wet bulb temperature of 21.4 ⁰C, the annual average maximum value of 22.3⁰C, the annual average minimum value of 20.5 ⁰C, the maximum of monthly average value for years in succession of 26.9 ⁰C with occurring in June and the minimum of 13.5 ⁰C in January is observed. From Figure 4, it is evident that Temperature of Arabian Coast at Karachi is increasing with time.

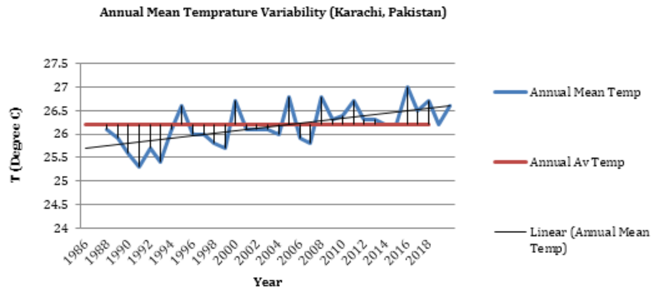

Figure 4: Annual Mean Temperature Variability of Karachi Coast

The extreme maximum temperature of Karachi airport is 46 ⁰C. The extreme minimum temperature is 1.3 ⁰C. Extreme temperature in Karachi urban area shows positive trend (Hussain et al., 2010). Arabian sea water temperature data sets near Karachi coast reveal increasing trend (Hussain et al., 2012).

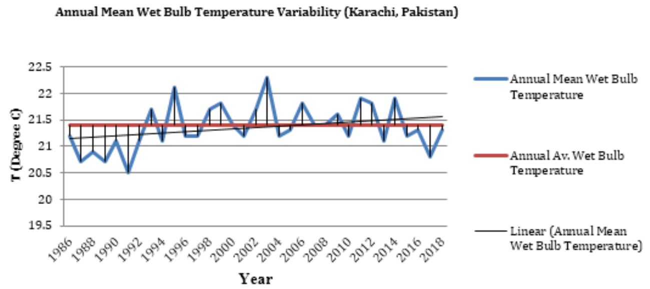

Figure 5: Annual Mean Wet Bulb Temperature Variability

3.1.3 Relative humidity

Relative humidity (RH) changes when temperatures change. Because warm air can hold more water vapor than cool air, relative humidity falls when the temperature rises if no moisture is added to the air (Skilling, 2009). For the representative meteorological station, the annual average relative humidity of 65%; the minimum value of annual average relative humidity of 60% in 2012 and the maximum of 70% in 1990 and 1995; the minimum of monthly average relative humidity of 52% in January and the maximum of 77% in August, the extreme minimum relative humidity of 1% (appearing on March 2003 and March 2012) is observed. The decline trend of relative humidity, as shown in Figure 6, also endorse Figure 5 i.e., increase in Temperature.

