Chapter Five

CLIMATIC CONDITIONS

Climatic data indicates that the UAE is an arid country with a long hot summer and a short mild winter. The mean annual rainfall for the UAE is 110 millimeters (mm). Precipitation occurs mainly between November and March, with the maximum intensity during February and March. February is the rainiest month with an average of 37.9 mm while June is the driest month with an average of 0.3 mm. During wet years, there may be as many as nine rainy days during the winter months, although more than six days is not common. However, rainfall is extremely variable in space and time, depending on the climatic conditions, geographic location, local topography, and rainfall-driving mechanism. Generally, the rainfall increases in the north and east and decreases in the south and west. Evaporation is extremely high in the UAE and evaporation rate ranges from 5 to 15 mm/day (mm/d).

Distinction between the four seasons in the UAE is not clear. The winter is generally from December to February and may extend to mid March, while spring is from April to May and the summer is from June to September. The most settled weather conditions are in autumn, which extends from early October to late November. The summer season is long and dry, extending from April or May to October. The average temperature in July is 35 degree Celsius (°C). The winter season has a moderate temperature and a few rainy days. January is coolest month with an average temperature of 18°C and February is the rainiest month with an average rainfall of 42 millimeters (mm).

The UAE has 132 meteorological stations operated by the MEW, in addition to other stations in different airports (Rizk and Alsharhan, 2008). The Eastern Coast Region falls almost totally within the semi-arid belt of the UAE, which is characterized by mild climatic conditions reflected in the relatively dense cover of natural vegetation. The climatic records used in this study were obtained from a number of stations including: Sinnah, Al Ruheib, Ghayl, Asimah, Masafi, Siji, Sifuni, Farfar, Buthna, Munai and Howeliat (Figure 5.1).

The climatic data covering the last four decades (1976-2009) were used to investigate the temporal and spatial variations of key climatic parameters in the Eastern Coast Region in the UAE with a special emphases to the stations closed to the area of the study, including: solar radiation (mW h/cm^2), air temperature (C°), relative humidity (%),wind speed (km/h), evaporation and evapotranspiration (mm/d) and rainfall (mm/month).

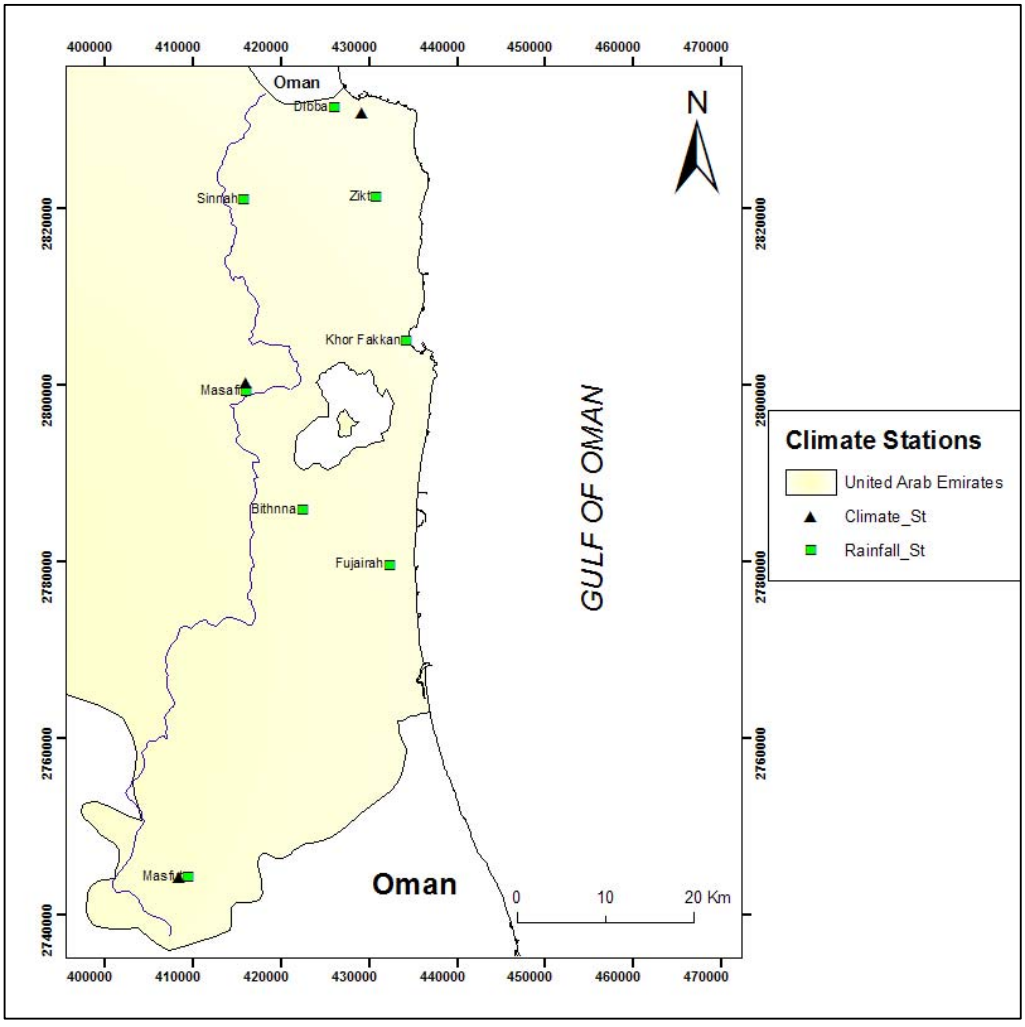


Figure 5.1 Location map of the meteorological stations used for investigation of climatic conditions in the Eastern Coast Region of the UAE (ALHOGARATY).

5.1 Solar Radiation

The UAE land receives the highest solar radiation during June 796 megawatt-hour per cubic centimeter (mW.h/cm^2) and the lowest in December (425 mW.h/cm^2), with a general increase from December towards June and a decrease from June to September (Alsharhan et al., 2001). The average annual hours of sunshine in the area of study is 10 hours per day (hr/d), with a maximum of 12 hr/d in May and a minimum of 9 hr/d in December. The high intensity of solar radiation in the study area enhances the water loss through evapotranspiration.

5.2 Air Temperature

The UAE is semi-permanently dominated by subtropical high pressure cells, from which the subsiding air results in heating and prolongs the hot weather conditions. This keeps the annual average of temperature high and makes the area as one of the hottest areas of the world. The air temperatures in the UAE are generally high throughout the year. The annual average temperature varies between 25 and 30°C with minimum winter temperatures as low as 4°C and maximum summer temperatures reaching up to 50°C.

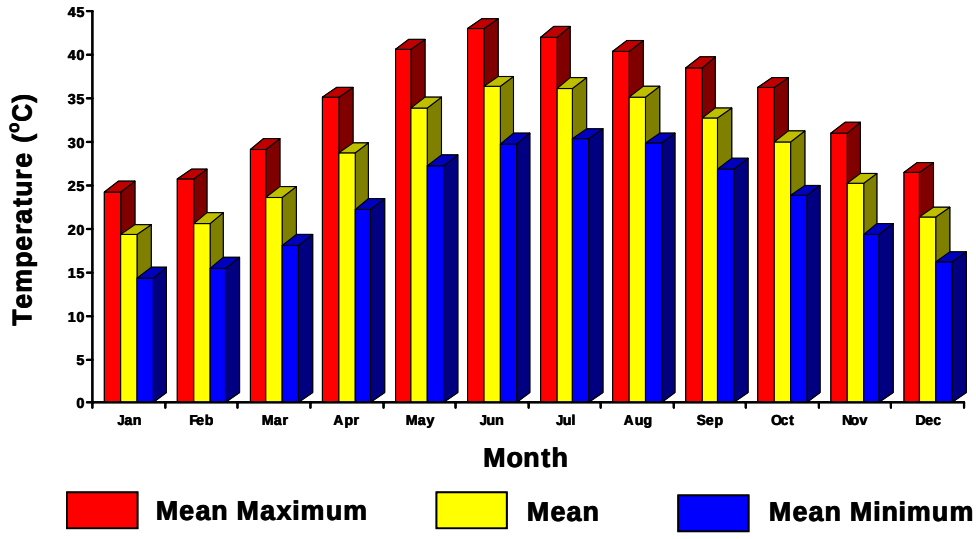


Figure 5.2 Mean maximum, mean and mean minimum monthly air temperatures (°C) in the Eastern Coast Region of the UAE during the period 1976-2006 (ALHOGARATY).

