VARIATION OF METEOROLOGICAL PARAMETERS OVER SAUDI ARABIA (1990–2006)

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Abstract: The annual and seasonal variation of meteorological parameters has been studied for twenty stations in Saudi Arabia. The contour maps showed temperature and rainfall increasing and wind speed decreasing trends with decreasing latitudes. The mean temperature varied between a minimum of 8.4°C and a maximum of 34.61°C while overall mean was 23.95°C. The Mean, minimum and maximum values of pressure were 932.12, 923.3 and 944.6mb, respectively. The corresponding relative humidity values were 42.7, 78.5 and 21.5%, respectively. The empirical models developed for the prediction of monthly mean values of individual parameters were able to estimate the values with acceptable accuracy.

Keywords: meteorology; seasonal and annual variation; temperature; barometric pressure; precipitation; wind speed; relative humidity; climate.

INTRODUCTION

The meteorological parameters such as air Temperature (T), barometric Pressure (P), daily total rainfall (RFT), Wind Speed (WS) and Relative Humidity (RH) play important role in the day-to-day life of human beings. Accordingly, climate change on global, regional, and local scales has attracted attention of researchers and scientists. The growing materialistic life styles and towering energy needs have aggravated the climatic conditions and caused global warming, acid rain, excessive floods and tsunami like happenings. Over the past century or so the world has warmed by approximately 0.6°C, as quoted by Nicholls and Collins (2006). The climatic studies are very common and have been conducted in almost every part of the world.

According to Nicholls and Collins (2006) the temperatures across nearly all of Australia increased through the 20th century, as did sea surface temperatures in the surrounding oceans. Shepherd (2006) employed 108-year precipitation historical data to identify possible anomalies in

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rainfall in and around two major arid urban areas, Phoenix, Arizona and Riyadh, Saudi Arabia. Temperature records suggested (Shepherd, 2006) that Riyadh has experienced an adjustment in mean temperature in response to the growth of urban surfaces. On the other hand, the ground-based precipitation records indicated an upward trend in mean and total precipitation in and around Riyadh during last 10–15 years. Turkes et al. (2002) analysted mean, maximum and minimum surface air temperatures recorded at 70 climatological stations in Turkey during the period from 1929 to 1999 to study the spatial and temporal patterns of long-term trends, change points, significant warming and cooling periods and linear trend rates. Hasanean (2001) investigated the trends and periodicity of air temperature series from eight meteorological stations in the east Mediterranean using different correlation tests. He found a significant positive trend at 99% confidence in Malta, Jerusalem and Tripoli, and negative trend at 95% confidence level in Amman. Over the Indian Continent, Nizamuddin (1995) discussed the spatial and temporal variability of precipitation during the northeast and southwest monsoons.

Freiwana and Kadioglub (2008) studied the climate variability of Jordan by examining the annual, seasonal and monthly precipitation and extreme temperature time series of 14 meteorological stations. Signals of climate trends such as warming in maximum temperature, more statistically significant warming in minimum temperature, decreasing trends in daily temperature range and statistically insignificant decreasing precipitation trends were detected. The incidence of heat waves, hot days, very hot days and extremely hot days in Kuwait during the warm seasons (May–August) from 1958 to 2000 was investigated by Nasrallah et al. (2004). Their results showed that the extremely high temperatures in the warm season were due to the changes in the regional circulation pattern. Elagib and Addin Abdu (1997) studied the climate of Bahrain during the past six decades, particularly through the temperature and rainfall trends. They further evaluated the consequent degree of aridity on the Islands.

Alkolibi (2002) assessed the possible impact of climatic change on Saudi Arabia's agriculture and water supplies using climatic change scenarios using General Circulation Models and related research. His assessment indicated an increase in temperature and decrease in precipitation which could have a major negative impact on agriculture and water supplies in Saudi Arabia. It is noticed from previous climatic studies that temperature and rainfall time-series are much used in climate variability analysis (see e.g., Elagib and Mansell, 2000; Kadıoglu, 1997; Maki and Kurose, 1990; Lazaro et al., 2001; Moonen et al., 2002; Morrison et al., 2002; Velichko et al., 2002; Sneyers, 1990; Solow, 1987; Turkes et al., 1996).

This paper utilises daily mean values of the air temperature, barometric pressure, precipitation, relative humidity and wind speed from 20 stations spread all over Saudi Arabia to study the variation over different years and seasons. The study also presents the contour maps of all the parameters and national series of each parameter obtained by taking the arithmetic mean of all the stations.

DATA AND SITE DESCRIPTION

Saudi Arabian consists of desert and semi-desert with oases, where half of the total surface is uninhabitable desert. The major part of the western area of Saudi Arabia is plateau while the east is lowland with very hot climate. The southwest region has mountains as high as 3000 m. Saudi Arabia, one of the

driest and hottest countries in the world, is roughly located between north latitudes of 17 and 31 and east longitudes of 37 and 56 (Alkolibi, 2002). Maximum summer temperatures often exceed 45°C, relative humidity is very low and skies are clear most of the time. Very little precipitation is observed in the central region of Saudi Arabia.

The latitudes, longitudes, altitudes and instrument heights for 20 stations are summarised in Table 1. The location map is shown in Figure 1. Tabouk, Al-Jouf, Arar, Guriat, Turaif, Rafha and Qaisumah are located in northern region while Bisha, Gizan, Abha, Khamis-Mushait and Nejran in southern part of the country. Gassim lies slightly north west of the capital city Riyadh and Tabouk, a mountaneous area in the western part. Al-Wejh and Yanbo are the only stations located on the west sea coast of Saudi Arabia. The southern part is surrounded by complex range of mountains. Taif is a hill station and is located

Table 1 Site coordinates of stations used in the present study

S. No.	Station	Latitude	Longitude	Altitude (m)	Instrument height (m)
1	Dhahran	26° 06	50° 10	22	10
2	Gizan	16° 52	42° 35	5	8
3	Guriat	31° 25	37° 16	540	10
4	Jeddah	21° 30	39° 12	17	10
5	Turaif	31° 41	38° 40	827	8
6	Riyadh	24° 42	46° 44	624	10
7	Yanbo	24° 07	38° 03	6	10
8	Abha	18° 13	42° 31	2200	12
9	Hail	27° 31	41° 44	992	9
10	Al-Jouf	29° 56	40° 12	562	7
11	Al-Wejh	26° 14	36° 26	22	10
12	Arar	30° 54	41° 08	542	6
13	Bisha	19° 58	42° 40	1167	5
14	Gassim	26° 18	43° 58	648	7
15	Khamis	18° 18	42° 48	2060	9
16	Nejran	17° 34	44° 14	1275	8
17	Qaisumah	28° 20	46° 07	359	8
18	Rafha	29° 38	43° 29	443	12
19	Tabouk	28° 22	36° 35	771	9
20	Taif	21° 29	40° 32	1471	8

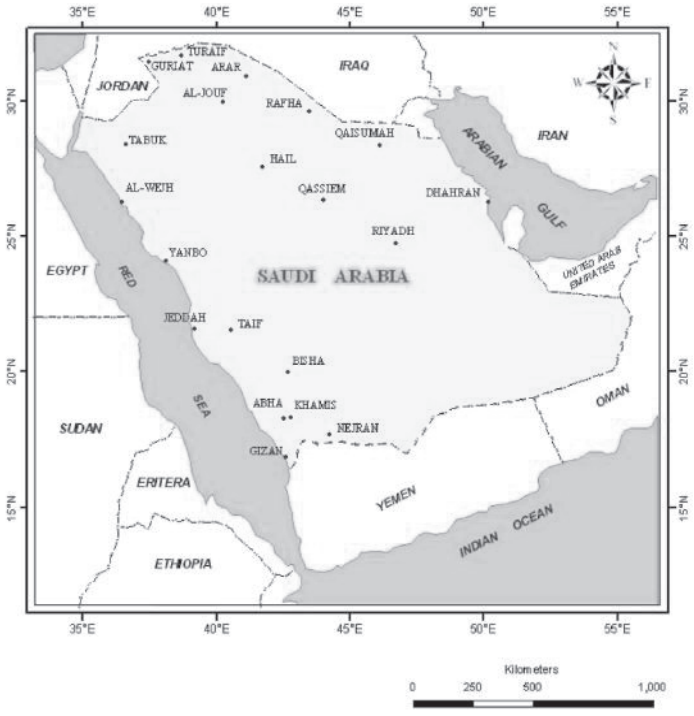

Figure 1 Location map of meteorological stations

in the western region of the Kingdom. As seen from Table 1, the site altitude varies between a minimum of 5 m at Gizan and a maximum of 2200 m above mean sea level at Abha. The fifth column of the table provides the height of the mast above ground level on which the wind speed sensors were installed.

The measured data used in this study covered a period of 17 years between January 01, 1990 and December 31, 2006. The daily mean values of all the parameters have been used in this study.

RESULTS AND DISCUSSION

The long-term daily average records of meteorological parameters were used to obtain site dependent averages, annual and seasonal statistical summaries.

Long-term variation of meteorological parameters

The long-term minimum, mean and maximum values of temperature, barometric pressure, precipitation, wind speed and relative humidity are summarised in Table 2. The long-term mean temperature varied between a minimum of 19.8°C at Khamis-Mushait and a maximum mean of 30.2°C at Gizan. The extreme higher side temperature of 42°C was observed at Qaisumah. The extreme lower side temperature of –4.3°C was found in Guriat, a station in the northern part of the Kingdom. The mean maximum barometric pressure of 1007.9 mb was found at Al-Wejh while the minimum of 794 mb in Abha.

