturbance generated primarily over the Mediterranean Sea, tracks easterly and brings rainfall over the Kingdom. Hence, during winter season the rainfall is of cyclonic type.

It is obvious from the comparison of mean monthly rainfall amounts in Figures 7b, 8b, and 9b that during the winter season in December there exists almost north-south trending high rainfall belts which takes southwest-northeast direction in January with relatively higher rainfall amounts. However, in February there appear two

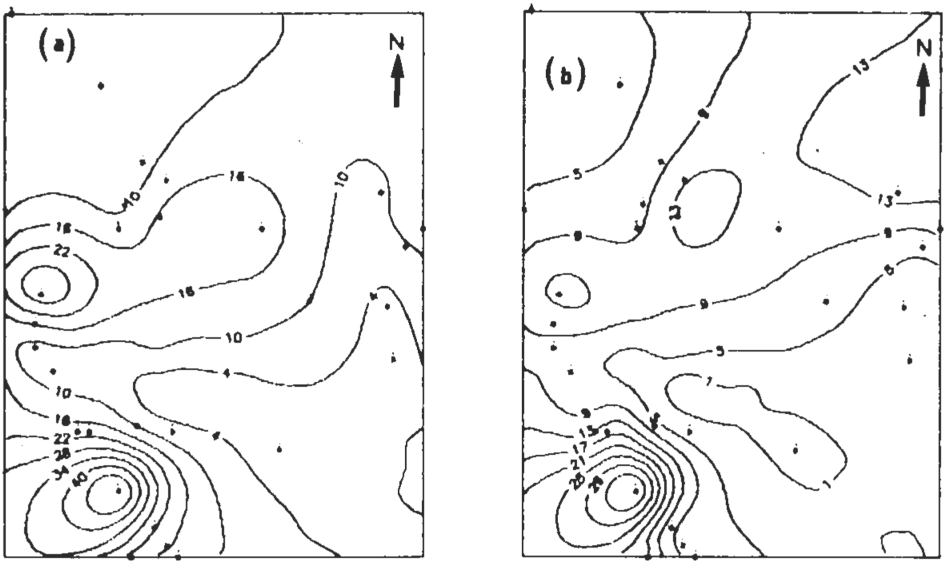

FIG. 7. Spatial rainfall pattern for December. a) Standard deviation b) Mean.

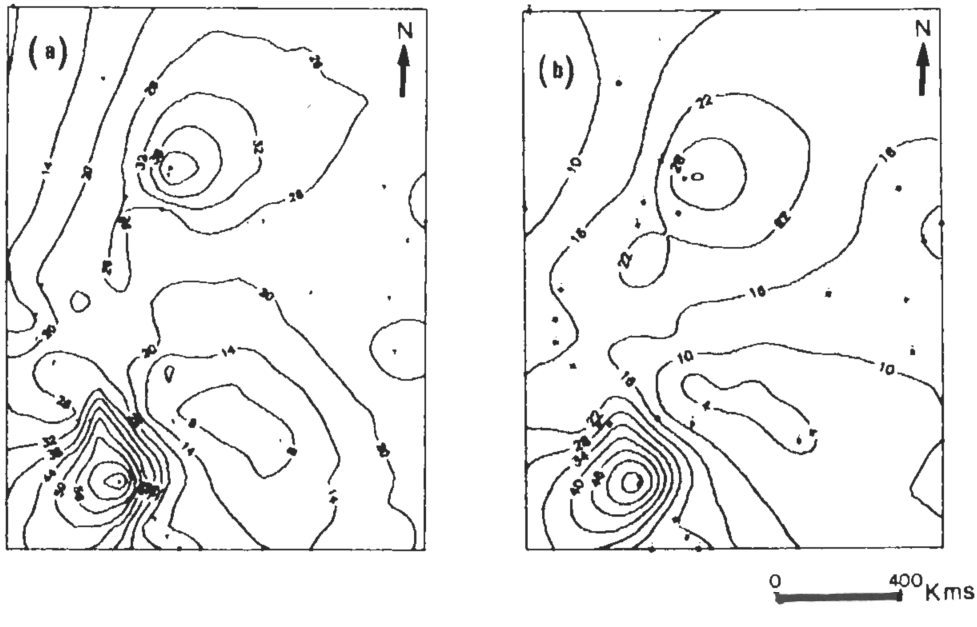

FIG. 8. Spatial rainfall pattern for January. a) Standard deviation b) Mean.