The eastern coastal zone in the UAE is one of the hottest areas of the world. In winter, the daily mean temperature varies between 18.2 and 22.5°C, while the minimum night temperature may reach less than 5°C over inland areas. During spring, temperature increases, where daily means of 26-28.4°C and extreme maximum of 44-47°C are common. In summer, temperature may exceed 45°C, but the daily mean usually ranges from 32 to 37°C. In autumn, temperature decreases, averaging between 24 and 29°C (Figure 5.2).

5.3 Relative Humidity

The relative humidity in the UAE reaches its maximum values during the December-March period and its minimum values during July and August. The general pattern of relative humidity throughout the year is related to the temperature cycle. The annual curve for relative humidity shows two maxima: in January, where it has an average of 58 percent (%) and in August where the average is about 49% (Figure 5.3). The relative humidity curve shows also two minima: in October, where it has an average of 45% and in May, where the average is 33%.

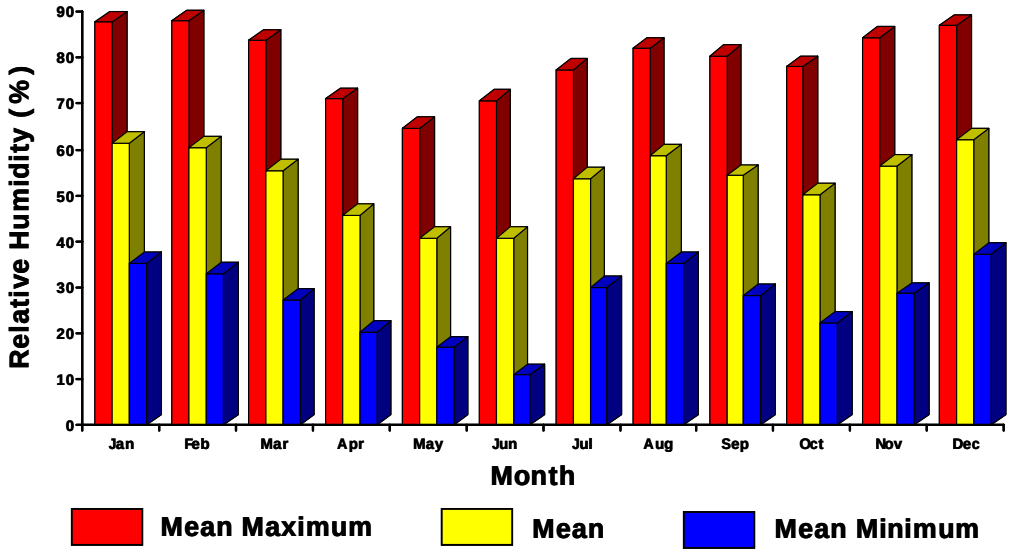
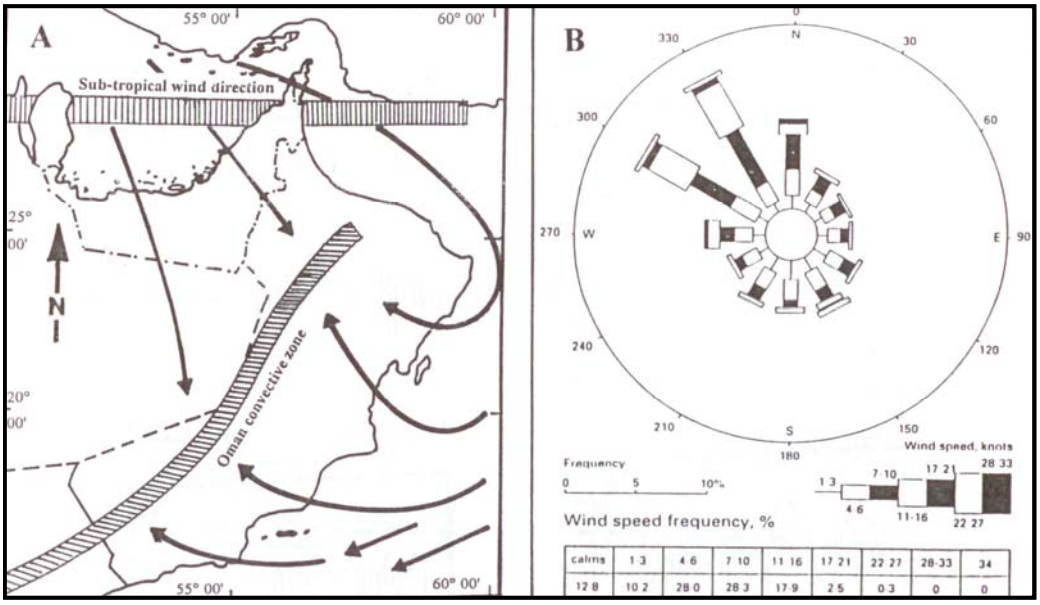


Figure 5.3 Mean maximum, mean and mean minimum monthly relative humidity (%) in the Eastern Coast Region of the UAE during the period 1976-2006 (ALHOGARATY).

The daily mean relative humidity may range from 50 to 70% while the annual mean relative humidity in the study area is about 54%, decreasing from 45% near Masafi in the west to 20% near Masfut in the southwest. In the study area, the annual mean relative humidity varies between 45% and 54%.

5.4 Wind Speed

The wind speed in the UAE tends to be light to moderate with an annual mean of 12.8 kilometers per hour (km/hr) or (6.9 knot), decreasing from the north-northwest to the south-southeast (Al Shamesi, 1993). Two wind systems affect the UAE (Figure 5.4). The first system is represented by winter depressions coming from the north and northwest, descending towards the Arabian Gulf and causing the cold wind current known as "Shamal Winds".



calms	1-3	4-6	7-10	11-16	17-21	22-27	28-33	34
12.8	10.2	28.0	28.3	17.9	2.5	0.3	0	0

Figure 5.4 The two major wind systems affecting the UAE (A), and the azimuth frequency diagram of wind speed and direction (B) form (Al Shamesi, 1993).

These winds remain the whole year, but their speed increase between March and August reaching 41.0 km/hr (22.2 knot). The Shamal winds mainly affect the western coast of the UAE (Alsharhan et al., 2001). The second system is the "Monsoon

Winds" originating on Rub' al Khali Desert and affect the study area (Figure 5.5). The speed of these winds is high along the Gulf of Oman coast, over the Northern Oman Mountains and in desert areas close to the coast. The speed of Monsoon Winds decreases during autumn (September and October) and towards inland, averaging 4.0 km/hr (2.2 knot).

The wind pattern is generally dominated by southeasterly overnight land-sea breeze circulating at 7.3 km/hr (4 knot) to 14.6 km/hr (8 knot). With the approach of an upper trough, freshening south-easterly winds sometimes cause sandstorms. The wind reaches its maximum speed 41 km/hr (22.6 knot) in the summer between March and August. The fall season (September and October) has the lowest records of wind speed 2 - 6 km/hr (1.1 - 3.3 knot). In spring, the wind regime is mainly dominated by the land-sea breeze. In summer (June-September), the wind regime remains influenced by the land-sea breeze circulation. However, during the first half of June, fresh northwesterly winds may occasionally develop to relieve the very hot and humid weather conditions.