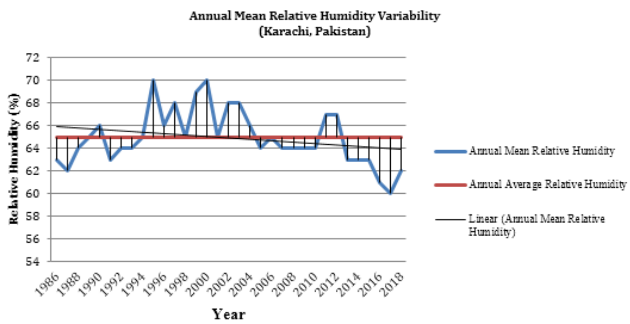

Figure 6: Annual Mean Relative Humidity Variability

3.1.4 Vapor pressure and dew point temperature

Dew point temperature has usually been the most frequently used humidity measure. If there is a change in dew point temperature, it will result in a corresponding variation in relative humidity (Mortuza et al., 2014). At Karachi South met station and Karachi Airport met station, the observation of vapor pressure (VP) is not available. The Tetens empirical formula is used to calculate the saturated vapor pressure of water expressed in E, i.e., E=6.1078exp[17.2693882 (T-273.16) / (T-35.86)]. Then, according to the definition of relative humidity, the calculated value of vapor pressure can be obtained by E multiplied by the relative humidity, which is shown in Fig. 7, as annual mean vapor pressure variability. When there is no dew point temperature data, through the above formula, the temperature which the vapor pressure is taken as saturation vapor pressure is the dew point temperature, i.e., Tv=237.3*ln (e/6.1078) /[17.2693882-ln (e/6.1078)] and annual mean variability is shown in Fig. 8. For the representative meteorological station, the annual average water vapor pressure of 22.8hpa; the annual average minimum water vapor pressure of 21.3hpa in 2012, the annual average maximum of 24.5hpa in 1998; the minimum of monthly average vapor pressure for years in succession of 11.4hpa in January, the maximum of 32.5hpa in June is observed.

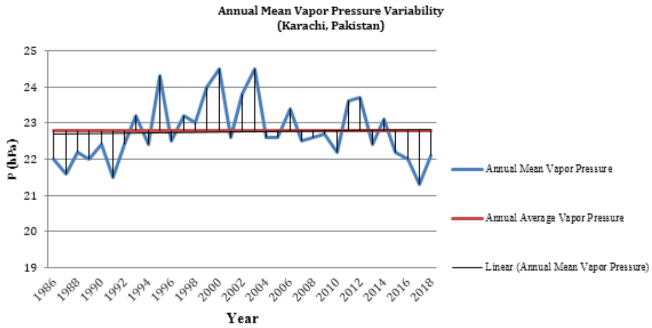

Figure 7: Annual Mean Vapor Pressure Variability

For the representative meteorological station, the annual average dew point temperature of 17.7 ⁰C; the annual average minimum value of 16.7 ⁰C in 1986, the annual average maximum value of 19.5 ⁰C in 1998; the minimum of monthly average dew point temperature of 7.6 ⁰Cin January, the maximum of 24.7⁰C in June is observed.

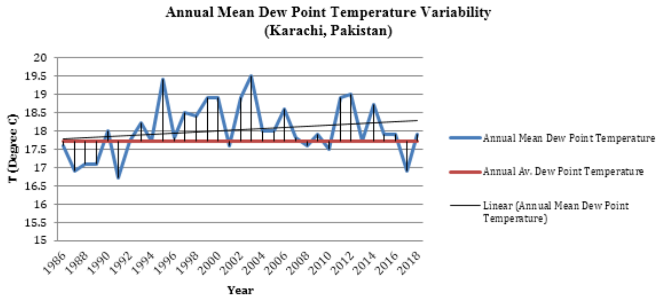

Figure 8: Annual Mean Dew Point Temperature Variability

3.1.5 Precipitation

For the representative meteorological station, the annual average precipitation of 163.8mm, the maximum annual precipitation of 487.0mm appearing in 1994, the minimum annual precipitation of 2.5mm appearing in 1987; the maximum daily precipitation of 203mm on July 28, 2009; the number of annual average days of rainfall of 12.3 days, the maximum continuous precipitation for years in succession of 213mm with the duration of 1 days appearing on July 28, 2009 is observed and annual mean precipitation variability along with annual rainy days variability is shown in Figure 9 and 10 respectively.