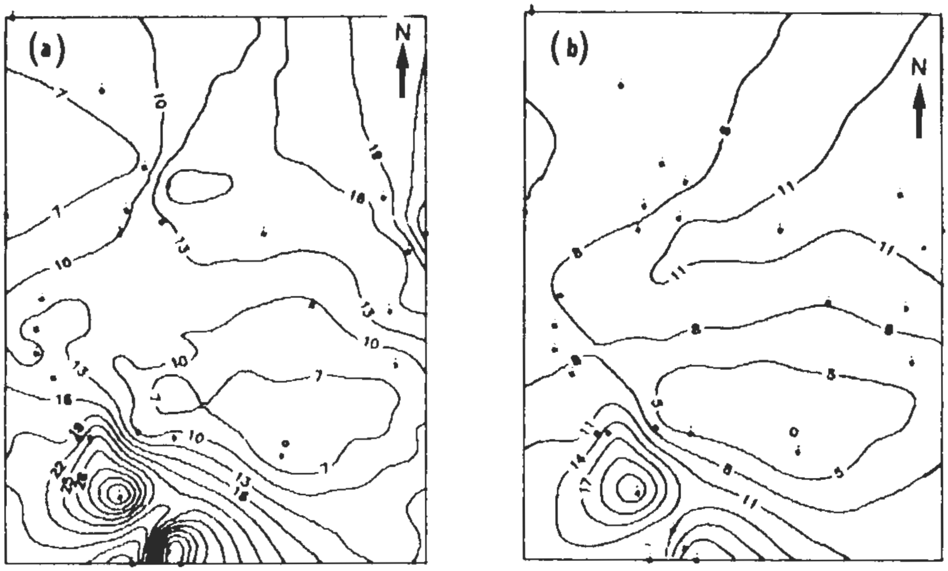

FIG. 9. Spatial rainfall pattern for February. a) Standard deviation b) Mean.

peaks one near the central area including Unayza and Burayda cities in Al-Qasim region but more spiky one in the south western corner of Saudi Arabia, i.e. in Asir mountains. On the other hand, in January and February surprizingly the regional standard deviation patterns have more or less the same trends.

In general, the maximum monthly rainfall occurs in January. In the southwestern region, the rainfall is totally distinctive from the other regions in that it has appreciable amounts of rainfall throughout the season almost with no dry period. In this part of the Kingdom, the high amounts of rainfall could be attributed to the maritime polar air mass coming from the Mediterranean Sea and Atlantic Ocean which occur to a certain extent overlappingly. Furthermore, the high mountains in that part of the Kingdom where the elevations more than 3000 meter above sea level give an orographic appearance to the rainfall. Similar to the mean rainfall values the standard deviation follows the same pattern and has its maximum value in January. It is, hence, obvious that there appears a directly proportional relationship between the mean and standard deviation. This implies that increase in the rainfall intensity gives rise to increase in the standard deviation, i.e. high intensities occur quite randomly in the month of January.

In the northern province, the rainfall takes place due to the first frontier from the Mediterranean born moist and cool air masses to form convective rainfall. This area is characterised by all its rainfall in the winter season.

On the other hand, both western and eastern regions are characterised by its low rate of rainfall. Nevertheless, the rainfall amounts increase relatively towards the east which is due to the topography as well as the area that lies totally within the zone of winter rainfall due to affect of the Mediterranean Sea depression.

In central region, maximum rainfall occurs due to the extreme southern boundary for the Mediterranean Sea born air masses that penetrate this area.

(ii) Spring Season (March-May)

During this season intertropical front starts to move northwards and the south of Saudi Arabia comes under the influence of monsoonal moist air stream from the Indian Ocean which results in widespread rain throughout the southern area and along the escarpment. The maximum peak of rainfall occurs in April as shown in Figures 10 to 12.