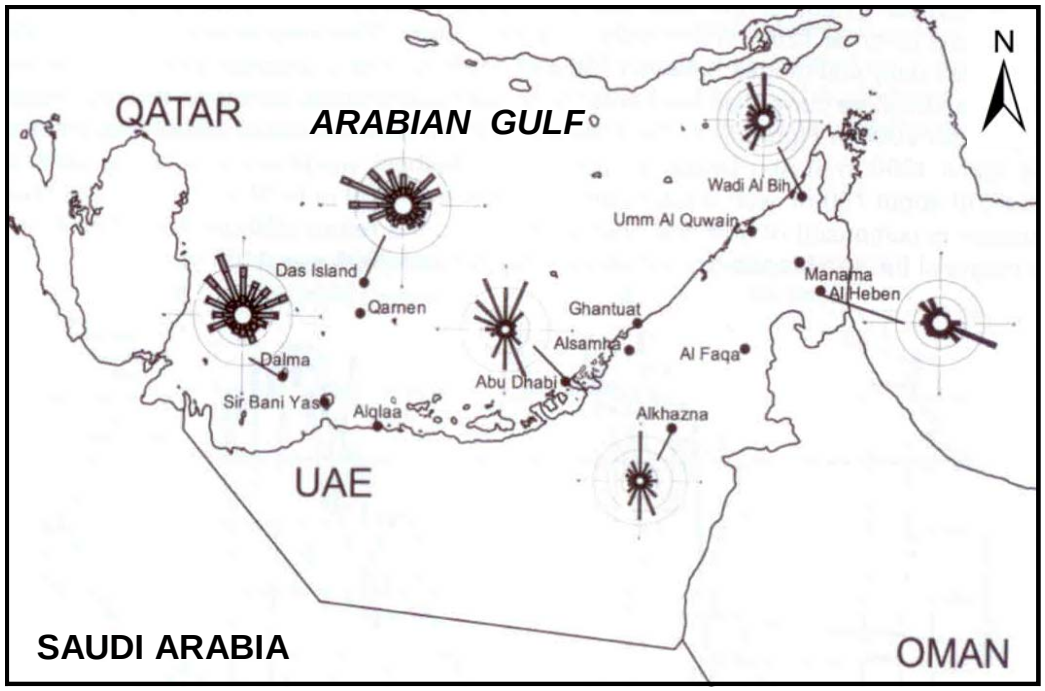


Figure 5.5 The wind systems affecting the UAE (Al Shamesi, 1993).

The annual values of wind speed within the study area show two maxima (Figure 5.6): in February where mean maximum wind speed is 10.92 km/hr (5.90 knot) and in August where the mean is 11.05 km/hr (5.97 knot). The wind speed curves also show two minima: in May, where it has a mean of 3.55 km/hr (1.92 knots) and in October, where the mean is 3.35 km/hr (1.81 knots).

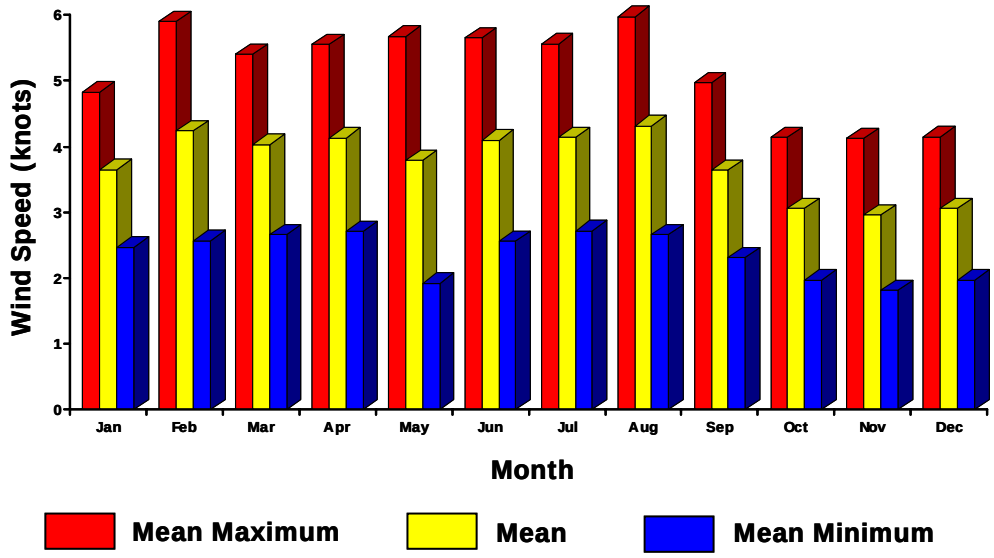


Figure 5.6 Mean maximum, mean and mean minimum monthly wind speed (Knots) in the Eastern Coast Region of the UAE during the period 1976-2006 (ALHOGARATY).

5.5 Evaporation and Evapotranspiration

The natural evaporation is extremely high in the study area particularly during summer months May, June and July during which evaporation exceeds 20 mm/d. June has the highest evaporation values of 22.4 mm/d mean maximum, 16.8 mm/d mean and 11.2 mm/d mean minimum (Figure 5.7 a-d). January has the lowest evaporation rates of 6.4 mm/d mean maximum, 4.5 mm/d mean and 2.6 mm/d mean minimum (Figure 5.8).

Evapotranspiration in the UAE is measured daily in some places, using the American Class-A Pan. The corrected total average annual measurements are adjusted to set an

estimate for the reference crop evapotranspiration. In the littoral zone the yearly average total crop evapotranspiration varies from 1,300 to 1,620 mm (IWACO, 1986).

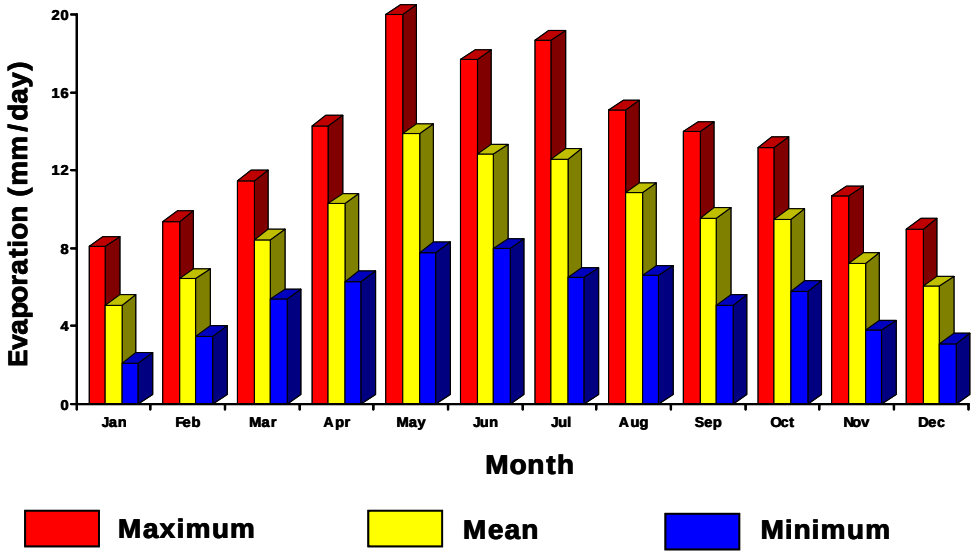


Figure 5.7a Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Dibba meteorological station, Eastern Coast Region of the UAE during the period 1967-2006 (ALHOGARATY).

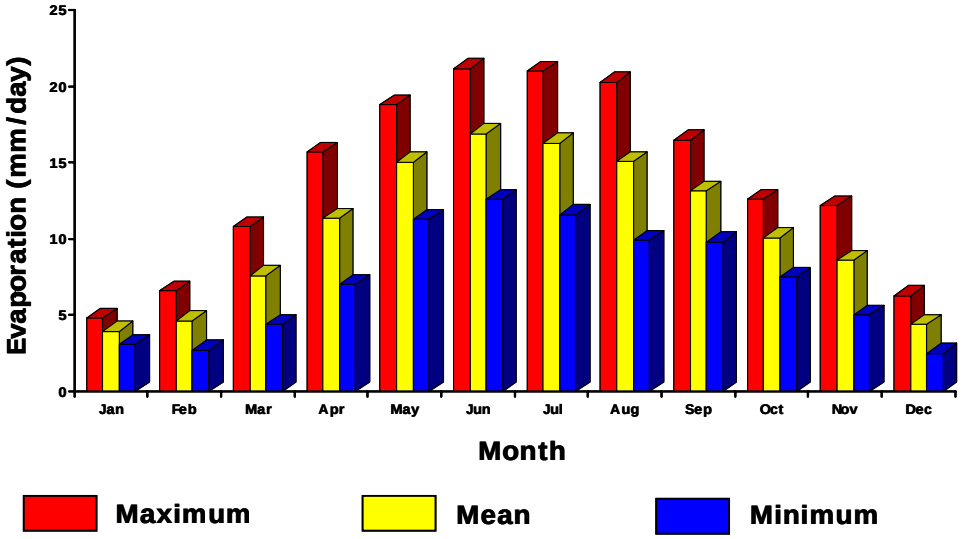


Figure 5.7b Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Masafi meteorological station, Eastern Coast Region of the UAE during the period 1967-2006 (ALHOGARATY).