The long-term total rain fall (RFT) means obtained using daily totals are found to vary between a minimum of 0.06 mm/day

Table 2 Long-term summary of meteorological parameters (January 01, 1990 to December 31, 2006)

Station	Temperature* (°C)			Pressure* (mb)			Precipitation (mm)		Wind speed* (knots)		RH* (%)
	Min	Mean	Max	Min	Mean	Max	Mean	Max	Mean	Max	Mean
Dhahran	7.7	26.4	41.0	990	1006.7	1028	0.27	125	8.5	23	52.5
Gizan	20.3	30.2	37.5	997	1007.7	1019	0.44	90	6.3	15	68.4
Guriat	–4.3	19.5	38.2	935	954.8	973	0.12	37	8.2	32	43.5
Jeddah	16.0	28.2	37.7	996	1007.3	1021	0.20	55	7.2	22	61.4
Turaif	–3.0	19.0	37.1	902	916.9	932	0.21	26	8.4	28	40.3
Riyadh	5.3	26.7	41.6	929	942.4	959	0.28	70	6.0	17	26.2
Yanbo	2.1	27.7	40.9	995	1007.8	1025	0.11	73	7.3	20	53.8
Abha	3.8	18.6	29.4	787	794.0	799	0.65	120	5.7	29	54.6
Hail	–0.4	22.4	38.6	892	901.3	915	0.32	48	6.3	21	33.2
Al-Jouf	0.9	22.0	39.7	923	936.1	953	0.17	34	7.8	31	32.1
Al-Wejh	11.0	25.1	36.6	996	1007.9	1023	0.09	116	8.6	23	64.6
Arar	–0.7	22.2	40.4	936	949.6	967	0.13	38	7.0	25	36.2
Bisha	3.0	25.9	40.2	876	884.0	894	0.26	40	4.8	20	29.3
Gassim	3.7	25.1	40.9	926	937.6	955	0.43	86	5.4	18	29.0
Khamis-Mushait	8.1	19.8	33.2	788	797.9	803	0.57	99	6.1	25	51.4
Nejran	11.0	25.7	38.0	868	879.4	891	0.23	157	3.9	17	30.1
Qaisumah	3.0	25.5	42.0	955	969.5	988	0.35	64	6.9	23	31.4
Rafha	0.8	23.4	40.3	945	960.3	979	0.26	121	7.5	24	38.4
Tabouk	3.0	22.1	37.0	915	926.0	938	0.06	36	5.3	30	34.0
Taif	2.0	23.1	33.4	849	855.4	863	0.52	169	7.1	20	43.3

*Based on daily mean values of respective meteorological parameter.

in Tabouk to a maximum of 0.65 mm/day in Abha. These low averages indicate that these locations belong to harsh and arid environment. The maximum value of the precipitation collected in one day during the data collection period was 169 mm in Taif while the minimum was 26 mm in Turaif. The mean wind speed varied between 3.9 knots and 8.6 knots corresponding to meteorological stations Nejran and Al-Wejh, respectively, as given in Table 2. The relative humidity varied between 26.2% and 68.4% at Riyadh and Gizan, respectively.

The mean temperature increases from 21°C in the area of Turaif with decreasing latitude to 26°C towards Gizan, as shown in the contour map of Figure 2. The variation of barometric pressure is shown in Figure 3. The long-term mean rainfall increases with

decreasing latitudes, as shown in Figure 4. Higher values of the order of 0.5 mm/day are observed in the southern region and lower in the upper region. Higher wind speed is observed in the northern, western and eastern part of Saudi Arabia, as depicted in Figure 5. In general, a decreasing trend in wind speed values was noticed from north towards south. Higher relative humidity values were observed in coastal areas and lower in inland areas, as shown in Figure 6.

National time series of meteorological parameters

The national meteorological time series were constructed by taking arithmetic averages of daily mean values from all the stations. The daily national minimum, mean and the maximum air temperature, barometric pressure, rainfall, wind speed and relative humidity are shown in Figures 7–11, respectively. The national mean temperature indicates an increasing trend with time, as can be observed in Figure 7. The minimum and maximum of the daily mean national temperatures also show an increasing trend but at a bit slow rate compared to that of mean values. The national mean temperature varied between a minimum of 8.4°C and a maximum of 34.61°C while then overall mean national temperature remained as 23.95°C. The extreme high temperatures (maximum of the daily mean) varied between 16.6°C

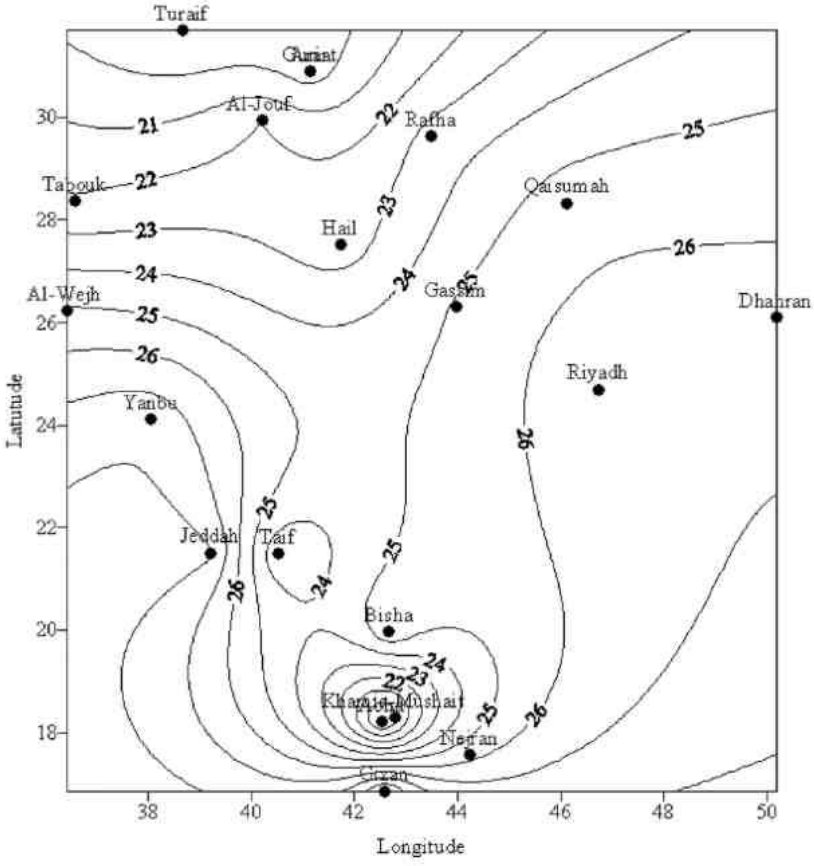

Figure 2 Contour map of mean air temperature (January 01, 1990 to December 31, 2006)

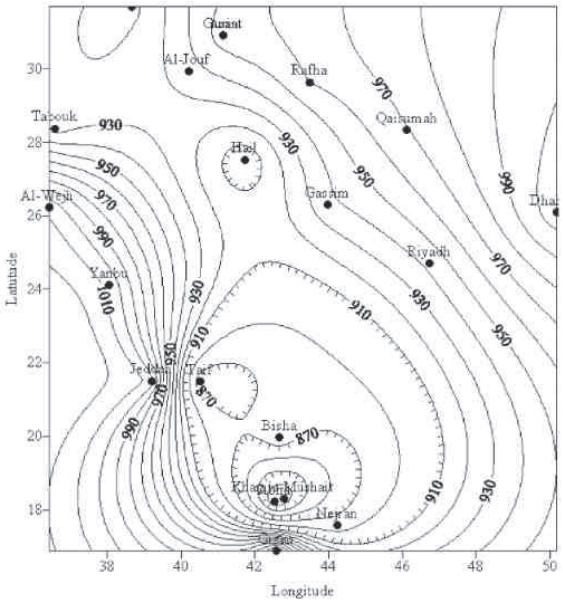

Figure 3 Contour map of mean barometric pressure (January 01, 1990 to December 31, 2006)

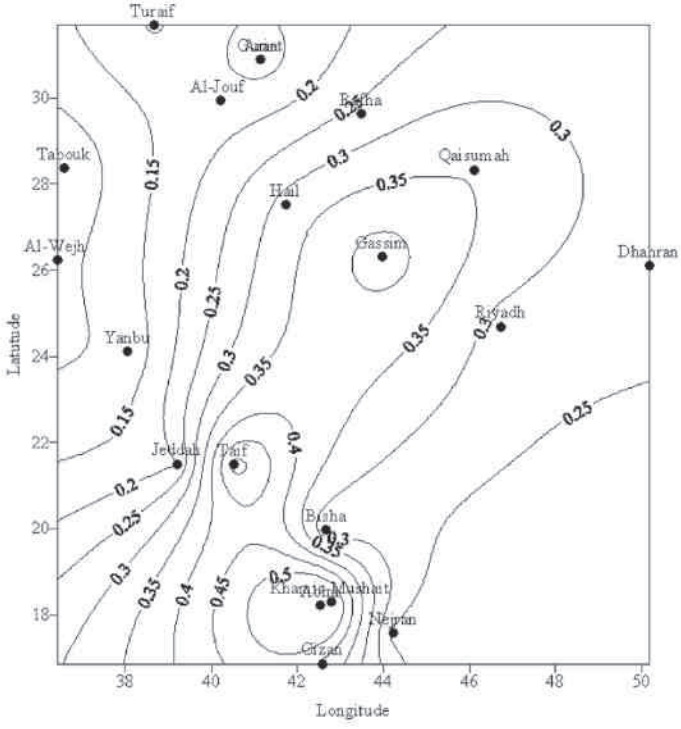

Figure 4 Contour map of mean rainfall (January 01, 1990 to December 31, 2006)