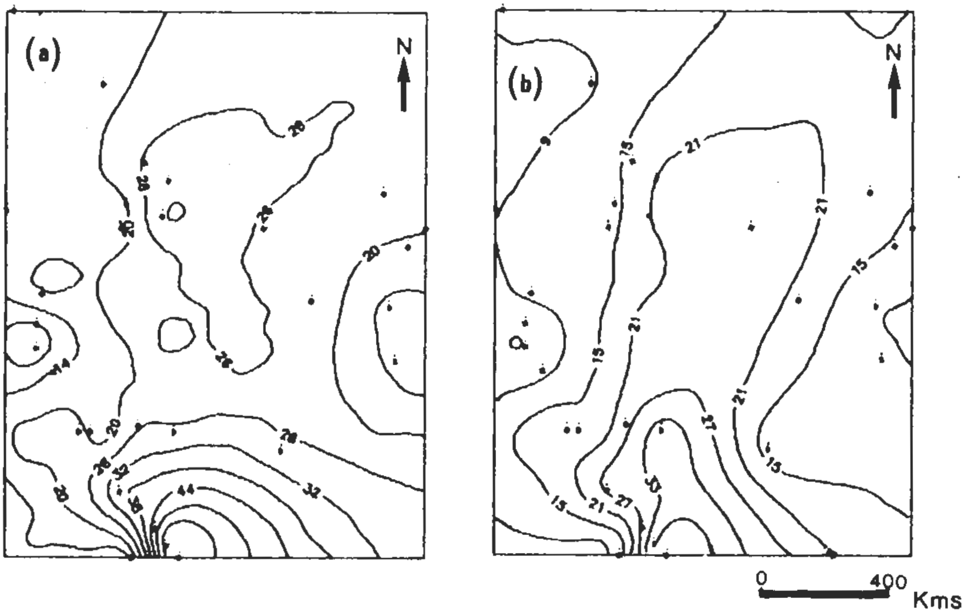

FIG. 10. Spatial rainfall pattern for March. a) Standard deviation b) Mean.

It is obvious that the least areal effectiveness takes place in May during the spring season with least rainfall amounts. However, throughout this season the southwestern Asir mountains pressure has its unique distinction. Furthermore, comparison of Figures 10a, 11a, and 12a indicates that the effect of Mediterranean air movement diminishes whereas south born monsoon takes its place but does not penetrate the Kingdom except in the southern regions. So far the regional standard deviation distribution is concerned its maximum concentrates throughout the season in Asir mountains. There is a continual decrease of standard deviation from March to May inclusive.

Furthermore, the northern and central regions have low rate of rainfall which might be due to these areas becoming under the influence of dry northern air masses.