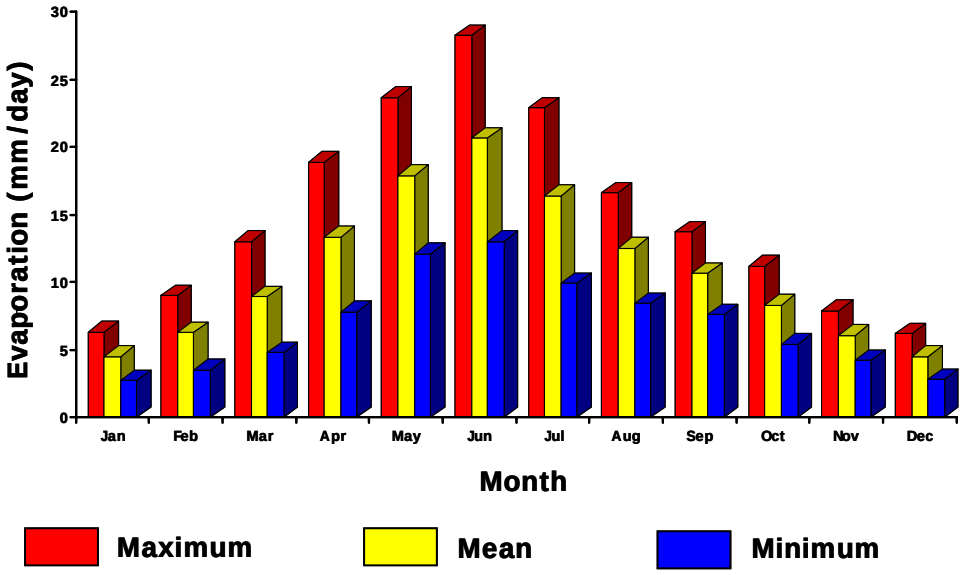


Figure 5.7c Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Masfut meteorological station, Eastern Coast Region of the UAE during the period 1967-2006 (ALHOGARATY).

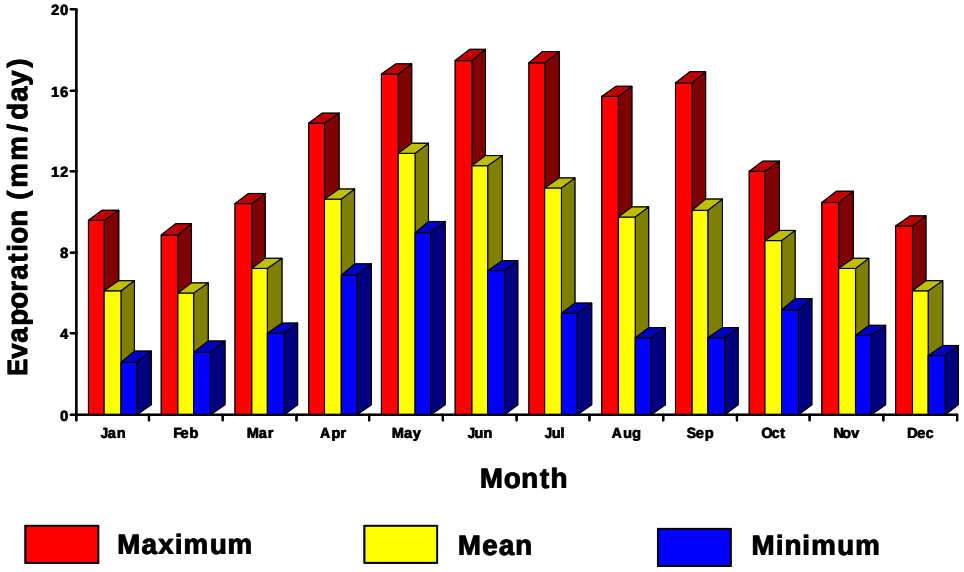


Figure 5.7d Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Kalba meteorological station, Eastern Coast Region of the UAE during the period 1967-2006 (ALHOGARATY).

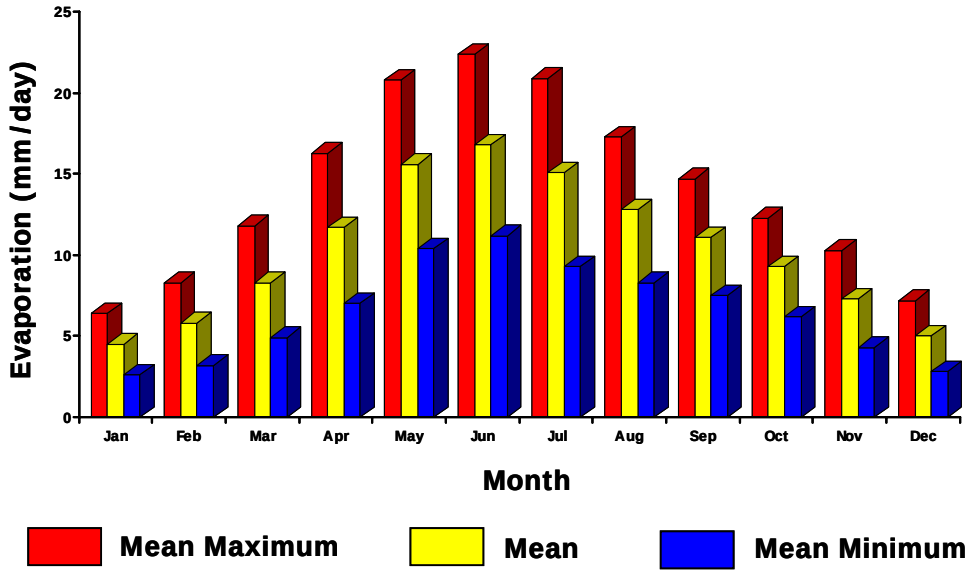


Figure 5.8 Mean maximum, mean and mean minimum monthly evaporation (mm/d) in the Eastern Coast Region of the UAE during the period 1976-2006 (ALHOGARATY).

The reference crop evapotranspiration is also calculated with climatological data (Penman Method). The crop evapotranspiration is obtained by multiplying the reference crop evapotranspiration with the crop coefficient. The crop coefficients for the Northern Emirates were calculated by FAO (1970).

5.6 Rainfall

Most of the rain in the UAE falls between November and March with the highest intensity during February and March, where 60% of the annual rain falls. On the other hand, about 90% of annual rain in the UAE falls during February, which is the rainiest month with an average of 38 mm. In contrast, June is the direst month with an average of 0.3 mm. The average annual rainfall in the UAE is 111 millimeters per year (mm/yr), varying greatly in space and time depending on climatic condition, geographic location, topography and rainfall-driving mechanism (Rizk et al., 1997). The eastern coastal area has an average annual rainfall of 120 mm/yr at the Fujairah station (Figure 5.9). This rainfall is strongly influenced by the mountain range. In

spring time, convectional rainfall takes place occasionally and results from the temperature differences between the land and the sea.