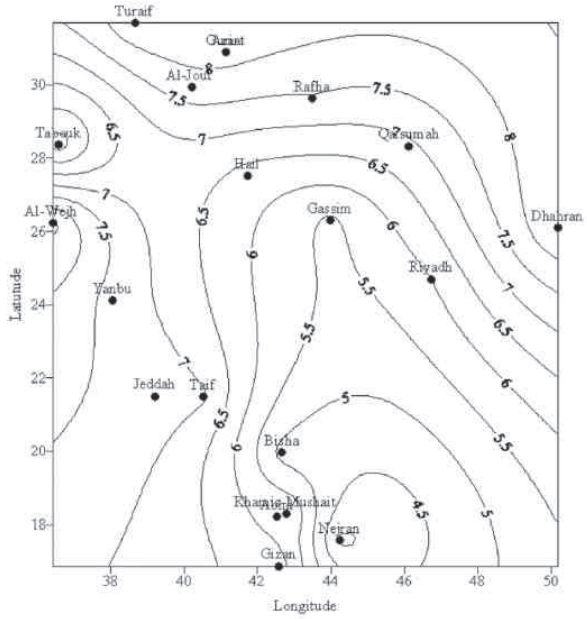

Figure 5 Contour map of mean wind speed (January 01, 1990 to December 31, 2006)

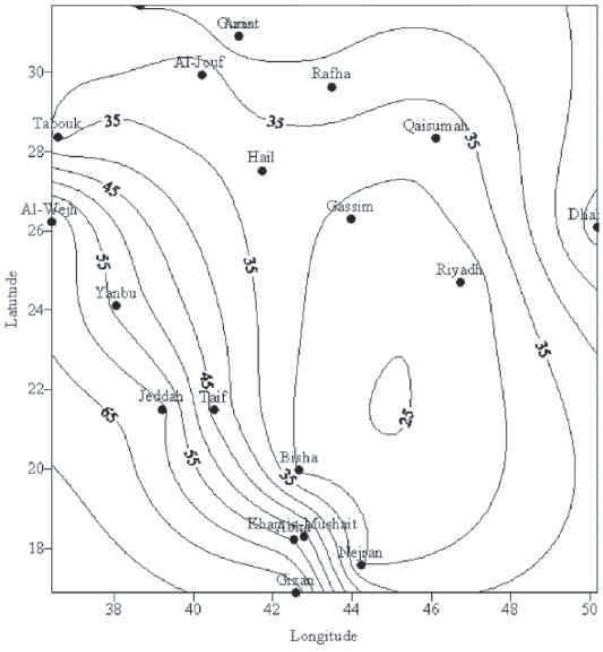

Figure 6 Contour map of mean relative humidity (January 01, 1990 to December 31, 2006)

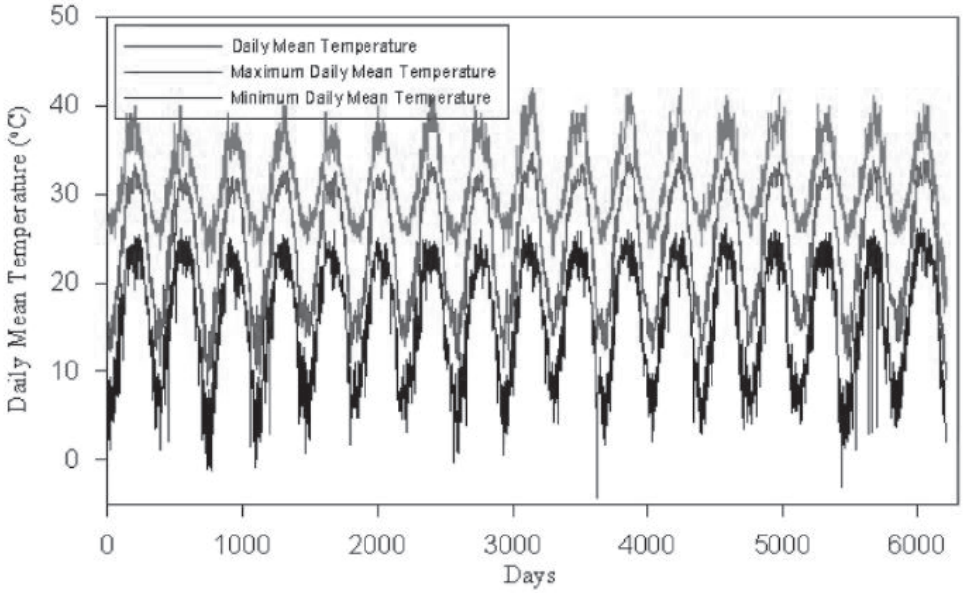

Figure 7 National daily mean air temperature

and 42°C while the mean of the maximum was 31.59°C. The extreme low (minimum of the daily mean) temperatures were found to vary between –4.3°C and 27.2°C with an overall mean of 15.92°C.

The national mean, minimum and maximum values of the pressure obtained from daily means were 932.12, 923.3 and 944.6 mb, respectively. On the other hand, the means of the maximum and minimum pressure were 1009.85 and 794 mb with respective ranges of 29.1 mb and 11.5 mb. The daily barometric pressure values showed both annual and seasonal variability over entire period of data used in this study, as indicated in Figure 8. However, the range between upper and lower values of daily maximum was the highest and lowest in case of daily minimum. The overall national mean of the daily total rainfall was 0.28 mm while 11.33 mm of maximum rainfall was collected in one day. Figure 9 shows the maximum daily total rainfall collected at national level. The rainfall is very irregular in Saudi Arabia and there is no well defined rainy season.

The overall mean, minimum and maximum of the daily national mean wind speed values were 6.7, 3.8 and 13.25 knots and 12.8, 6 and 32 knots corresponding to maximum of the daily mean wind speeds. The daily national mean, minimum and maximum values of wind speed are shown in Figure 10. The national wind speed has small magnitude and has no definite pattern. The national mean, maximum and minimum of the daily relative humidity values are shown in Figure 11. The overall national mean maximum and minimum RH values were 42.7, 78.5 and 21.5%, respectively. The mean and minimum RH values depicted a more regular annual and seasonal pattern compared to maximum RH values.

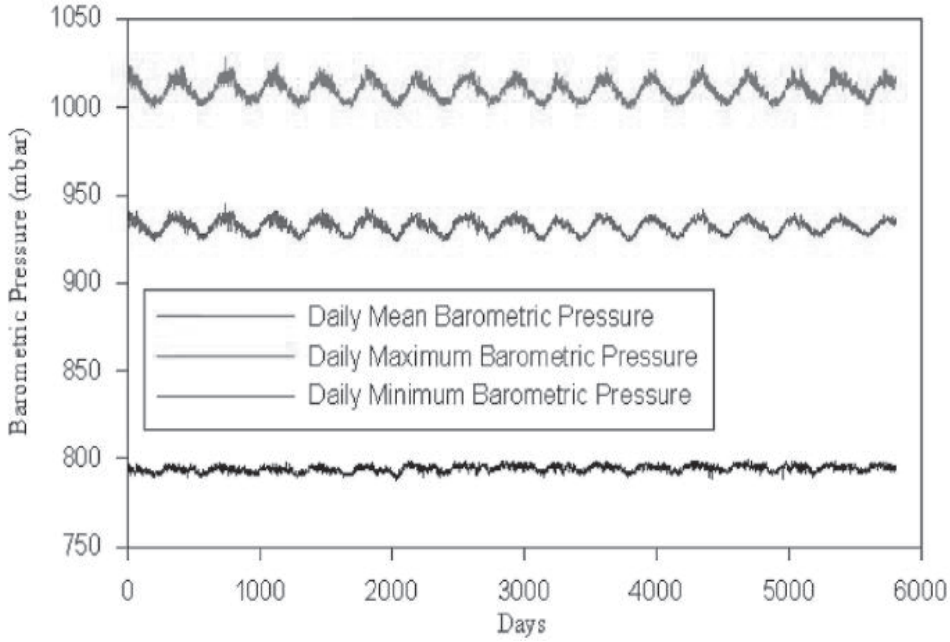

Figure 8 National daily mean barometric pressure (January 01, 1990 to December 31, 2006)

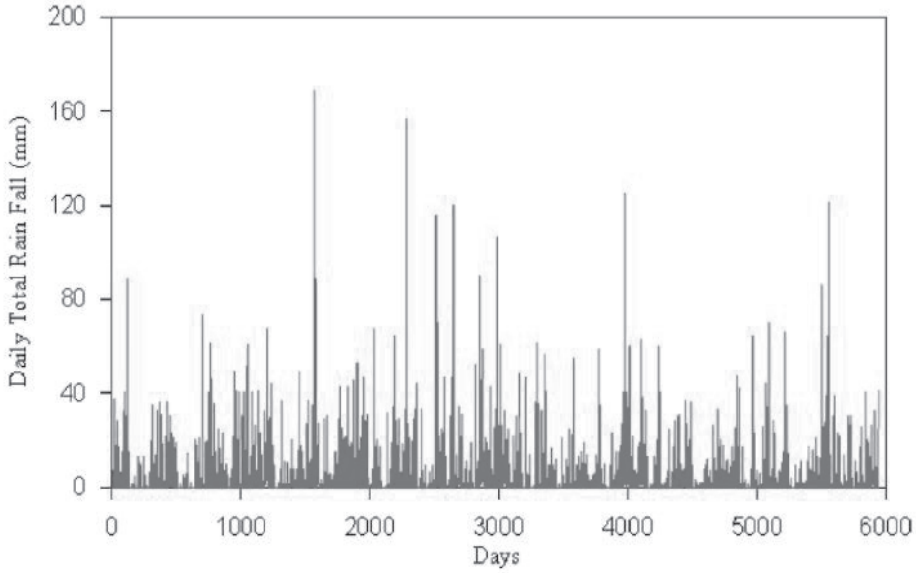

Figure 9 National maximum daily total rainfall (January 01, 1990 to December 31, 2006)