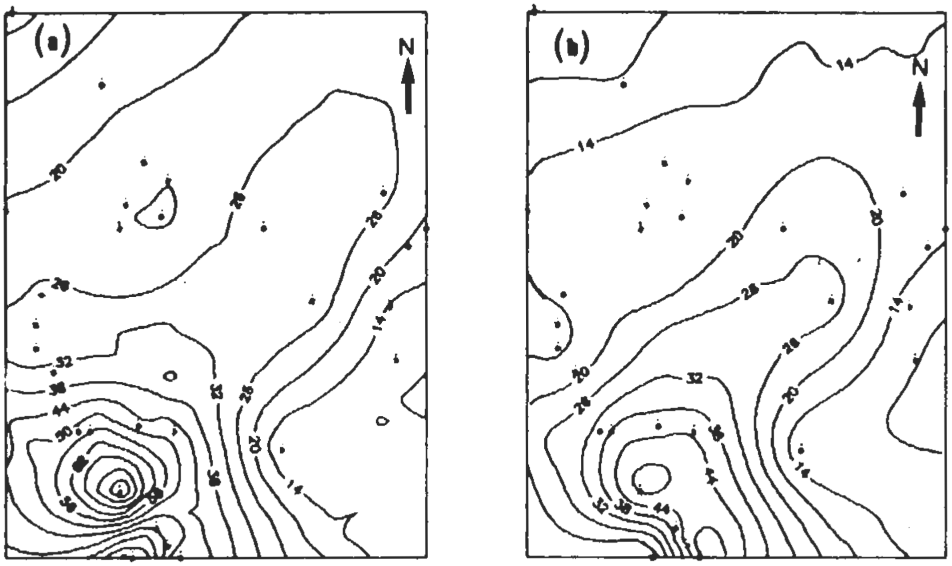

FIG. 11. Spatial rainfall pattern for April. a) Standard deviation b) Mean.

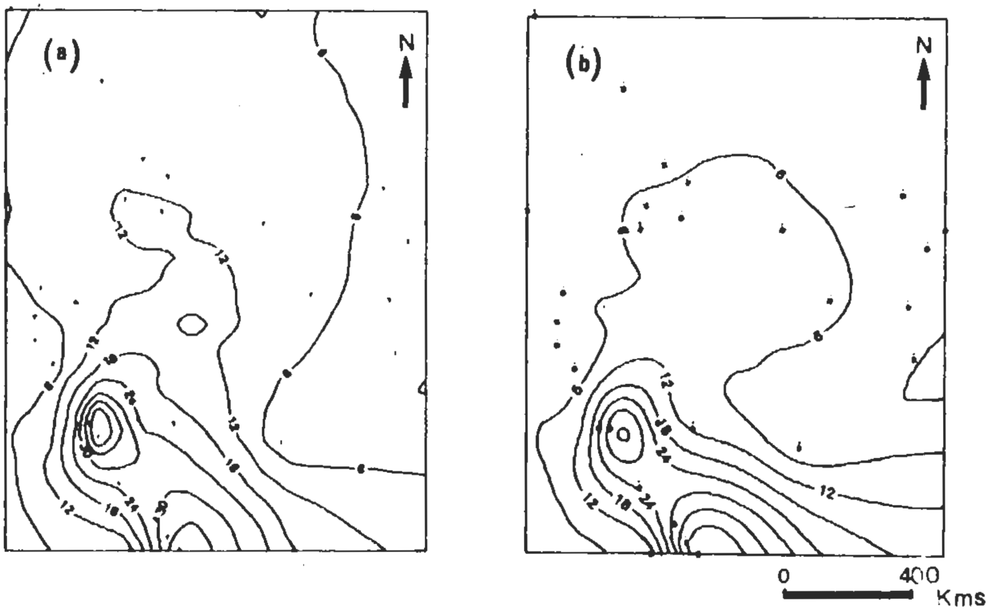

FIG. 12. Spatial rainfall pattern for May. a) Standard deviation b) Mean.

(iii) Summer Season, (June-August)

In this season, rainfall is the result of the convectional instabilities of the air. The moisture continues to be supplied from the south easterly flow of monsoon air that creates thunderstorms in the south and along the Red Sea escarpment (see Figures 13 to 15).