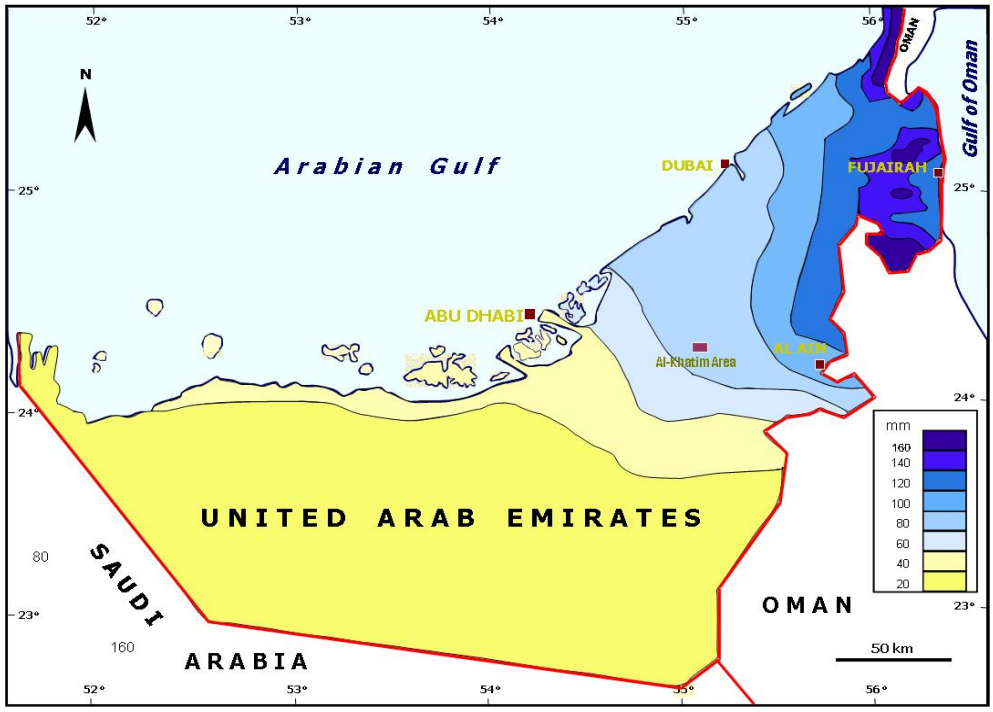


Figure 5.9 Map showing the mean annual rainfall in the UAE in mm/year (UAE National Atlas, 1993).

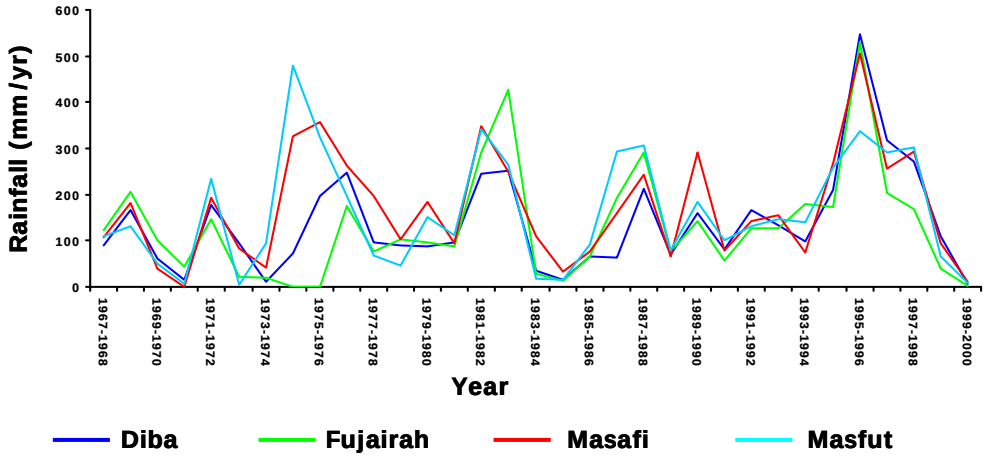


Figure 5.10 Records of average annual rainfall (mm) in four meteorological stations along the eastern coast of the UAE for the period 1967-2000 (Rizk and Alsharhan, 2008).

The wet periods of 300 to 600 mm/yr alternate, within three to five years, with dry periods, where the rainfall is reduced to less than 15 mm as for example Dibba during 1973-1974 and 1984-1985 and Fujairah and Kalba during 1984-1985 (Figure 5.10). There is a rapid increase in the average annual rainfall from 120 mm along the coast to 150 mm inland.

Rainfall exhibits wide spatial and variations within the study area as illustrated in Figures 5.9 to 5.12. Figure 5.9 shows that the average annual rainfall in the study area is the highest in the UAE reaching more than 4 to 5 time rainfall in the western region. Figure 5.10 illustrates the wet and dry periods and indicates the variation within each of both periods. For example, the wet seasons 1971-1972, 1987-1988 and 1989-1990 had average annual rainfall between 200 and 300 mm, while the periods 1975-1976, 1982-1983 and 1996-1996 had average annual rainfall of 500 to 600 mm. The dry periods 1970-1971, 1973-1974 and 1984-1985 had average annual rainfall less than 20 mm, while the dry periods 1978-1979, 1988-1989 and 1993-1994 had average annual rainfall less than 50 mm. Figure 5.11 shows that annual rainfall within the Eastern Coast Region varies between 125 mm near the Gulf of Oman coast and 160 mm further inland. The areas receiving the lowest annual rains are Dibba, Khor Fakkan and Fujairah, from which rainfall increases towards the water divide line (Figure 5.11). The southwestern part of the study area, near Masfut, receives that highest annual rainfall.

In desert areas, the annual rainfall varies remarkably around its mean. The rainfall data obtained from Dibba, Masafi and Masfut meteorological stations were presented in Figure 5.12. The rainfall records indicated that annual rains during 1975-1976, 1982-1983 and 1995-1996 greatly exceeded their annual averages. Predicting above-average rainstorms allows preparation for rainwater harvesting and artificial recharge of depleting aquifer system.

In June 2007, the UAE and Oman has experienced an unusual weather condition related to the passage of the Cyclone Gonu originated on the Indian Ocean and moved north through the Gulf of Oman and Hormuz strait, where 25% of the world oil

shipment crosses. The storm represented the most violent tropical storm to hit the Gulf region in six decades.

On Tuesday June 5, the Cyclone Gonu peaked as a maximum-force Category Five hurricane, faded to a Category One hurricane on Wednesday June 6 and became an ordinary tropical storm on Thursday June 7th, 2007. The Cyclone lashed the eastern and central coastal areas in Oman with driving sheets of rain and heavy winds after midnight of Tuesday June 5th, 2007. Wind speeds were roughly 14 km/hr (7.7 knot) near the coast and 185 km/hr (102 knot) to 204 km/hr (112 knot) at and around the storm center. The Cyclone thunderstorms, gusting winds, combined with 12-meters high tidal waves killed 54 people in Oman and Iran, evacuated hundreds of thousands of people in coastal cities in Oman, UAE and Iran, and caused considerable damage in the eastern and central coastal areas in Oman. Further north, the UAE port of Fujairah (Figure 5.1), one of the largest ship refueling centers in the world, closed on Wednesday June 6th, 2007 due to this unusual weather conditions.

Rainfall is the most important components of climate. Therefore, it was studied in details in order to have a better understanding of the rainfall pattern, density and seasonal variation in the Eastern Coast Region of the UAE, and to make use of results reached for identifying the potential for groundwater recharge and predict the frequency and intensity flash flood events.

The UAE in general has a typical desert climate where years may pass with very little or no rain followed by few short-lived storms which may bring up to 65 mm of rain. Hence, infrequent rainfall gives rise to an annual average of 70 to 160 mm covering a period of 9 to 19 days of the whole year.

As indicated earlier, 80% of the annual rainfall occurs during winter (December-February period). In spring (April-May), rainfall is infrequent and is usually associated with isolated thunderstorms. In summer, rain is rare and occurs as a result of the afternoon thunderstorm over the eastern high lands or due to isolated thunderstorm accompanying the rarely occurring sea breeze fronts. On very few occasions the Inter-tropical convergence zone (ITCZ) may move northwards and give

some rainfall over the area (Figure 5.4). The most settled weather conditions with very little rain prevail in autumn (October-November), especially in October.

The rainfall records of five meteorological stations for the period 1979-2006 are plotted in Figure 5.11. Temporal variations in rainfall at these meteorological stations are illustrated in Figures 5.10, 5.12, 5.13 and 5.14. Inspections of these figures show that the mean annual rainfall (mm) within the study area decreases from the southeast (167 mm at Khor Fakkan) to northeast (136 mm at Zikt), rainfall exhibits noticeable variations in space and time, most of the rain falls during the February-March period, and cycles of four to five years with above average rainfall maxima are clearly illustrated.