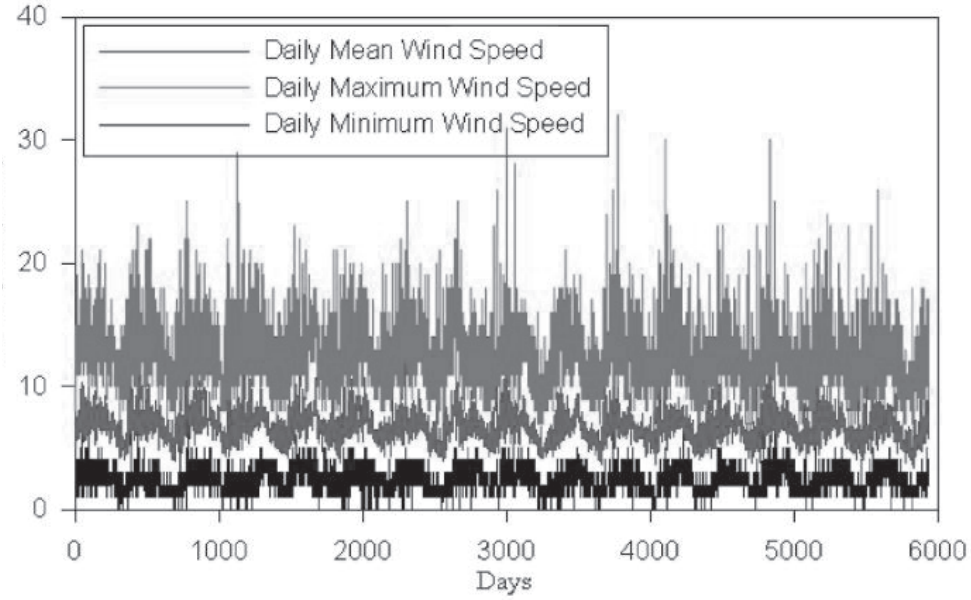

Figure 10 National daily mean wind speed (January 01, 1990 to December 31, 2006)

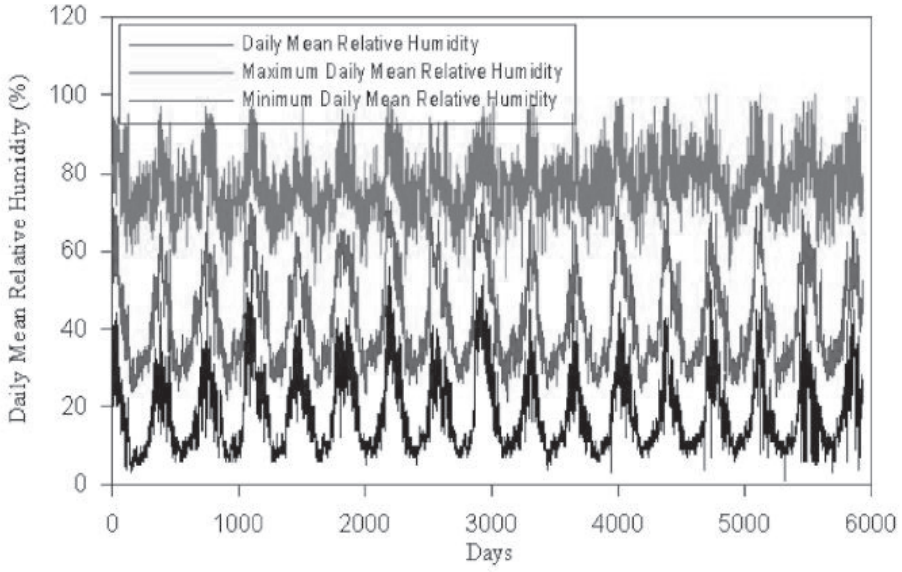

Figure 11 National daily mean relative humidity (January 01, 1990 to December 31, 2006)

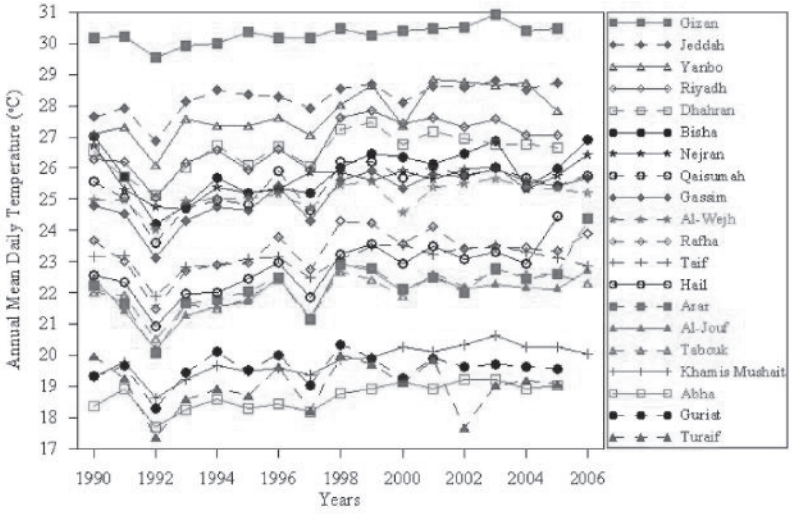

Figure 12 Variation of annual mean air temperature at all stations

Annual variation of meteorological parameters

The annual behaviour of meteorological parameters over long period provides the trend (increasing/decreasing) over different time spans. It should be studied carefully and accurately to minimise the errors in predicting these parameters in future time domains. The annual mean values of air temperature at 20 stations are depicted in Figure 12. It is evident from this figure that all the stations under consideration can be put in four different categories based on temperature ranges. The first category (temperature between 26°C and 29°C) included Jeddah, Yenbo, Riyadh and Dhahran stations. The second category with temperature varying from 25°C to 26°C included Bisha, Nejran, Qaisumah, Gassim and Al-Wejh Stations. The next group of stations included Rafha, Taif, Hail, Arar, Al-Jouf, and Tabouk in which the temperature varied from 22°C to 24°C. The fourth group with temperature varying between 22°C and 24°C included Khamis–Mushait, Abha, Guriat and Turaif stations, as shown in Figure 12. Gizan was the only station which experienced the highest temperature of around 30°C, as it is clear from Figure 12. An increasing trend was noticed in temperature values over entire period and at all the stations. A temperature dip was observed at all the stations in the years 1992 and 1997. The lower values of annual mean temperatures in 1992 are attributed to the effect of oil well fires in the region during and after the Gulf-War-I. The annual mean values of barometric pressure, daily total rain fall and mean wind speeds are shown in Figures 13–15, respectively. The Pressure values are found to be almost constant throughout the data reporting period. Based on pressure range, the meteorological stations fall in high pressure range category above 1000 mb (Gizan, Jeddah, Yenbo, Al-Wejh and Dhahran), upper mid-range around 950 ± 25 mb (Riyadh, Qaisumah, Rafha, Arar, Gassim, Turaif, Guriat, Al-Jouf and Tabouk), lower mid-range of 900 ± 25 mb (Hail, Bisha, and Nejran) and the lower

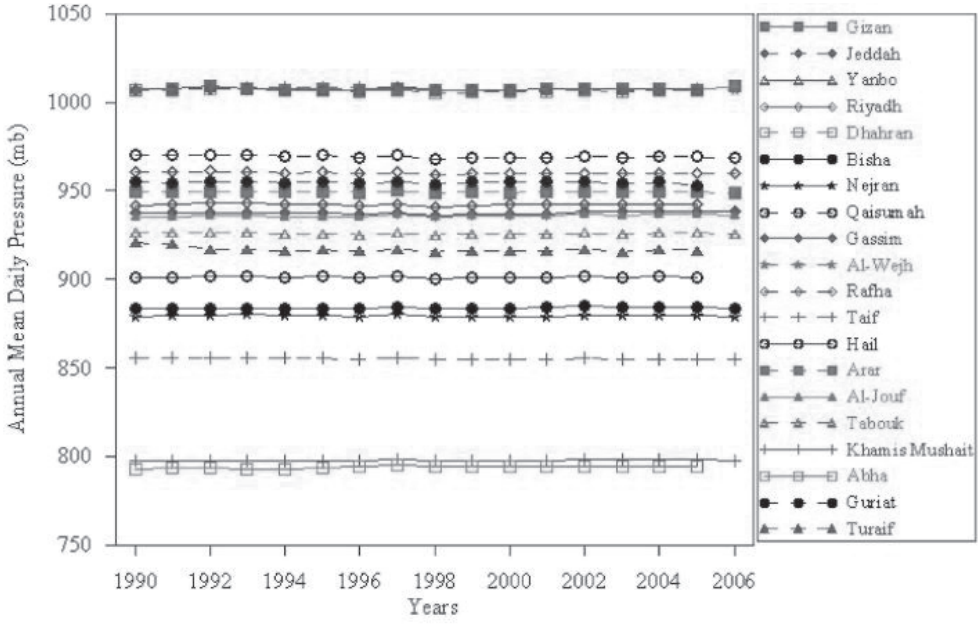

Figure 13 Variation of annual mean barometric pressure at all stations (January 01, 1990 to December 31, 2006)