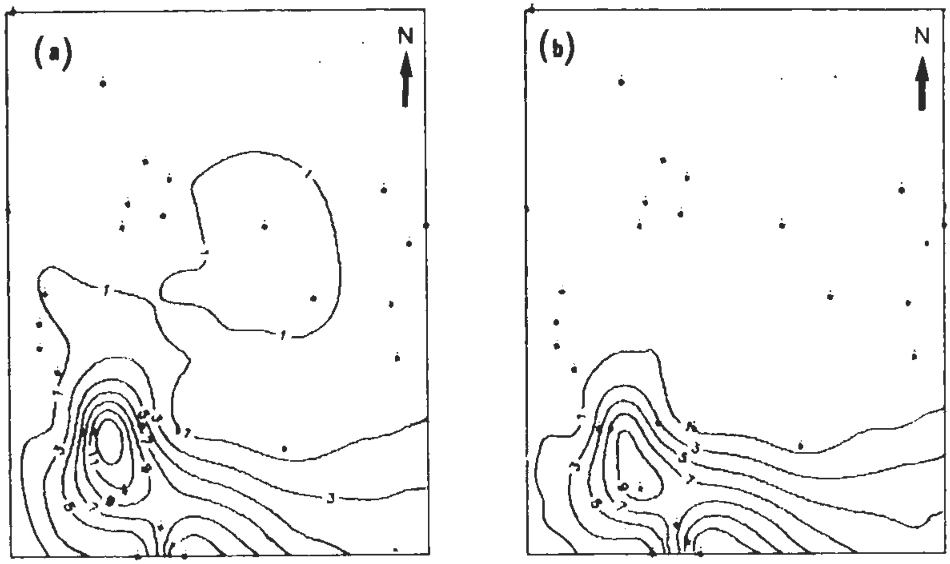

FIG. 13. Spatial rainfall pattern for June. a) Standard deviation b) Mean.

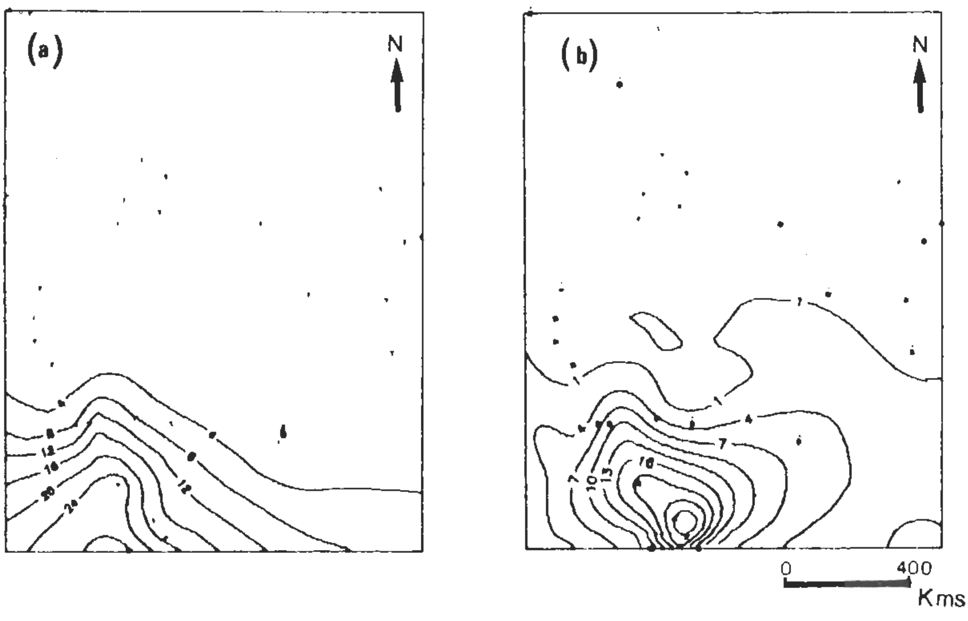

FIG. 14. Spatial rainfall pattern for July. a) Standard deviation b) Mean.