The rainfall in the study area varies continuously around its mean. This phenomenon does not occur randomly but rather in, more or less, well-defined cycles (Figures 5.13 and 5.15). Long records are required to determine the median value of rainfall and the frequency at which certain amounts of rainfall can be expected (Figure 5.15). The return period (recurrence) of each event in a long series of observations can be predicted with the use of the following equation (Rahn, 1986):

$T = (n + l) / m$

Where T = the recurrence of the m event,

m = the rank of the observation, and

n = the total number of observations in the record series.

The rainfall recurrence of the study area, as illustrated in Figure 5.15 and listed in Tables 5.1 and 5.2, is based on rainfall records of Dibba meteorological station during the 1979-2006 period.

Figure 5.13 shows that the median rainfall value of Dibba station during the period 1979-2006 is 98 mm/year. Above median rainfall, flood peaks are expected and below it drought seasons are predicted.

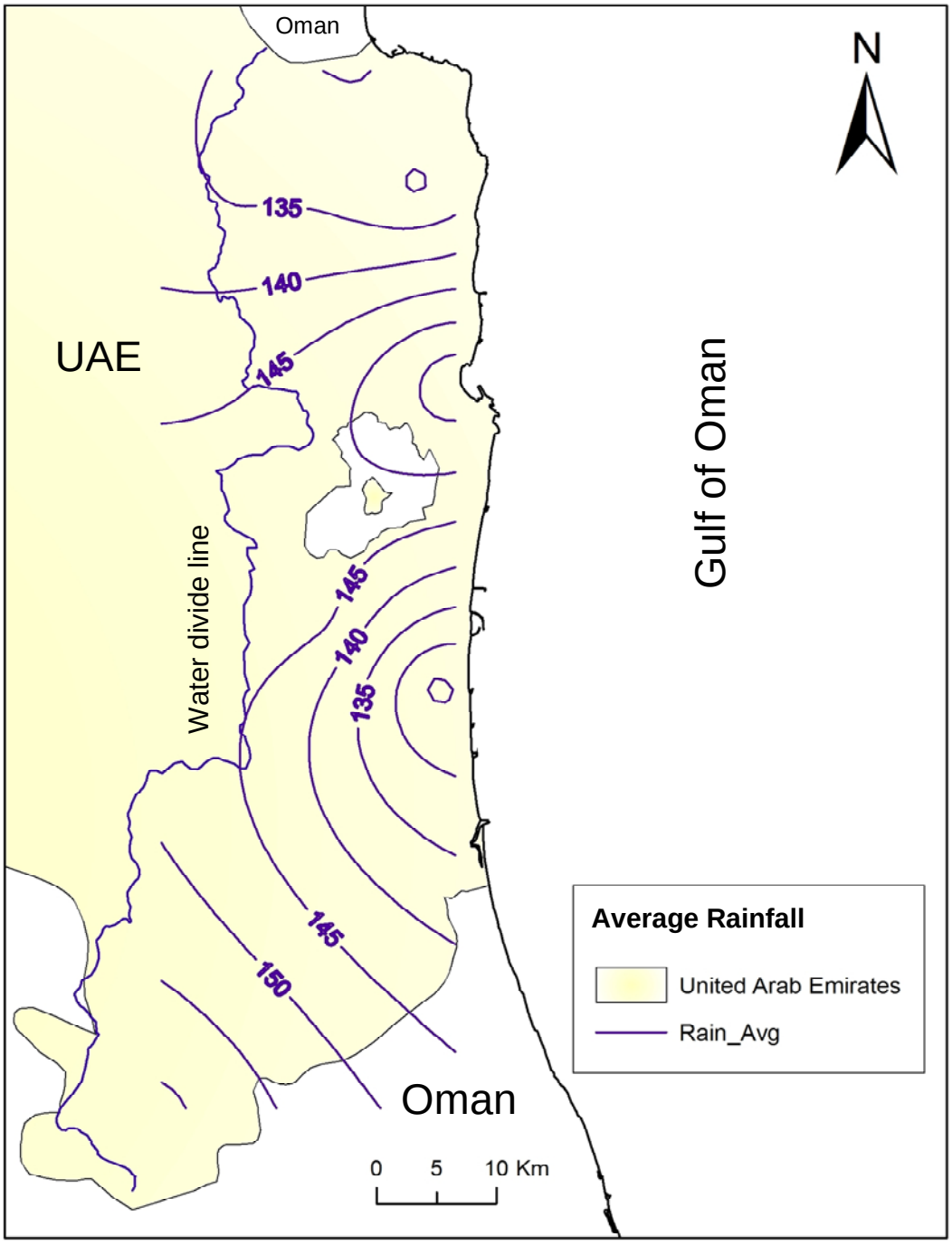


Figure 5.11 Isohytal map (mm/year) of the Eastern Coast Region of the UAE for the period 1976-2008 (ALHOGARATY).

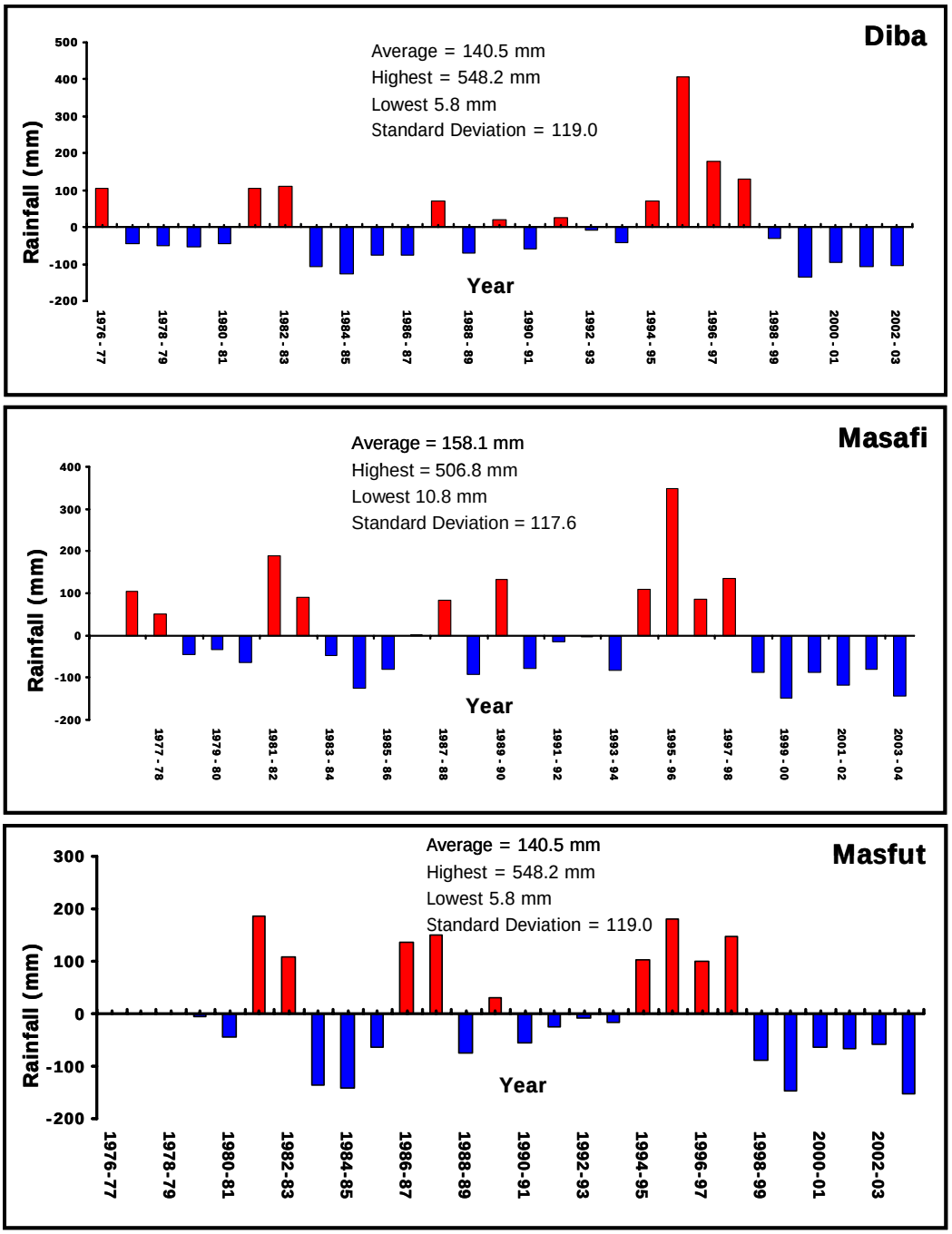


Figure 5.12 Positive and negative deviations from the average annual rainfall (mm) in three major meteorological in the Eastern Coast Region of the UAE for the period 1967-2003 (Rizk and Alsharhan, 2008).

