ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2521-5035 (Print)
ISSN: 2521-5043 (Online)
CODEN: ESMACU

Earth Sciences Malaysia (ESMY)

DOI: http://doi.org/10.26480/esmy.01.2020.15.22

RESEARCH ARTICLE

ROUTINE, EXTREME AND ENGINEERING METEOROLOGY ANALYSIS FOR KARACHI COASTAL AREA

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ARTICLE DETAILS

Article History:

Received 28 November 2019
Accepted 12 February 2020
Available online 25 February 2020

ABSTRACT

Pakistan's largest city, Karachi, which is industrial centre and economic hub needs focus in research and development of every field of Engineering, Science and Technology. Urbanization and industrialization is resulting bad weather conditions which prolongs until a climate change. Since, Meteorology serves as interdisciplinary field of study, an analytical study of real and region-specific meteorological data is conducted which focuses on routine, extreme and engineering meteorology of metropolitan city Karachi. Results of study endorse the meteorological parameters relationship and establish the variability of those parameters for Karachi Coastal Area. The rise of temperature, decreasing trend of atmospheric pressure, increment in precipitation and fall in relative humidity depict the effects of urbanization and industrialization. The recorded extreme maximum temperature of 45.5^{0}C (on June 11, 1988) and the extreme minimum temperature of 4.5 ^{0}C(on January 1, 2007) is observed at Karachi south meteorological station. The estimated temperature rise in 32 years is 0.9 ^{0}C, which is crossing the Intergovernmental Panel on Climate Change (IPCC) predicted/estimated limit of 2^{0}C rise per century. The maximum annual precipitation of 487.0mm appearing in 1994 and the minimum annual precipitation of 2.5mm appearing in 1987 is observed at same station which is representative meteorological station for Karachi Coast. Further Engineering meteorological parameters for heating ventilation air condition (HVAC) system design for industrial purpose are deduced as supporting data for coastal area site study for industrial as well as any follow-up engineering work in the specified region.

KEYWORDS

Routine Meteorology, Extreme Meteorology, Engineering Meteorology, Atmospheric Variability, Karachi Coast.

1. INTRODUCTION

Technological advancements are faster than speed of light today. Every calender day brings news of engineering innovations and improvements. The world is now shifting to information age from industrial age or somehow in transition phase. This evolutionary shift will not take long but effects of industrial revolution will remain for unkown period of time. Environmental and weather conditions are prolonged due to urban and industrial effects. The prolonged meteorological changes result in climate change which is now a definite change in natural systems around the world. Changes in extreme events like warm fronts, storms, floods etc. as well as shifts in natural climate variability (such as monsoons), can have dire effects on human society accustomed to or dependent on long-term temperature, wind, and rain in specific areas (Siddiqua et al., 2019). These changes in extreme weather conditions may have more severe and drastic effects on Pakistan (Rashid and Rasul, 2009). Climate change includes long-term changes, including rising temperatures, increasing greenhouse gas emissions and carbon dioxide concentrations, as well as non-uniform and cyclical distribution of precipitation (Ullah et al., 2018). Climate change might double the economic damage (Meldensohn et al., 2012).

Pakistan lies in temperate zone and is vulnerable to climate change. It's climate is highly variable (Ali et al., 2019). Extreme climatic conditions are a threat to food security (Liu et al., 2017). Pakistan is at threat due to climate changes and has very limited financial and technical capability to deal with the unwelcomed climate changes (Saif, 2017). Climate of Pakistan is classified into different zones such as arid, semi-arid, sub-humid and humid on a broad scale from a drier to wetter (Chaudhary and Rasul, 2004; Qureshi et al., 2017). The temperature of areas near the sea is high in Pakistan, and the temperature difference is small. The climate in northwest high mountains and Baluchi plateau is variable with large temperature difference, and even some north high mountains are snow-covered throughout the year. The climate in Baluchistan region with mountains and desert is very hot and dry. In view of the considerable variation and the peculiar nature of the general climate in the region, it is convenient to divide the yearly climate cycles into the following four seasons:

- Winter Season from December to the end of March
- Summer Season from April to the end of June
- Monsoon Season from July to mid-September
- Post-Monsoon Season from mid-September to the end of November

Reviewers, Scholars, Researchers, Doctors, Engineers, Scientists and Technologists are as successful as well they are equipped with in-situ data or information regarding their subject or area of interest. In this regard, a little investigative effort has been made by studying and analysing real

Quick Response Code	Access this article online	
	Website: www.earthsciencesmalaysia.com	**DOI:** 10.26480/esmy.01.2020.08.15