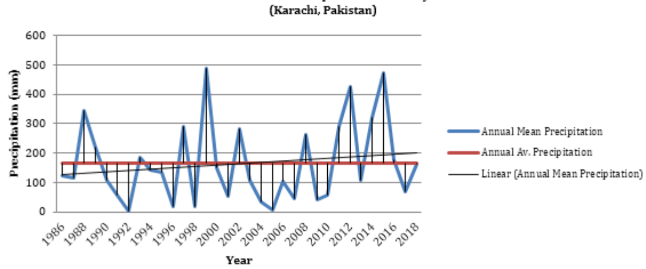

Figure 9: Annual Mean Precipitation Variability

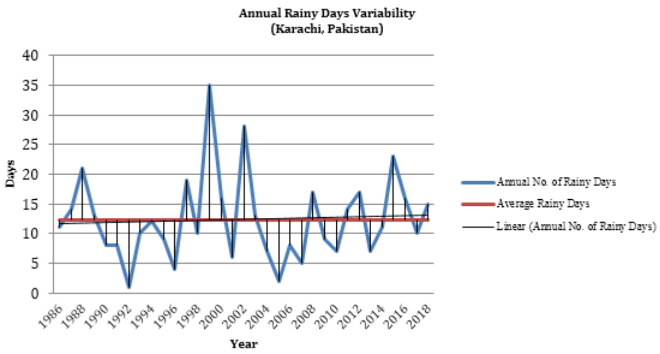

Figure 10: Annual Rainy Days Variability

3.1.6 *Wind direction and wind speed*

In general, wind regimes are dynamic in nature. So, they are sensitive to natural climate variability as well as anthropogenic-driven climate change, and reveal variation of wind velocity in a region (Dryden, 2008; Yim et al., 2009). For the representative meteorological station, the annual average wind speed of 4.7m/s; the extreme maximum wind speed of 29.1m/s (appearing on May 2, 1997) is observed and annual wind speed variability is shown in Figure 11. The prevailing wind direction of SW with the frequency of 38%, the secondary prevailing wind direction of W with the frequency of 19.3% , the prevailing wind direction of NE in winter and SW in other three seasons is observed.

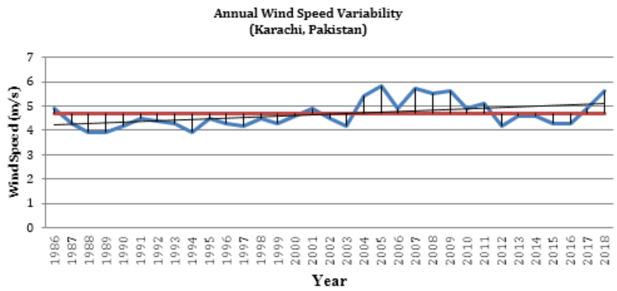

Figure 11: Annual Wind Speed Variability

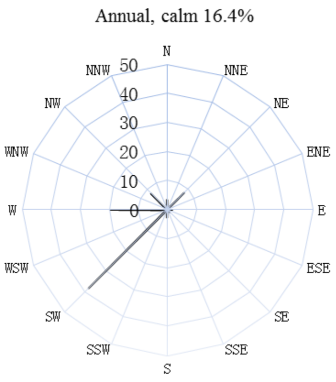

Figure 12: Observed Annual Wind Rose

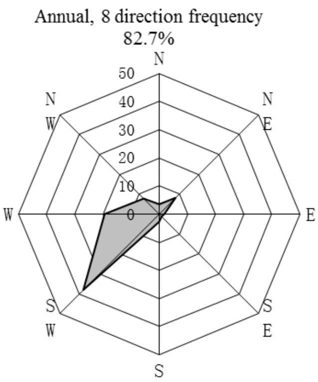

Figure 13: Rose Diagram of 8 Wind Direction

The precision of wind direction observation at the representative station is low with the resolution of 10 degrees, and the observed annual wind rose is shown Figure 12. In order to more intuitively understand the frequency of wind direction, the rose diagram of 8 wind direction is adopted, as shown in Figure 13.

3.2 Extreme Meteorology

The observed data for disastrous weather phenomenon during the period from 1986 to 2017 at the Karachi Airport and Karachi South is described in this section. Analysis shows that there exists a positive trend in the frequency of Arabian sea tropical cyclones in the past 120 years (Hussain et al., 2011). According to "Country Report of Pakistan (2017-2018)", latest extremely severe Cyclonic Storm "Mekunu" in Arabian Sea is observed during 21-27 May, 2018.