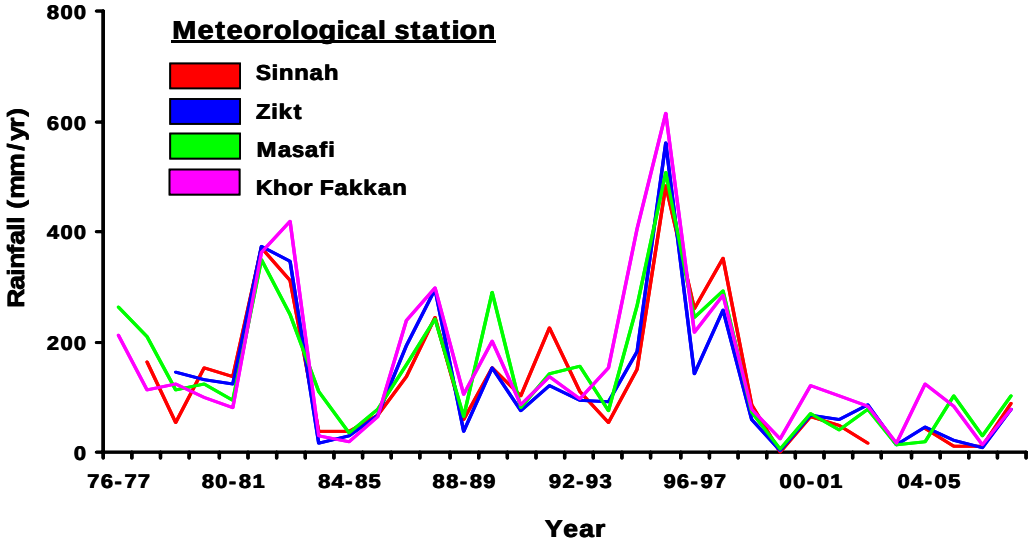


Figure 5.13 Records of maximum, mean and minimum annual rainfall (mm) in the Eastern Coast Region of the UAE for the period 1976-2006 (ALHOGARATY).

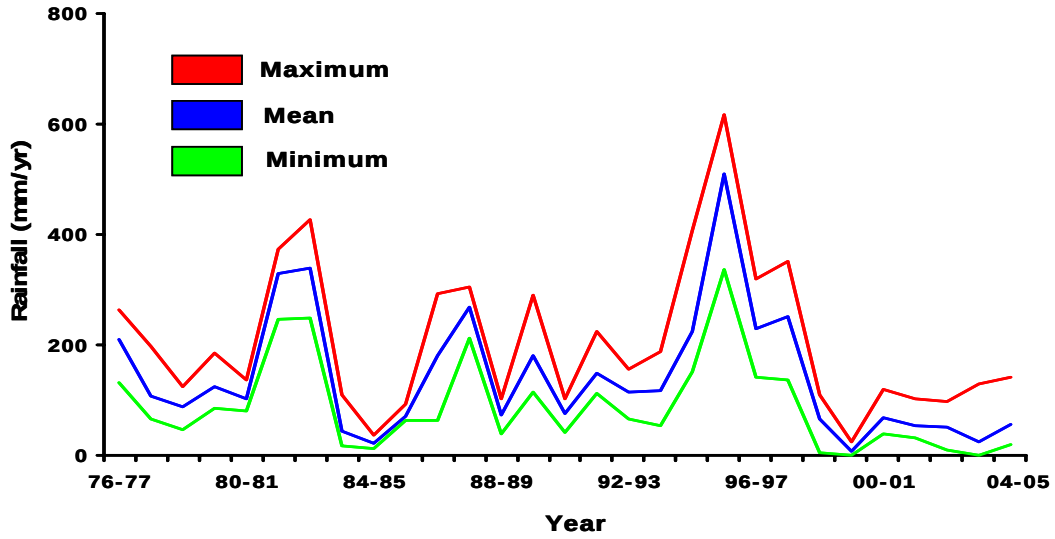


Figure 5.14 Records of maximum, mean and minimum annual rainfall (mm) in the Eastern Coast Region of the UAE for the period 1976-2006 (ALHOGARATY).

A plot of the flood and rainfall for Wurayah basin during the 1981-1997 gave a straight line that intersects the rainfall axis at a point (rainfall = 20 mm/month)

(Figure 5.16, Table 5.3). Below this point (rainfall < 20 mm/month), no flood from rainfall is expected, and above it (rainfall > 20 mm/month) flash flood from rain is predicted. A comparison between Figure 5.15 and Figure 5.16 shows that the annual rainfall which can contribute to flood occurs every four to five years. This flood is more likely to occur during cycles with the same time interval and above average rainfall.

Table 5.1 The average monthly values of rainfall (mm) at Dibba meteorological station for the period 1979-2006 (Hydrology Year Book, 2005 and ALHOGARATY).

Year	Month												Total (mm)
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
79-80	0.4	0	54.2	4	19.2	8.8	0	0	0	0	0	0	86.6
80-81	0	1	0	0.2	0.2	23.2	38.8	33	0	0	0	0	96.4
81-82	0	0	0	0.6	97.6	147.8	0.2	0	0	0	0	0	246.2
82-83	0	24	31.8	9.8	80.8	58.4	35.4	0	0	0	10.8	0	251
83-84	0	0	3.4	0.8	0	30.2	0.2	0	0	0	0	0	34.6
84-85	0	0	9.4	3.6	0	1.4	0.2	0	0	0	0	0.2	14.8
85-86	0	2.2	1.4	12.2	29.2	20.04	0.6	0.2	0	0	0	0.2	66.04
86-87	0	0	4	0	0.8	34.6	6.6	9.2	8.2	0	0	0	63.4
87-88	0	0.6	7.6	0.8	129.8	5	25.4	0.6	0	42.2	0	0	212
88-89	0	17.6	0	0	18.6	29.2	4.4	0	0	0	0	0.2	70
98-90	0	1.4	45	14.2	82.8	3.4	13.8	0	0	0	0	0	160.6
90-91	0	0	1.2	21.6	11	47.4	0.4	0	0.2	0	0	0.2	82
91-92	0	1.4	29.2	36.6	58.4	2.4	33.6	0.2	0	0	4.4	0	166.2
92-93	0	1.4	36.6	10	83.4	2	0.2	0	0	0	0	0	133.6
93-94	0	0	52.4	35.4	2.2	7.2	0	0	0	0	0.4	0	97.6
94-95	2	2	0	0	27	121.4	2.2	0	0	55.6	0	0.2	210.4
95-96	0.2	7.2	69.8	74.6	0	75	75.6	0.2	15.4	0	0	0	318
96-97	0.2	7.2	69.8	74.6	0	75	75.6	0.2	15.4	0	0	0	318
97-98	86.4	47.2	10.3	27	36.2	63.2	0.6	0.2	0	0	0	0	271.1
98-99	0	0	46	9	40	13.4	0	0.4	0.4	0	0	0	109.2
99-00	0.0	4.8	0.2	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	5.8
00-01	8.6	17.2	4.8	8.2	0.2	5.8	0.4	0.2	0.0	0.0	0.0	0.0	45.4
01-02	0.2	13.4	0.2	1.6	0	19.2	0	0	0	0	0	0	34.6
02-03	0.4	31.8	3	2.4	0	0	0	0	0	0	0	0	37.6
03-04	0	0	0	0	0	0	0	0	0	0	0	0	0
04-05	0	6.3	18.8	27.4	49.4	1.6	0	37.2	0	0	0	0	140.7
05-06	0	5	21.4	0	0	0	0	0	0	0.8	4.4	101	132.6

Table 5.2 Ranking of annual rainfall (mm) at Dibba meteorological station during the period 1979-2006 (ALHOGARATY).