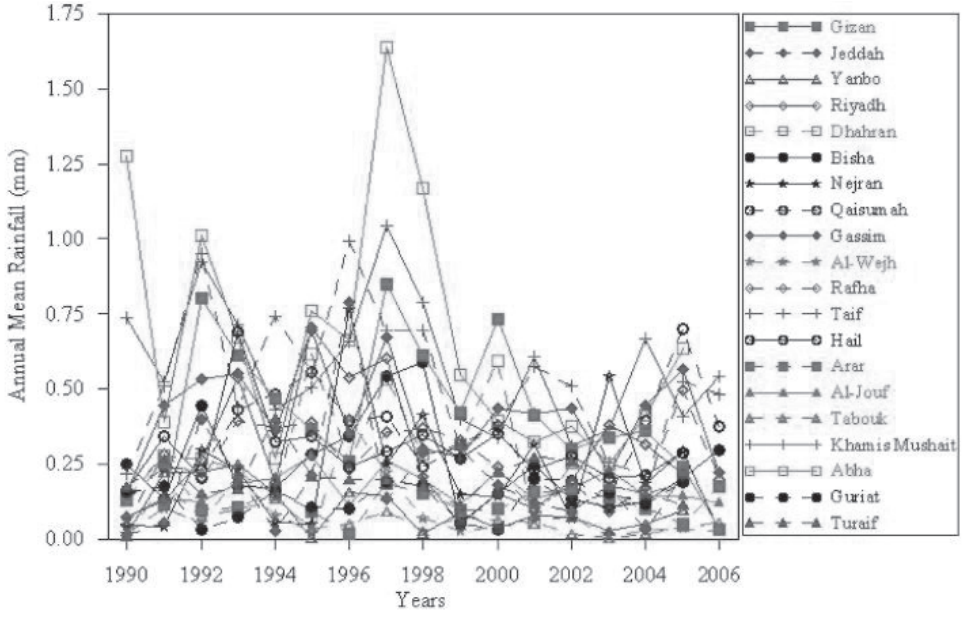

Figure 14 Variation of annual mean precipitation at all stations (January 01, 1990 to December 31, 2006)

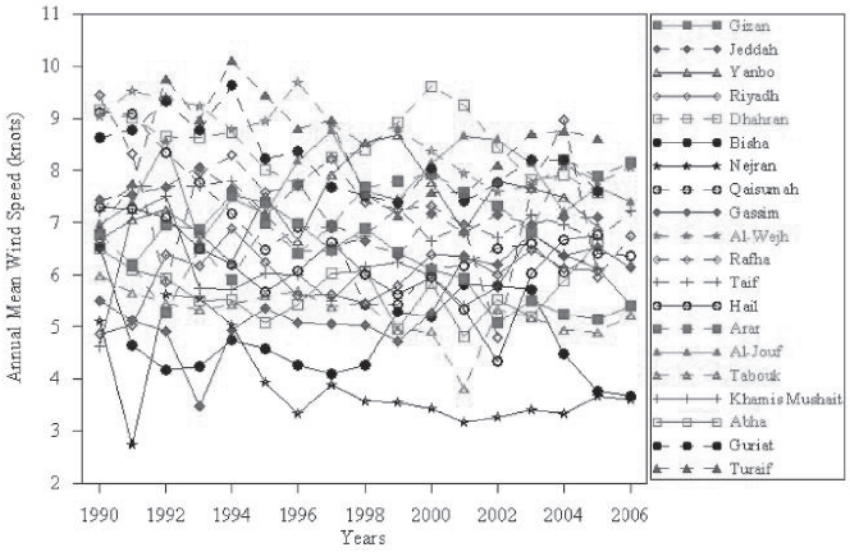

Figure 15 Variation of annual mean wind speed at all stations (January 01, 1990 to December 31, 2006)

range of less than 850 mb (Taif, Abha and Khamis-Mushait). The rain fall data could not reveal any pattern, as can be seen from Figure 14. Relatively higher rains were collected in Abha, Khamis-Mushait, Taif and Gizan and least in Tabouk area. Overall, years 1992 and 1997 could be identified as the years with higher rain fall. Higher mean wind speeds were observed in Dhahran, Al-Wejh and Turaif areas and lowest in Nejran area. Again, in case of wind speed, no definite increasing or decreasing trend could be identified, as depicted in Figure 15. In case of relative humidity, as shown in Figure 16, most of the stations belonged to the category with 20–40% of relative humidity range. Only at Gizan, Jeddah, Yenbo, Turaif, Abha, Dhahran, Khamis-Mushait and Al-Wejh, the relative humidity was found to be above 50% during most of the years of data collection. Again, no definite increasing or decreasing trend could be identified in the annual mean values of relative humidity at most of these stations.

Seasonal variation of meteorological parameters

The study of seasonal variation of meteorological parameters is useful in assessing the impact on the life cycle of human beings during the different seasons of the year. The seasonal trends of monthly mean values of air temperature at different locations are evident from Figure 17. The temperature increases from January till it reaches a maximum in August, then it decrease towards the end of the year. The seasonal patterns at Abha and Khamis-Mushait were very different from rest of the stations with highest temperatures occurring in June and lowest in January, as can be seen from Figure 17. Moreover, the overall temperature change during the year was about 11°C i.e., between about 13°C and 24°C. The lower temperature ranges at these two locations were expected as both are located at high elevations. The temperature behaviour at Jeddah, Gizan, Al-Wejh and Yanbo showed

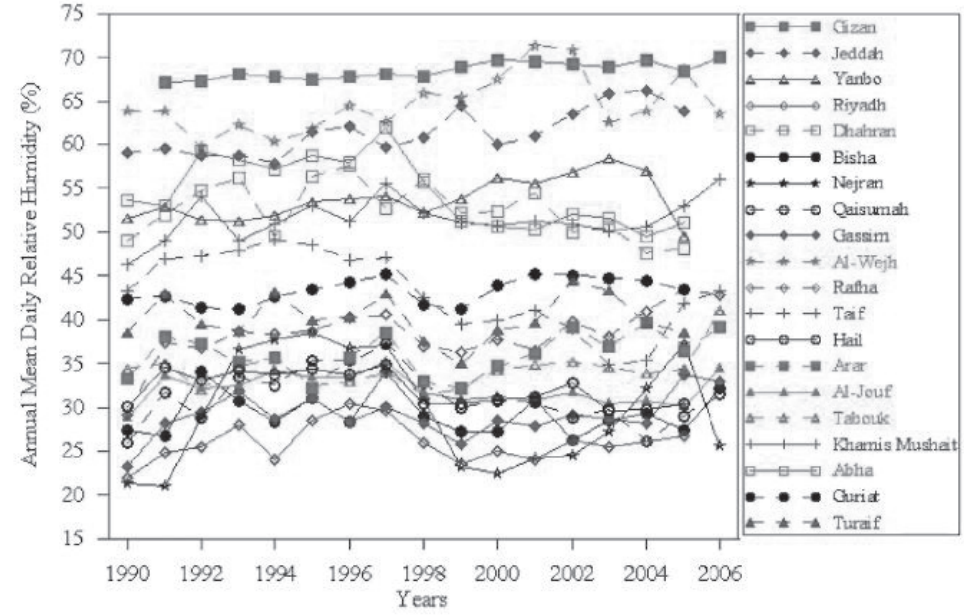

Figure 16 Variation of annual mean relative humidity at all stations (January 01, 1990 to December 31, 2006)

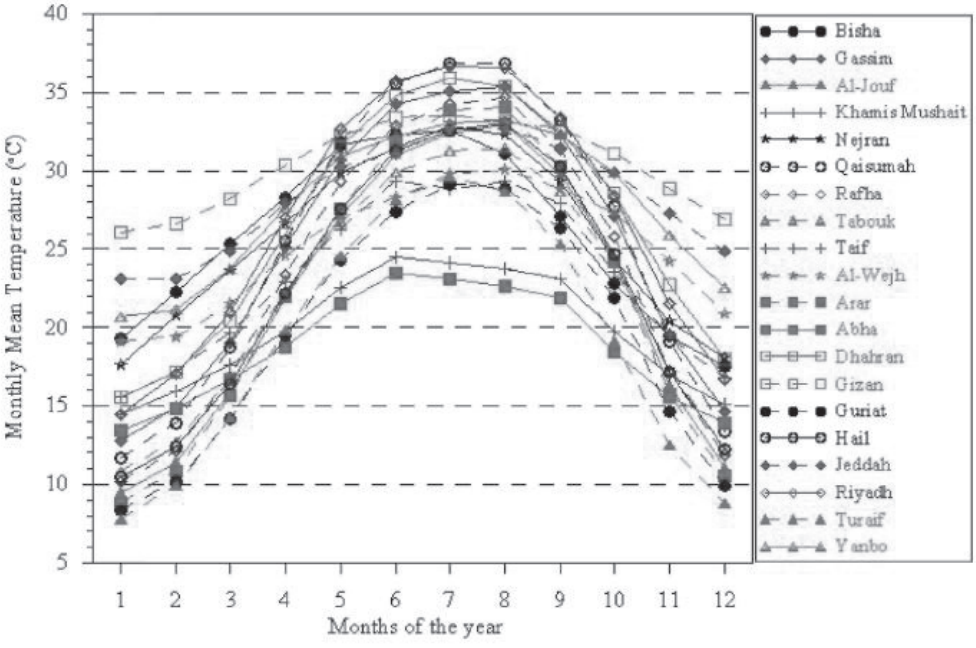

Figure 17 Monthly mean temperature variation at different stations (January 01, 1990 to December 31, 2006)