3.2.1 Sandstorm

There were 20 times of sandstorm occurrences at the Karachi Airport with the annual average occurrences of 0.6 times; there were 43 times sandstorms observed at the Karachi South meteorological station with the average of 1.3 times in a year. Days of monthly mean sandstorm occurrence over the years i.e., from 1986 to 2017 is shown in Table 3.

Table 3: Days of Monthly Mean Sandstorm Occurrence

Station	1	2	3	4	5	6	7	8	9	10	11	12	Ann.
Karachi Airport	0	2	5	2	1	0	1	1	0	1	3	4	20
Karachi South	5	0	2	4	2	5	1	1	0	2	18	3	43

3.2.2 Hail

Hail is a strong convective weather phenomena. During a day, the hail mostly appears between the afternoon and midnight. The hail is not a major disaster weather in this area, with only occurrences of 2 times at Karachi Airport station during the statistical period , i.e., once in February, 2000 and once in February, 2005. In last 32 years, the hail did not appear at the Karachi South station.

3.2.3 Thunderstorm

The characteristics of occurrence and variation of thunderstorm for two stations are the same, and the annual variation is shown as a single peak shape. Thunderstorms appeared mostly in Jun, Jul, Aug and Sep, and do not appeared in November.

Table 4: Total Days of Monthly and Annual Mean Thunderstorm

Station	1	2	3	4	5	6	7	8	9	10	11	12	Ann.
Karachi Airport	0.2	0.1	0.3	0.2	0.2	0.4	1.8	1.5	0.7	0.2	0.0	0.3	5.8
Karachi South	0.3	0.5	0.3	0.3	0.2	0.8	2.7	2.2	1.1	0.4	0.0	0.4	9.2

Total number of days of thunderstorm occurrence is 185 days during the statistical period of the Karachi Airport with the annual average of reaching 5.8 days; there are 293 days of thunderstorm occurrence at the Karachi south with the average annual of 9.2 days. Total days of monthly and annual mean thunderstorm over the years are given in the Table 4.

3.2.4 Fog

At the Karachi Airport, there are total 19 days for foggy occurrence (sky not seen) with the average number of 0.5 days; and 60 days for mist (sky seen) with the average of 1.9 days. There are 32 days for fog occurrence at Karachi South with the average of 1 day; and 120 days for mist with the average of 3.7 days. The main fog days at the two stations appeared during Jan. to Mar. and Oct. to Dec., and it less appeared during Apr. to Sep. Days of monthly and annual mean for foggy and misty over the years are shown below in Table 5 and 6 respectively.

Table 5: Days of Monthly and Annual Mean Foggy (Sky Not Seen)

Station	1	2	3	4	5	6	7	8	9	10	11	12	Ann.
Karachi Airport	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.5
Karachi South	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.0	1.0

Table 6: Days of Monthly and Annual Mean Mist (Sky Seen)													
Station	1	2	3	4	5	6	7	8	9	10	11	12	Ann.
Karachi Airport	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.9	0.2	1.9
Karachi South	0.4	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.4	0.7	3.7

3.3 Engineering Meteorology

The definition and statistical methods of meteorological parameters for system design of Heating, Ventilation and Air Conditioning (HVAC)follow the “Heating Ventilation and Air Conditioning Design Specification” (GB50019-2003). Engineering meteorological parameters for HVAC system design are industrial requirement, which is usually site or area specific. The information/design parameters being shared in Table 7 may be considered as design basis of HVAC system for Karachi Coast Area. The values belong to Karachi South Met. Station.