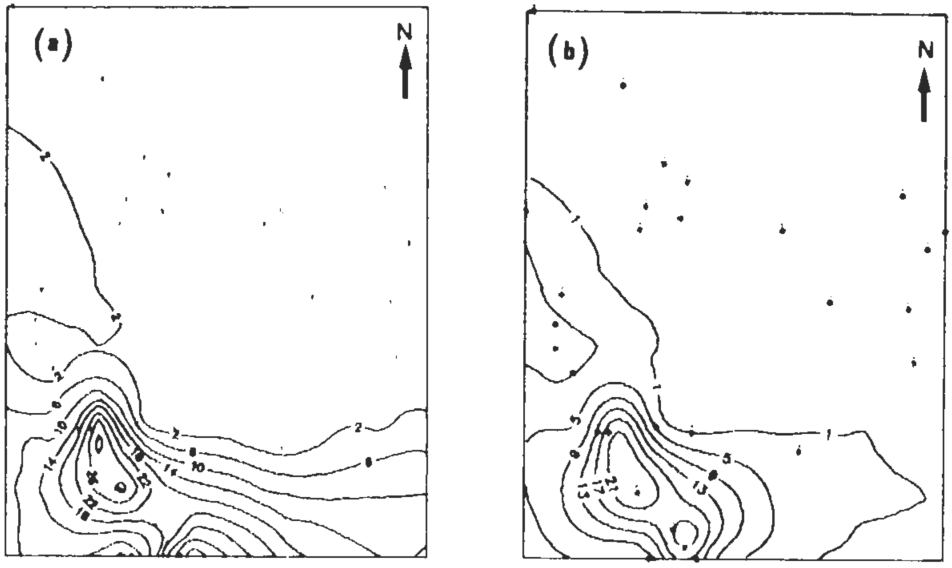

FIG. 15. Spatial rainfall pattern for August. a) Standard deviation b) Mean.

One of the distinctive characteristics of this season is that the peak occurrence in the standard deviation disappears in June, (see Figure 13a). In the same month the mean rainfall pattern peak is modified and shifted to extreme south. So far as the mean areal average is concerned in months July and August an areally extensive dry period occurs especially in all the Kingdom except in the Asir mountains. However, comparatively rainfall amounts in these mountainous regions are smaller than any other season in addition to their decreasing trend from June to August. At this time of the year, a steady upper level and the cyclonic flow sweep along the Mediterranean Sea from the west towards the east which then tracks an eastward run over the northern, eastern and central regions of Saudi Arabia. It may prevent the equator born maritime air of the northeasterly monsoon from penetrating into the north region of the Kingdom. Due to this effect, summer season will be rather dry in the western parts of the Kingdom. In the western region, the rainfall is significantly scarce compared to winter and spring seasons.

(iv) Autumn Season, (September-November)

In this season, south-easterly air flow diminishes and once again westerly air from the Mediterranean brings air moisture which gives way to tropical winter condition. In all regions considered together September is the driest month with its maximum rainfall in the southern area. This area comes under the influence of the combination of the Red Sea trough and the Mediterranean depression causing rainfall, (Figures 16 to 18).

Appearence of a significant regional peak in the central parts of the Kingdom implies the effect of convective rainfall type, (see Figure 17b).

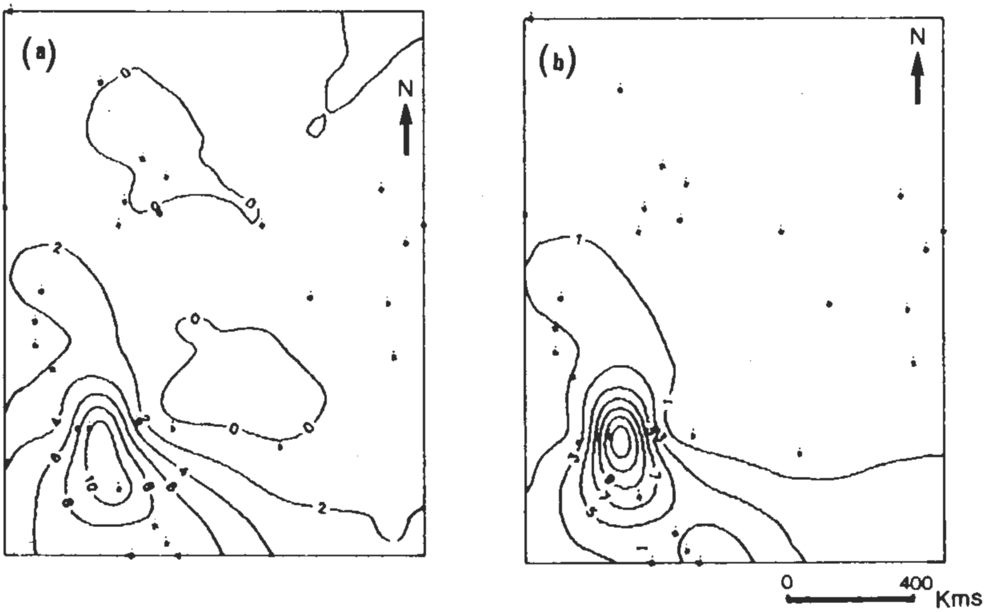

FIG. 16. Spatial rainfall pattern for September. a) Standard deviation b) Mean.