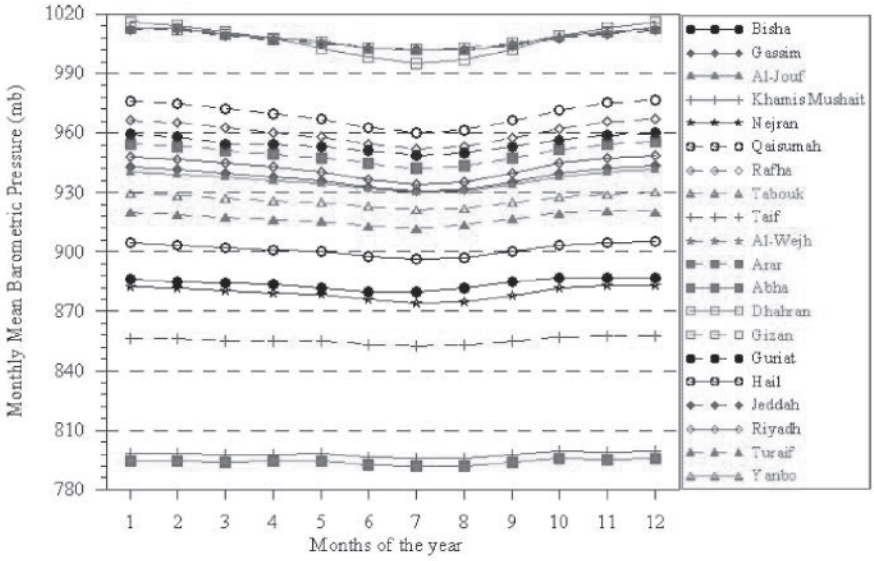

Figure 18 Monthly mean barometric pressure variation at different stations (January 01, 1990 to December 31, 2006)

similar patterns with less variation but were different from the rest of the stations. At all these coastal stations, the maximum temperature was observed in August while the minimum in January. Furthermore, the change in temperature during the year was 10, 7, 11 and 12°C at Jeddah, Gizan, Al-Wejh and Yanbo, respectively. At inland stations, the temperature trends were found to be very well defined compared to coastal stations. The highest temperature variation during the year was observed at Qaisumah while the lowest at Abha.

Relatively lower values of barometric pressure were observed in the month of July and higher in January and December, as shown in Figure 18. The overall change in barometric pressure during the year, at all locations, was about ±10 mb. Highest pressures were recorded at coastal stations such as Dhahran, Gizan, Jeddah, Yanbo and Al-Wejh and lowest at stations which were located at high elevations such as Abha and Khamis-Mushait. The long-term seasonal averages of daily total rain fall data could not depict any regular pattern, as can be seen from Figure 19. In general, higher rain fall occurred in the months of March, April, August and November at most of the stations. The monthly mean values of wind speed (Figure 20) were found to be relatively higher during summer and lower during winter. Highest wind speeds were observed at Guriat, a station located in the north part and lowest at Nejran which is located in the south part of the Kingdom. Furthermore, relatively higher wind speeds were noticed at coastal stations compared to those at inland stations. The relative humidity values showed a decreasing trend starting from January towards June and then an upward trend towards end of the year, as given in Figure 21. Highest monthly mean RH values were found at Gizan and Al-Wejh and the lowest at Riyadh, Gassim and Qaisumah. The relative humidity trend at Al-Wejh was found to be reversed as compared to rest of the stations. This may be due to its unique surrounding of the red sea coast.

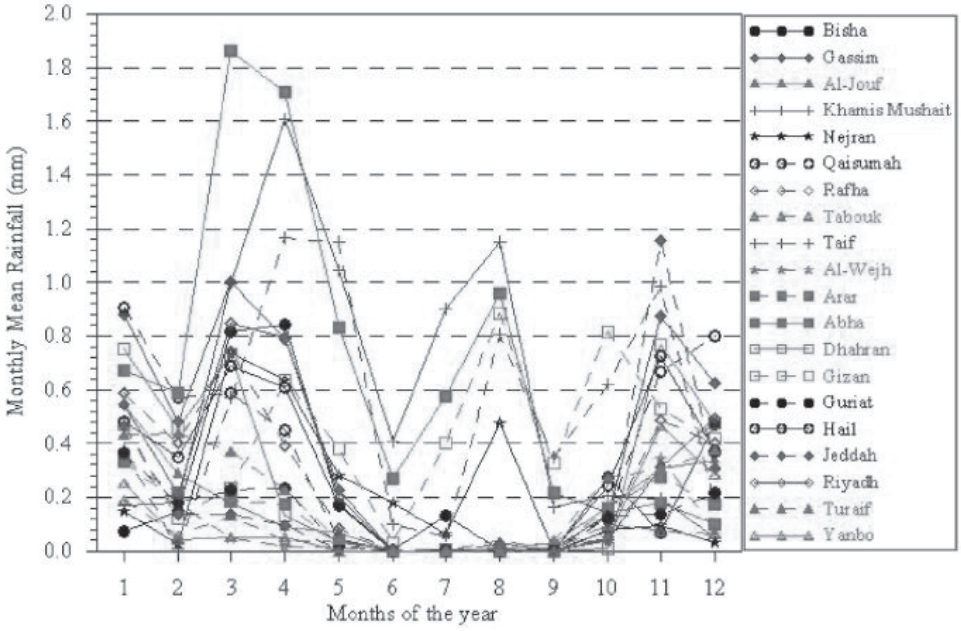

Figure 19 Monthly mean precipitation variation at different stations (January 01, 1990 to December 31, 2006)

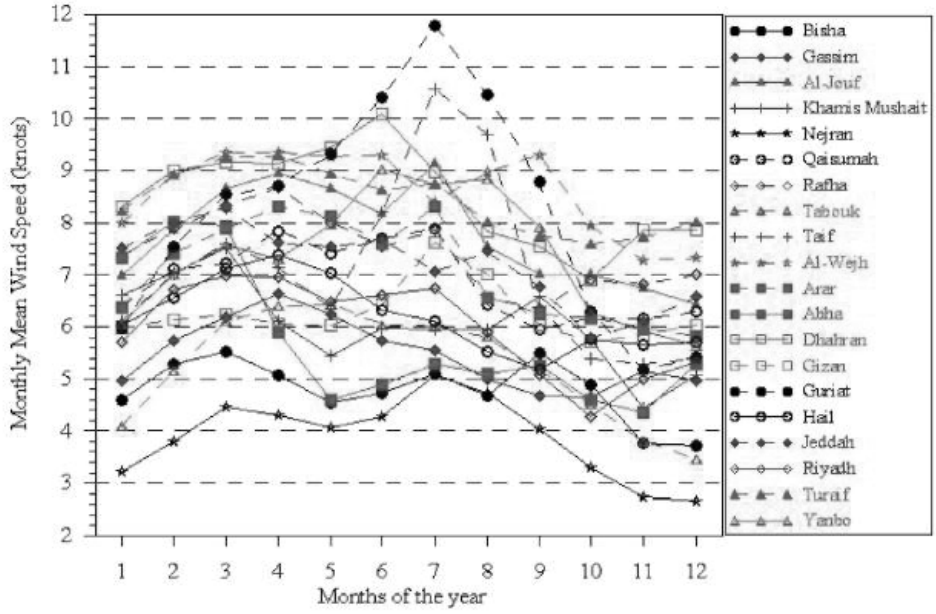

Figure 20 Monthly mean wind speed variation at different stations (January 01, 1990 to December 31, 2006)

Prediction of monthly mean air temperature

In order to study the long-term seasonal trends of mean temperature, barometric pressure, daily total rainfall, wind speed and relative humidity, we developed least-squares quadratic regression models. In estimating the regression models, we have used the simple least-squares approach with month of the year as the independent variable, and meteorological parameter values as the dependent variable. The statistical significance of each estimated X (β) coefficient was tested using the Student's t test for significance with (n – 2) degrees of freedom. The quadratic equations, so obtained, for each parameter and all the locations are given in respective figures along with the coefficient of determination values R^2.

The measured long-term monthly mean values of temperature along with the regression model equations are shown in Figures 22 and 23 for all the stations used in the present study. It is evident from these figures, that the regression models were able to predict the measured values with sufficient accuracy while retaining the annual seasonal pattern too. The coefficient of determination values varied between 91% and 95% which shows great degree of agreement between the modelled and actual values. The long-term seasonal variation of barometric pressure was also modelled using a quadratic regression equation and the resulting estimates are compared with the measured values in Figures 24 and 25 for all the stations. In general, the models predicted the pressure values with great accuracy in all the months except between July and September. The coefficient of determination R^2 varied between 56% for Abha and Khamis-Mushait and 90% for Gizan. Higher R^2 values were obtained for plain and coastal areas and lower for mountainous areas.

Higher values of R^2 (>80%) were found for models of monthly mean precipitation at Arar, Al-Jouf, Qaisumah, Guriat and Turaif stations, as can be seen from Figures 26(a), (d), (g) and 27(d), (j), respectively. All of these stations lie in the northern part of the

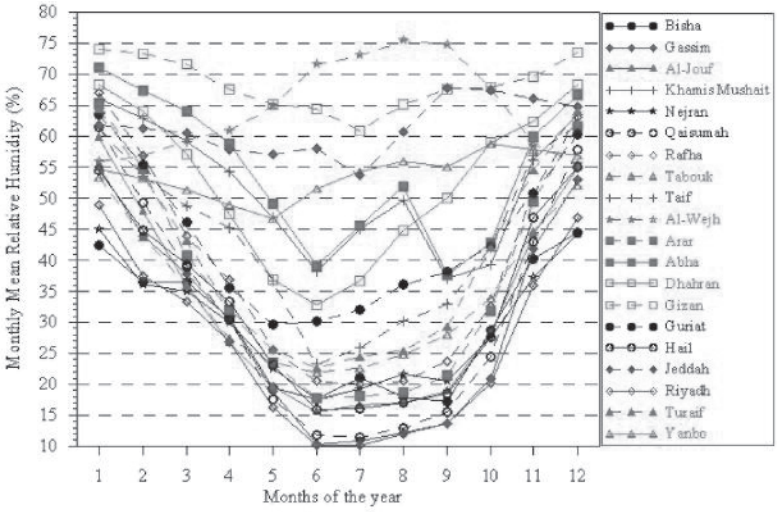

Figure 21 Monthly mean relative humidity variation at different stations (January 01, 1990 to December 31, 2006)