Table 7: Engineering Meteorological Parameters for HVAC Design			
	Name	**Illustration**	**Karachi South**
1.	Outdoor calculated temperature of heating , ^{0}C	The daily average temperature with 5 non-confirmed days over the years.	16.8^{0}C
2.	Winter ventilation outdoor calculated temperature, ^{0}C	The average temperature in normal coldest month for years	19.2^{0}C
3.	Summer ventilation outdoor calculated temperature, ^{0}C	the average value of the average temperature at 2PM in the most hottest month over the years	33.9^{0}C
4.	Summer ventilation outdoor calculated relative humidity, %	the average value of the average relative humidity at 2PM in the most hottest month over the years	61%
5.	Winter air conditioning outdoor calculated temperature, ^{0}C	The daily average temperature with 1 non-confirmed day over the years.	15.0^{0}C
6.	Winter air conditioning outdoor calculated relative humidity, %	The average RH in normal coldest month for years	52%
7.	Summer air conditioning outdoor calculated dry-bulb temperature, ^{0}C	The average dry-bulb temperature with 50 non-confirmed hours over the years.	37^{0}C
8.	Summer air conditioning outdoor calculated wet-bulb temperature, ^{0}C	The average wet-bulb temperature is non-confirmed in 50 hours over the years.	29^{0}C
9.	Summer air conditioning outdoor to calculate daily average temperature,^{0}C	The daily average temperature with 5 non-confirmed days over the years.	32.1^{0}C
10.	The average temperature in the hottest month, ^{0}C	The average value of average temperature in the hottest month over the years	31.0^{0}C
11.	The outdoor calculated average relative humidity in the hottest month, %	The average HR in the hottest month over the years	71%
12.	The average outside wind speed in winter, m/s	The average value of average outside wind speed in the three coldest months for years	3.1m/s
13.	The average outside wind speed in summer, m/s	The average value of average outside wind speed in the three hottest months for years	6.8m/s
14.	The most wind direction and its frequency in winter	The most wind direction and its average frequency in the three coldest months for years	NE,22.4%
15.	The most wind direction and its frequency in summer	The most wind direction and its average frequency in the three hottest months for years	SW,60.0%
16.	The average outside wind speed about the most wind direction in winter ,m/s	The average value of monthly average outside wind speed about the most wind direction in the three coldest months for years	4.4m/s
17.	The most wind direction and its frequency in a year	The most wind direction and its frequency for years	SW,38.1%
18.	Outdoor air pressure in summer, Pa	The average value of average outside air pressure in the three hottest months for years	999.0hpa
19.	Outdoor air pressure in winter, Pa	The average value of average outside air pressure in the three coldest months for years	1013.8hpa
20.	The days with average daily temperature less than or equal to +5^{0}C, and the starting date	The total days about the average daily temperature less than or equal to + 5^{0}Cfor years	No reach
21.	The highest temperature and its corresponding relative humidity, %	The extreme highest temperature of wet-bulb and dry-bulb for years, according to the daily statistics for 30 years	Dry-bulb:45^{0}C/22% Wet-bulb:32^{0}C/58%
22.	The lowest temperature and its corresponding relative humidity,%	The extreme lowest temperature of wet-bulb and dry-bulb for years, according to the daily statistics for 30 years	Dry-bulb:6^{0}C/63% ; Wet-bulb:2^{0}C/16%
23.	Percentage of sunshine in winter	Do not observation of sunshine in both station	No data

3.3.1 Outdoor design temperature for winter ventilation

The monthly average temperatures over the years are given in Figure 14. According to the Figure 14, January is the coldest month over the years for Karachi South stations. Thus, the outdoor design temperature for winter ventilation is 19.2^{0}C.

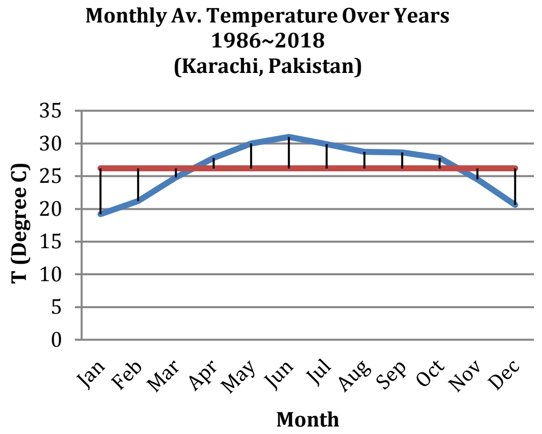

Figure 14: Monthly Average Temperature of Karachi (South) Coast

3.3.2 Outdoor design relative humidity for winter air conditioning

According to Figure 14, January is the coldest month over the years for Karachi South stations. Thus, outdoor design relative humidity for winter air conditioning is taken as 52%. Monthly average RH is shown in Figure 15.