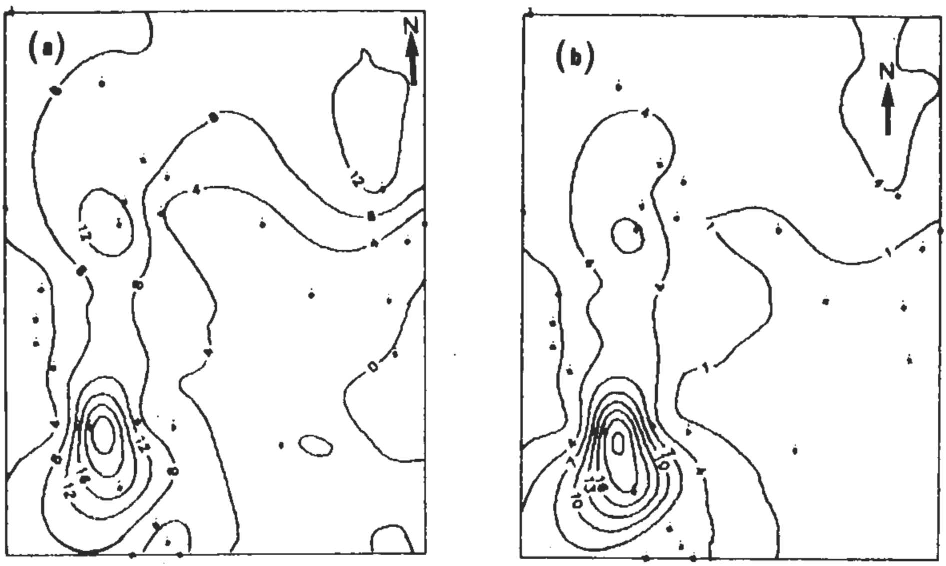

FIG. 17. Spatial rainfall pattern for October. a) Standard deviation b) Mean.

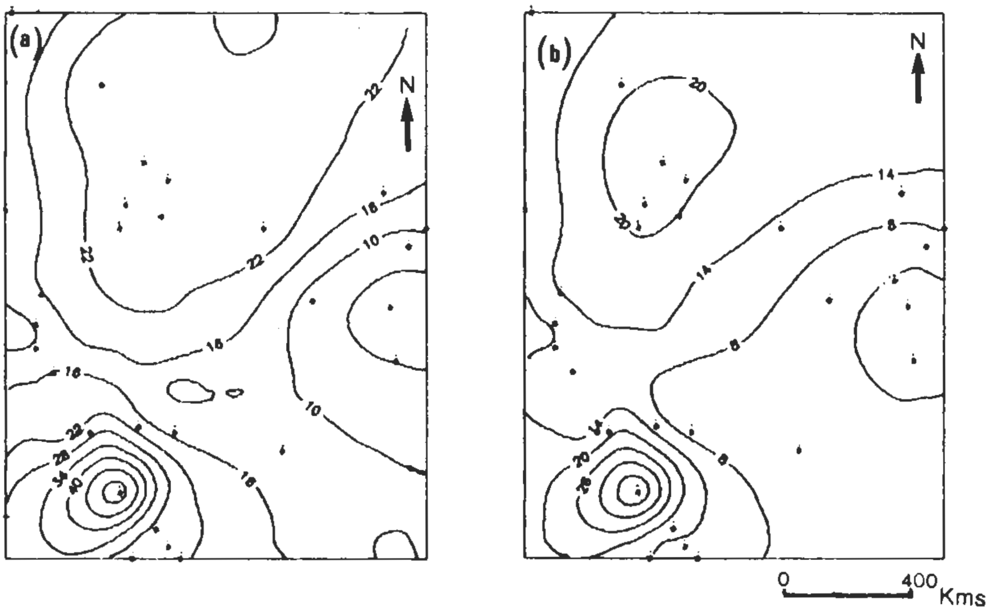

FIG. 18. Spatial rainfall pattern for November. a) Standard deviation b) Mean.