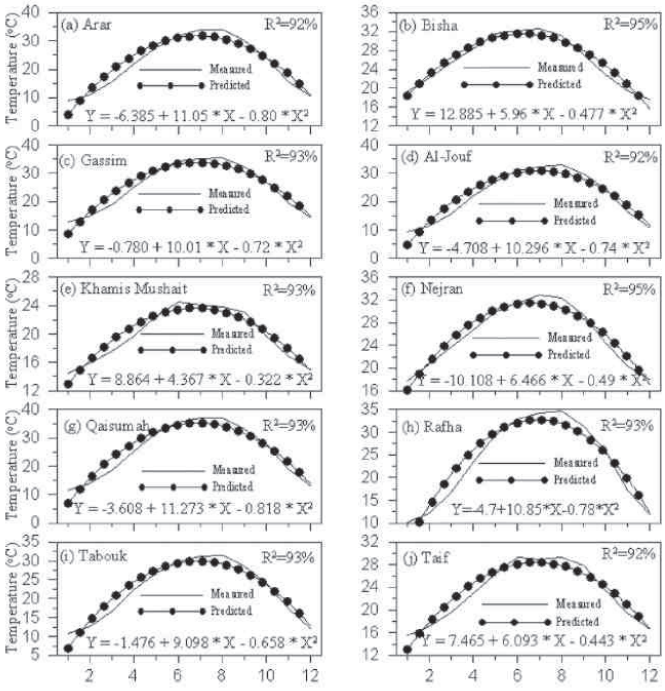

Figure 22 Prediction of monthly mean temperature (January 01, 1990 to December 31, 2006)

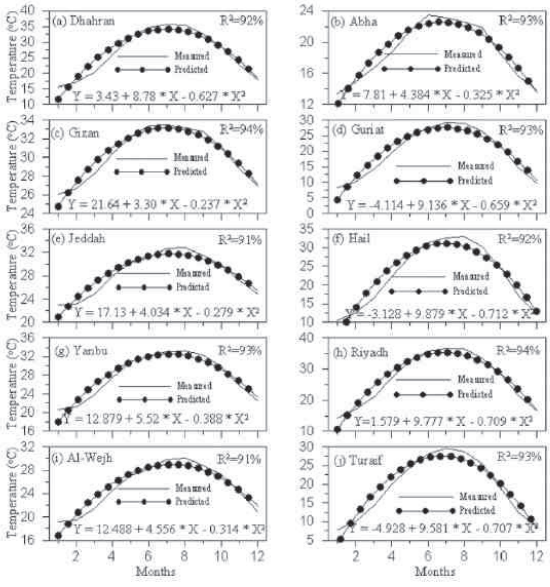

Figure 23 Prediction of monthly mean temperature (January 01, 1990 to December 31, 2006)

Kingdom. Among coastal locations, as seen from Figures 27(a), (c), (e), (g), (i), Dhahran, Yanbo and Al-Wejh daily total rain values could be estimated with better accuracy compared to those at Gizan and Jeddah. The estimated and measured monthly mean wind speed values for all the stations are shown in Figures 28 and 29. Relatively better estimates with R^2 value >70% were obtained for Arar, Al-Jouf, Nejran, Tabouk, Abha, Guriat, Yanbu and Al-Wejh as seen from Figures 28(a), (d), (f), (i) and 29(b), (d), (g), (i), respectively. Overall, at these stations, the regression models were able to retain the seasonal patterns with increasing trend from January to June and then a decreasing trend towards the end of the year. The monthly mean values of RH were predicted with relatively higher accuracy (R^2 > 90%), as can be seen from Figures 30 and 31. Relatively speaking, poor estimations were obtained for some coastal and mountainous areas such as Al-Wejh (Figure 31(i)), Jeddah (Figure 31(e)), Yanbu (Figure 31(g)), Kahmis-Mushait (Figure 30(e)) and Abha (Figure 31(b)).

SUMMARY OF FINDINGS

The paper utilised daily average values of meteorological parameters for 20 stations spread throughout the Kingdom of Saudi Arabia to study their behaviour using long-term averages. Empirical models for all the parameters were developed to estimate monthly mean values of respective parameters. The findings of the study can be summarised as follows:

- The contour maps showed temperature and rainfall increasing and wind speed decreasing trends with decreasing latitudes. Generally, higher relative humidity

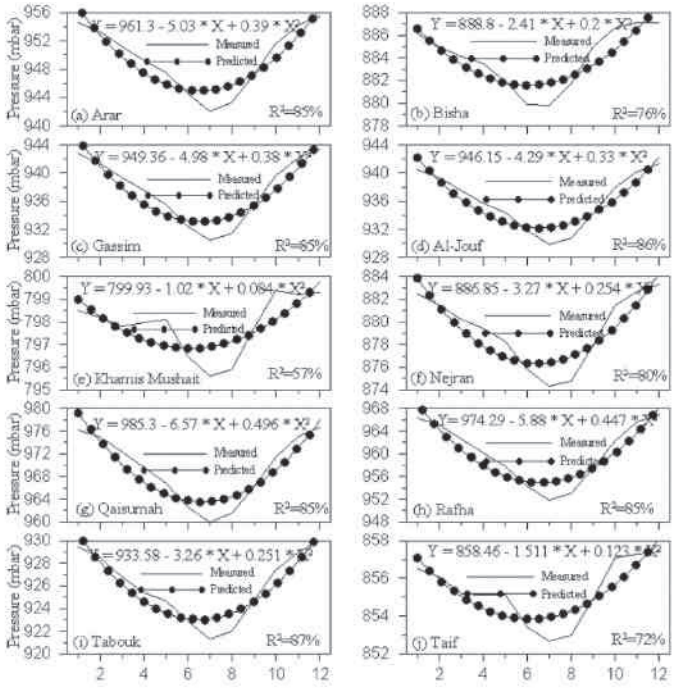

Figure 24 Prediction of monthly mean barometric pressure (January 01, 1990 to December 31, 2006)

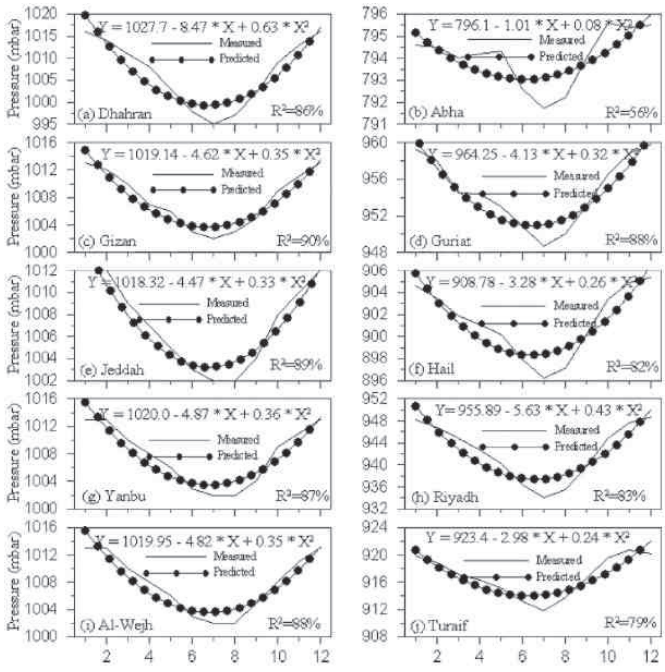

Figure 25 Prediction of monthly mean barometric pressure (January 01, 1990 to December 31, 2006)

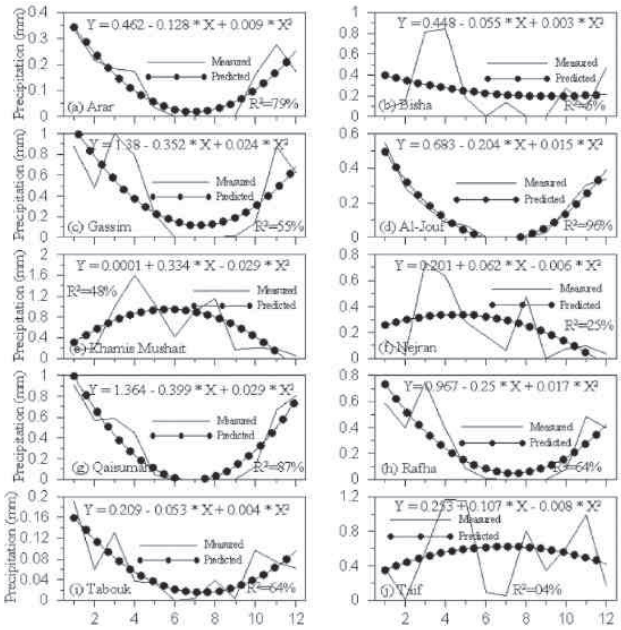

Figure 26 Prediction of monthly mean precipitation (January 01, 1990 to December 31, 2006)

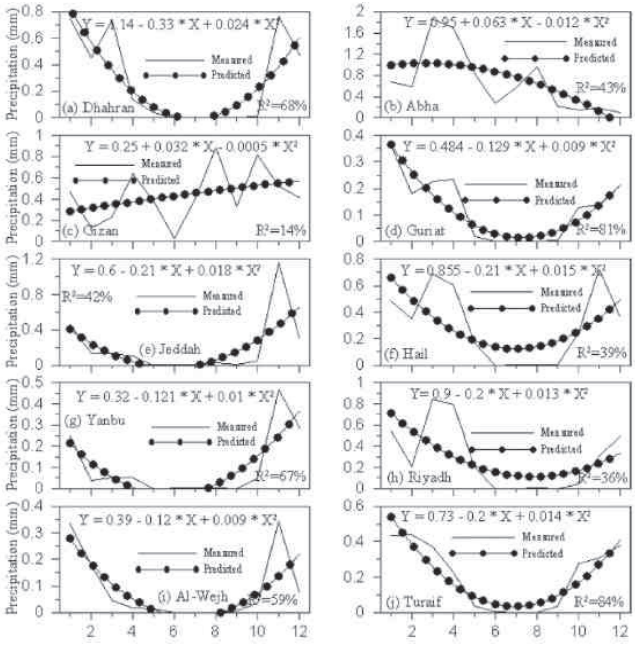

Figure 27 Prediction of monthly mean precipitation (January 01, 1990 to December 31, 2006)