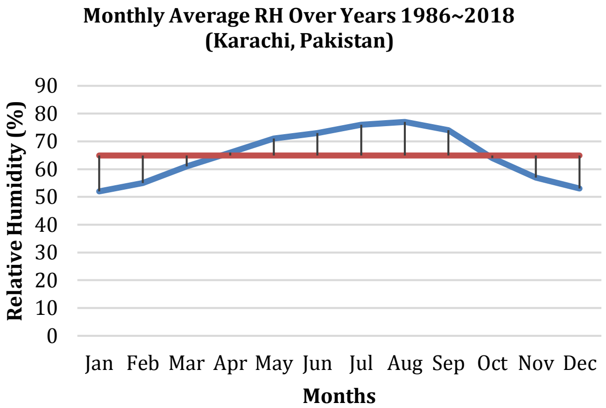

Figure 15: Monthly Average RH of Karachi (South) Coast

3.3.3 Outdoor design temperature and relative humidity for summer ventilation

Outdoor design temperature and relative humidity for summer ventilated are shown in Table 7, it is determined from the observation values of the temperature and relative humidity at 1400 hrs in the hottest month over the years. Firstly, the hottest months over the years are selected. Then, the average temperature and relative humidity at 1400 hrs in the hottest month are picked out, as shown in Table 9. Finally, after taking the average of values for all years, the outdoor design temperature for summer ventilation is 33.9 ^{0}C, and the outdoor design relative humidity for summer ventilation is 61%.

Table 8: Average Value of Temperature (^{0}C) and Relative Humidity (%) At 1400 hrs In The Hottest Month Over The Years

Karachi South							
Year	**Month**	**TEMP**	**RH**	**Year**	**Month**	**TEMP**	**RH**
1986	6	34.0	61.1	**2003**	6	34.6	63.3
1987	6	33.4	60.5	**2004**	6	33.1	61.3
1988	6	34.0	60.9	**2005**	6	/	57.4
1989	6	32.6	/	**2006**	6	33.9	60.2
1990	6	32.2	66.1	**2007**	6	34.0	60.5
1991	6	33.7	60.5	**2008**	6	33.8	61.8
1992	6	33.9	61.7	**2009**	6	34.8	57.9
1993	6	33.9	58.2	**2010**	6	34.7	57.3
1994	6	33.4	61.7	**2011**	6	34.3	57.1
1995	6	32.9	66.4	**2012**	6	35.0	59.6
1996	6	33.4	65.1	**2013**	6	34.9	58.8
1997	6	33.4	63.4	**2014**	6	35.1	56.0
1998	6	34.0	62.0	**2015**	7	34.0	63.1
1999	6	34.2	59.7	**2016**	6	34.6	55.8
2000	6	33.8	69.2	**2017**	6	33.8	56.6
2001	6	34.3	60.2	**2018**	6	34.9	53.4
2002	7	32.8	75.6	**2019**			

3.3.4 Outside average wind speed in winter and summer

The calculated parameters are the 12th and 13th items listed in Table 7. The monthly average wind speed over the years is shown in Figure 16. For the coldest three months of December and January and February, the monthly average wind speed of the coldest three months (winter outdoor average wind speed) is 3.1m/s. For the hottest three months of May, June and July, the monthly average wind speed of the three hottest months (outdoor average wind speed) is 6.8m/s.