On the other hand, during the late autumn outbreaks of westerly air become more frequent and associated with retreat of the monsoon front, widespread rainfall of medium to high intensity takes place over the escarpment and the northwesterly region.

From the discussion above it is concluded that the southwestern region is completely different from the other areas in that throughout any year it displays no dry month at all and the maximum peak of rainfall occurs in April, with minor peaks also in winter (January) and summer (August).

Conclusion

Monthly rainfall patterns over the Kingdom of Saudi Arabia have been assessed by considering temporal and spatial distribution of rainfall amounts. The results are presented in the form of frequency distributions as well as the regional maps. The following significant results can be drawn from this study;

(i) four distinctive reasons of rainfall can be depicted within the Kingdom due to the movement of various air masses.

(ii) monthly rainfall amounts are almost log-normally distributed in the Kingdom.

(iii) as expected invariably the maximum rainfall concentrations are located in the mountainous heights in the southwestern corner. Additionally, in February and October there exists another concentration area of rainfall in the central provinces.

(iv) standard deviation variations in all the months are rather wide which implies that the change in rainfall intensity might occur unexpectedly sudden throughout the Kingdom of Saudi Arabia.

On the other hand, the following points show the expected benefits from such a study as well as the future research possibilities;

(i) on the basis of presented regional mean monthly rainfall maps it is possible to identify quantitatively recharge and drought areas within the Kingdom of Saudi Arabia at any desired month.

(ii) prediction of monthly rainfall amounts on a temporal basis by some fundamental simple statistical concepts such as the regression technique.

(iii) regional modelling of rainfall amounts by using geostatistical models.

Acknowledgement

The authors would like to express, their appreciation to the Ministry of Agriculture and Water for making the rainfall data used in this paper freely available through its annual reports.

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التغـيرات الإقليميـة لكميات الأمـــطار الشهريـة للمملكة العربية السعودية

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المستخلص . ظهور التشتت والعشوائية للتغير المكاني والزماني لشدة الأمطار في المناطق الجافة مثل المملكة العربية السعودية يتطلب بعض التغيرات المفصلة لقيم الأمطار والتي غالبًا ما تكون شرط أساسي لعدة أنشطة مختلفة مثال ذلك التخطيط الزراعي ، إدارة مصادر المياه ، ومعرفة كميات التغذية للمتكونات المائية الموجودة .

وفي الدراسة الحالية تم استخدام ٢٩ محطة لقياس الأمطار وكانت البيانات المسجلة لهذه المحطات تزيد عن ١٥ سنة في صورة أمطار شهرية .

ويمكننا الكشف على التغيرات المكانية والزمانية لقيم الأمطار بوساطة استخدام وسائل تقويم مختلفة وقبل الخوض في هذا فهنالك بعض الأسس الإحصائية مثل المتوسط الحسابي ، الانحراف المعياري ، التفرطح والالتواء تكون غالبًا مطلوبة لكي يتم التعرف على الأشكال الطبيعية للتغير الزماني لقيم الأمطار .

وعمل المدرج التكراري للمطر لكل محطة يمكن أن يزود ويضيف بعض المعلومات لهذه النماذج والأشكال التي تم التعرف عليها إضافة إلى ذلك توقيع التفرطح مع الالتواء يمكن أن يعطي فكرة بالأساسيات لعمليات ثبات القرار المعمول على تلك الأشكال المميزة من ناحية أخرى عملت أشكال التغير المكاني لقيم الأمطار الشهرية معتمدة أساسًا على قيم الانحراف المعياري والمتوسط الحسابي بطريقة كريكنج للمملكة العربية السعودية ويقترح هنا تطبيق الخطوات المتبعة لهذه الأشكال في أي مكان في العالم إضافة إلى ذلك فإن هذه الوسائل تعتبر من المتطلبات الأولية لوضع نموذج إقليمي أو نموذج للتغير الزماني للأمطار .