Rank	Wet year	Dry year	Recurrence	Rank	Wet year	Dry year	Recurrence
	Rainfall (mm/yr)				Rainfall (mm/yr)		
1	0	318	28.0	8	63	166	3.5
2	6	318	14.0	9	66	161	3.1
3	15	271	9.3	10	70	141	2.8
4	35	251	7.0	11	82	134	2.5
5	35	246	5.6	12	87	133	2.3
6	38	212	4.7	13	96	109	2.2
7	45	210	4.0	14	98	98	2.0

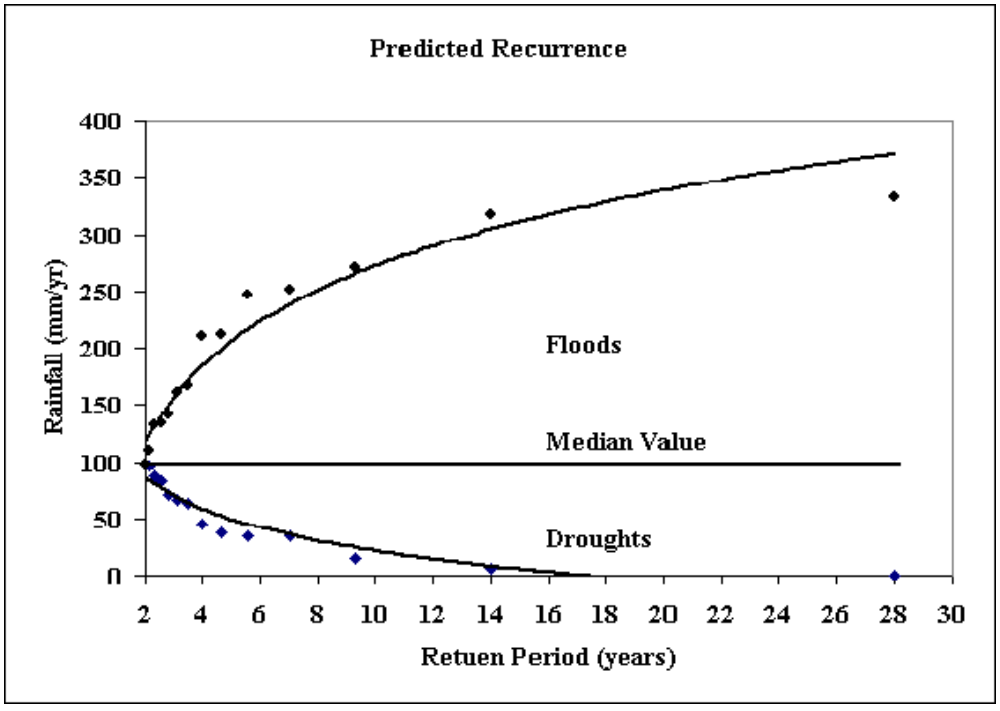


Figure 5.15 Predicted recurrence of rainfall maxima and minima of the study are for the period 1976-2006 (ALHOGARATY).

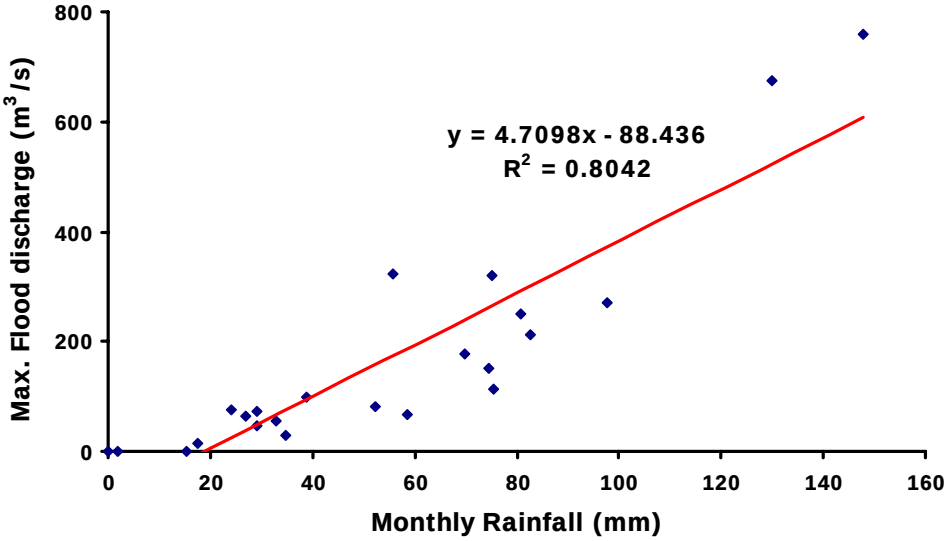


Figure 5.16 Rainfall - runoff relationship for Wadi Wurayah basin in the Eastern Coast Region of the UAE (ALHOGARATY).

Table 5.3 Monthly rainfall (mm) and maximum flood discharge (m^3/s) for Wadi Wurayah basin during the period 1981-1990 (Hydrology Year Book, 2005).

Date	Mon. Rainfall (mm)	Max. Discharge (m3/s)	Date	Mon. Rainfall (mm)	Max. Discharge (m3/s)
30/04/1981	38.8	98.68	24/11/1991	29.2	47.61
02/05/1981	33	55.21	03/02/1992	58.4	66.71
14/02/1982	97.6	270	25/12/1993	52.4	80.01
28/03/1982	147.8	760	31/10/1994	2	0
01/11/1982	24	76.81	24/02/1995	27	63.33
11/02/1983	80.8	249.04	23/07/1995	55.6	323
30/03/1987	34.6	28.75	11/12/1995	69.8	178.9
17/02/1988	129.8	673.74	10/03/1996	75	319
09/12/1988	17.6	15.41	17/06/1996	15.4	47.61
17/03/1989	29.2	73.48	25/01/1997	74.6	151.2
11/02/1990	82.8	213	22/04/1997	75.6	114

The previously mentioned information about the climate of the Eastern Coast Region of the UAE and off course the climate of the study area indicate that the climate of Wadi Wurayah and its hinterlands characterized of a hot hyper-arid mountain desert environment, where the temperatures are highest during the period of April to October and are coolest from November to March.

According to Boer (1997) the catchment lies in a sub-humid bio-climatic zone and in the area which is the wettest in the U.A.E is not surprising therefore that the perennial waterfalls are unique to Wadi Wurayah protected area. Annual precipitation is however highly variable, as with the rest of the UAE. The majority of rainfall events occur during winter months from cloud bands that migrate from the eastern coast of Africa, or from the frontal systems that originate in the Mediterranean when Siberian high pressure shrinks north-eastwards by late winter, or may be due to southward advance of active westerly troughs over southwestern part of the Arabian Peninsula. Rainfall can occur during summer months with clouds drifting from the Indian monsoon over the Arabian Sea, afternoon convective clouds due to orographic effects, rare cases of the Inter Tropical Convergence Zone shifting northward over UAE and causing overcast weather and thunderstorm activity or the temperature contrast between land and sea (at the hottest time of the year) which may be large enough to produce what's known as a sea breeze front that may give traces of rainfall along coast.

Interestingly, the data for the closest climate stations surrounding the study area shows that the rainfall might be closely linked with the Pacific Decadal Oscillation, or ENSO EL Nino and La Nina events. For all El Nino years the annual rainfall is above average for that year including 1995 which is the strongest recorded El Nino year and also the highest rainfall year reached in Khor Fakkan. Given the proven cyclic nature of the pattern of above average annual rainfall it is predicted that the next high rainfall years will be 2006-2009.