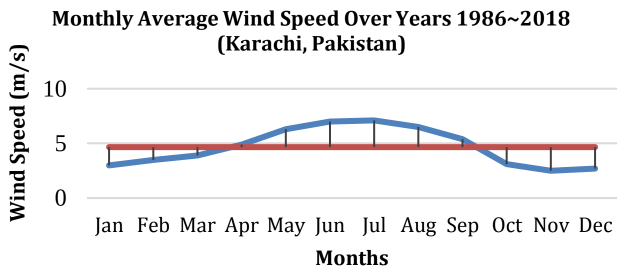

Figure 16: Monthly Average Wind Speed of Karachi (South) Coast

3.3.5 Winter, summer and annual most wind direction and its frequency

According to the statistics of the frequency of wind direction during 1986-2018, the most direction in winter for Karachi south is NE (except calm) with the frequency of 22.4%; the most direction in summer is SW with the frequency of 60%; and the annual most direction is SW with the frequency of 38.1%.

3.3.6 Average air Pressure in winter and summer

The calculated parameters are the 18th and 19th items listed in Table 7. The average atmospheric pressure for each month over the years is shown in Figure 17. In the coldest three months of December, January and February, the monthly average atmospheric pressure is 1013.8hPa. In the hottest three months of May, June and July, the average pressure is 999.0hPa.

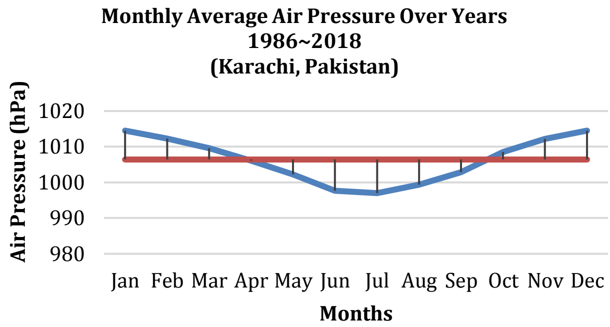

Figure 17: Monthly Average Air Pressure of Karachi (South) Coast

3.3.7 Days of daily average temperature less than or equal to +5(0C) and corresponding average temperature

According to the national standard GB50019-2003, the days of heating period is defined as the total days that the daily mean temperature stability is steadily less than or equal to outdoor critical temperature for heating. When the daily average temperature is calculated day by day from 1986 to 2018 for the Karachi south station, the daily average temperature over the years is found more than 5^{0}C. Thus, the days of the daily average temperature ≤ +5.0 ^{0}C are zero.

4. CONCLUSION

Climatic variability of Karachi coast is intelligible in this meteorological investigation. The effects of greenhouse gases and urbanization (with the passage of time) resulted in rise in temperature. Following is deduced for Karachi coastal area in the light of above analytical study.

- The extreme meteorological parameters result statistical Range of temperature for Karachi coast over 32 years of time as 44.7 ^{o}C.

- The routine and extreme meteorology estimates June as month of hot peak and January as month of cold peak season for Karachi
- The estimated temperature rise in 32 years is 0.9 °C, which is crossing the Intergovernmental Panel on Climate Change (IPCC) predicted/estimated limit of 2°C rise per century. The annual rise in temperature is alarming situation. Over population and industrialization is one of the major reason behind this activity.

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Nomenclatures

°C	degree centigrade, S.I. unit of Temperature
m/s	meter per second, S.I. unit of (Wind Speed) Velocity
%	percent, unit of Relative Humidity
hPa	hecta Pascal, S.I unit of (Air) Pressure
mm	millimeter, unit of measurement for precipitation
NE	North-East, direction for wind
NW	North-West, direction for wind
SE	South-East, direction for wind
SW	South-West, direction for wind

Abbreviations

RH	Relative Humidity
VP	Vapour Pressure
Temp	Temperature
Ann.	Annual
Met.	Meteorological
PMD	Pakistan Meteorological Department
WMO	World Meteorological Organization
HVAC	Heating Ventilation Air Condition (System)

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