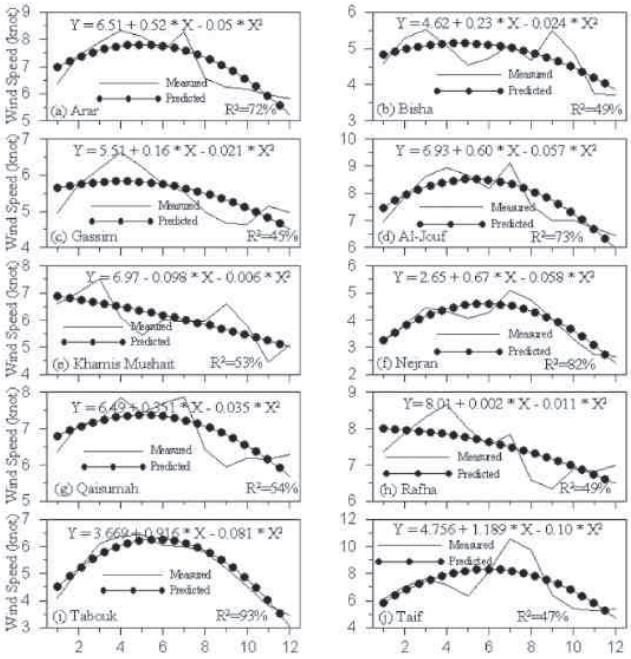

Figure 28 Prediction of monthly mean wind speed (January 01, 1990 to December 31, 2006)

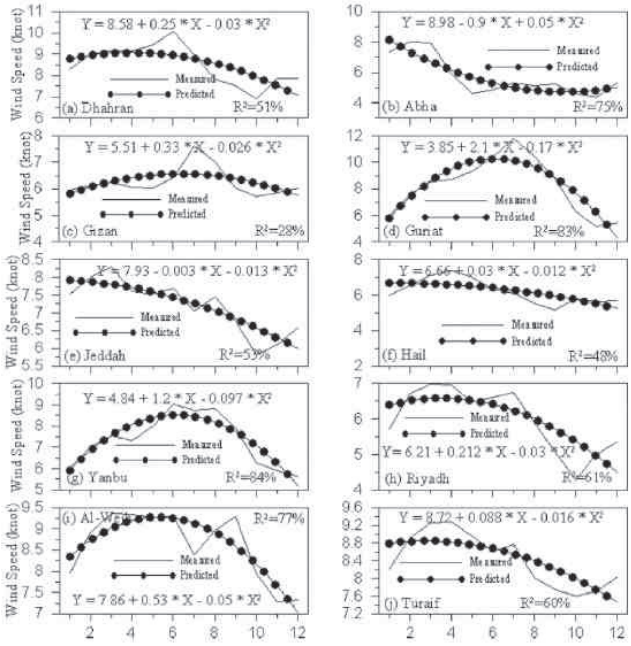

Figure 29 Prediction of monthly mean wind speed (January 01, 1990 to December 31, 2006)

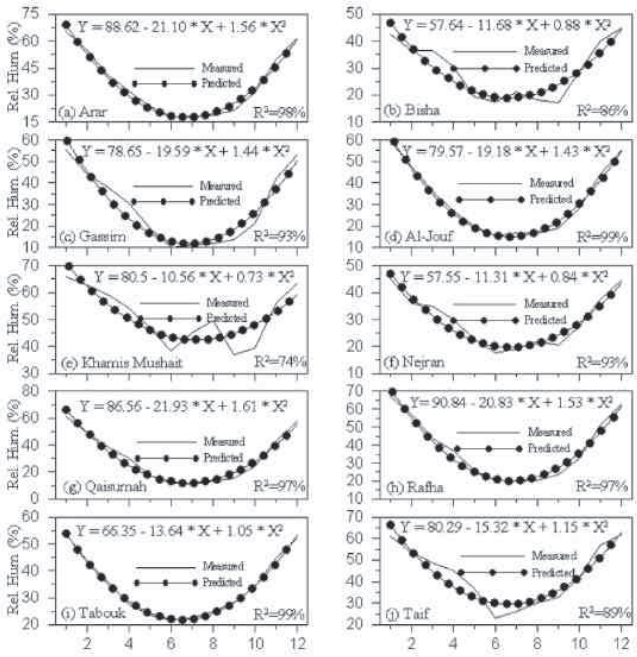

Figure 30 Prediction of monthly mean relative humidity (January 01, 1990 to December 31, 2006)

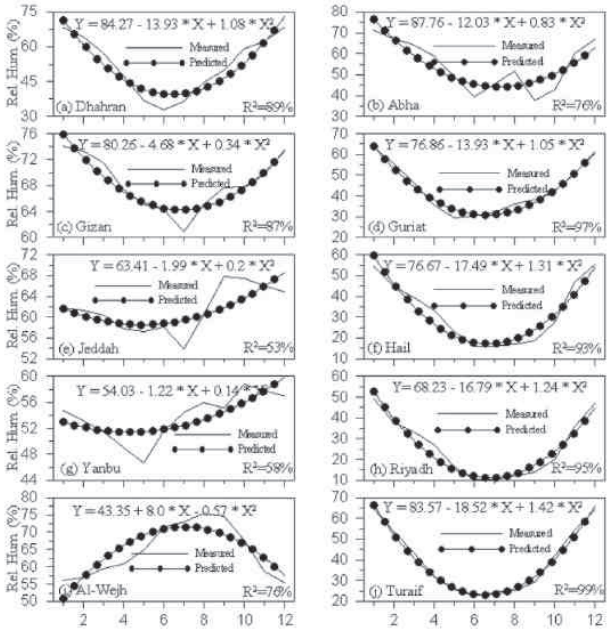

Figure 31 Prediction of monthly mean relative humidity (January 01, 1990 to December 31, 2006)

was observed in coastal areas and lower in inland areas.

- The national mean temperature varied between a minimum of 8.4°C and a maximum of 34.61°C while the mean national temperature remained as 23.95°C. The national mean, minimum and maximum values of the pressure obtained from daily means were 932.12, 923.3 and 944.6 mb, respectively. The national mean of the daily total rainfall was 0.28 mm while 11.33 mm of maximum rainfall was collected in one day. The mean, minimum and maximum national mean wind speed values were 6.7, 3.8 and 13.25 knots. The national mean maximum and minimum RH values were 42.7, 78.5 and 21.5%, respectively.
- An increasing trend was noticed in temperature values over entire period and at all the stations. A temperature dip was observed at all the stations in the years 1992 and 1997. The lower values of annual mean temperatures in 1992 could be attributed to the effect of oil well fires in the region during and after the Gulf-War-I.
- The Pressure values are found to be almost constant throughout the data reporting period.
- The rain fall data could not reveal any pattern. Higher rains were collected in Abha, Khamis-Mushait, Taif and Gizan and least in Tabouk area. Overall, years 1992 and 1997 could be identified as the years with higher rain fall.
- In case of wind speed, no definite increasing or decreasing trend could be identified.
- In case of relative humidity, most of the stations belonged to the category with 20–40% relative humidity range. Only at Gizan, Jeddah, Yenbo, Turaif, Abha, Dhahran, Khamis-Mushait and Al-Wejh, the relative humidity was found to be above 50% during most of the years

of data collection. Again, no definite increasing or decreasing trend could be identified in the annual mean values of relative humidity at most of these stations.

- At inland stations, the temperature trend was found to be very well defined with lower values in winter and higher in summer. The highest temperature variation was observed at Qaisumah during the year while the least at Abha.
- Relatively lower values of barometric pressure were observed in the moth of July and higher in January and December. The overall change in barometric pressure during the year, at all locations, was about ±10 mb.
- The long-term seasonal averages of daily total rain fall data could not depict any regular pattern. In general, higher rain fall occurred in the months of March, April, August and November at most of the stations.
- The monthly mean values of wind speed were found relatively higher during summer and lower during winter. Highest wind speeds were observed at Guriat, a station located in the north part and lowest at Nejran which is located in the south part of the Kingdom.
- Furthermore, relatively higher wind speeds were noticed at coastal stations compared to those at in-land stations. The relative humidity values showed a decreasing trend starting from January towards June and then an upward trend towards end of the year. Highest monthly mean RH values were found at Gizan and Al-Wejh and the lowest at Riyadh, Gassim and Qaisumah. The relative humidity trend at Al-Wejh was found to be the reverse of the rest of the stations. This may be due to its unique surrounding by the red sea coast.
- The empirical models developed for the prediction of monthly mean values of individual parameters were able to estimate the values with acceptable accuracy.

BIOGRAPHY

Shafiqur Rehman is Research Engineer-II (Associate Professor) at the Centre for Engineering Research, KFUPM, Saudi Arabia. He obtained BS and MS Degrees in Mechanical Engineering from Aligarh Muslim University, India and KFUPM in 1981 and 1985. His research interests include meteorology, environment, solar, wind and geothermal energy resources assessment and related power plant design. He has published and around 100 papers in journals and conferences. He was awarded *Distinguished Researchers Award* by the University in 2007. He completed 40 client funded projects. He is member of International Solar Energy Society, Solar Energy Society of India and Institution of Engineers India etc.

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