Cite The Article: Muhammad Taqui,Jabir Hussain Syed, Ghulam Hassan Askari (2020). Routine, Extreme And Engineering Meteorology Analysis For Karachi Coastal Area. *Earth Sciences Malaysia , 4(1): 15-22.*

time atmospheric data of Karachi Coast, which includes data collection, statistical analysis of regional climate and routine meteorological observation, coast extreme weather and its statistical analysis, and design basis evaluation for engineering meteorological calculations. It will provide useful data and scientific study, for any industrial design and technical follow-up works. The case study is about Karachi coastal area (figure 1) situated in the Sindh Province of Pakistan. Karachi is largest city, financial and commercial capital of Pakistan which generates 60% of the total national revenue (Sajjad et al., 2009).

The urban population of the developing countries increased from 286 to 1,515 million during 1950 and 1990. This figure is expected to reach four billion by 2025 (Gupta, 2004). Most of the urban growth in the developing world is concentrated in 'mega cities' (Mills, 2006). All over the world urban areas are being affected by urban climate change. Increasing temperatures of Dhaka ,increase of 2^{0}C temperature of Saö Paolo, increasing tendencies of Beijing temperatures, 0.28–0.44^{0}C/10a increase rate of annual mean air temperature in city-belt of Yangtze River Delta in China and 1.5^{0}C increase in annual mean temperature of Seoul are the global examples of urban climate change (Sajjad et al., 2009). The extreme and disastrous events require urgent attention to mitigate their effects. Changes in extremes can differ significantly even in neighboring territories as a result of local factors, topography, distance from the sea, etc. (Rimkus et al., 2011). Therefore, meteorology of Karachi coastal area is analyzed.

Figure 1: Pakistan Map Outline (*Source: https//carwad.netwallpaper-647166*)

The aims and objectives of study are;

- To analyse the in-situ meteorological (met.) parameters (including routine, extreme and engineering) and to estimate the climate variability trends over the period of time for a specific area
- To estimate the design basis of engineering meteorology
- To establish a base/background meteorology for Karachi coast with observed data

The investigation provides basis for coastal area evaluation regarding applied meteorology. The routine met. parameters serve the purpose of daily operation, whereas extreme parameters serve the purpose of conservative approach design in engineering meteorology. The analytical skills improvement and knowledge/information sharing for research community is also expected to be fulfilled by this study.

2. MATERIALS AND METHODS

The conventional meteorological observation data over the years is collected for statistical analysis of the meteorological stations which are located within the range of 70 to 90 km-radius around the coast. The background and the observation history of each meteorological station is given below in Table 1. The in-situ data is evaluated to estimate trends of meteorological parameters. The detailed information regarding data, errors observed in data and remedies for observed errors are described in next sub sections 2.1, 2.2 and 2.3 respectively. The graphs are drawn using the meteorological (met.) stations data. Microsoft excel is used to plot the met. data and its trends to observe the variation with the passage of time.

Table 1: Location and Status of Karachi Coast Met. Stations

Station Name	Location		Status of Met. station	
	Latitude	Longitude	Construction Year	Current Status
Karachi South	2454	6656	1945	Active
Karachi Airport	2454	6708	1928	Active

The observation elements of each weather station include: temperature, pressure, humidity, wind, precipitation, cloud, etc., with artificial observations and recording instruments.

- The data from 1986 to 1994 were three-hourly and the data from 1994 to 2018 (where, lacking 2003, 2004 and 2007) were one-hourly at the Karachi Airport station.
- The data from 1986 to 2007 were three-hourly and the data from 2008 to 2018 were one-hourly at the Karachi South station.

2.1 Detailed information of meteorological data

The acquired data of meteorological stations cited above (which are close to the coast) include:

- The hourly observation data of Karachi Airport station in 1994-2018 (lacking 2003, 2004 and 2007), including local pressure, sea level pressure, wet bulb temperature, dry bulb temperature, dew point temperature, relative humidity, low cloud cover, total cloud cover, precipitation, wind direction and wind speed;
- The hourly observation data of Karachi South station in 2008-2018, including local pressure, sea level pressure, wet bulb temperature, dry bulb temperature, dew point temperature, relative humidity, low cloud cover, total cloud cover, precipitation, wind direction and wind speed;
- The three-hourly observation data of Karachi Airport station in 1986-1993, including local pressure, sea level pressure, wet bulb temperature, dry bulb temperature, dew point temperature, relative humidity, wind direction, wind speed, low cloud cover, total cloud cover, daily maximum temperature, daily minimum temperature and daily precipitation;
- The three-hourly observation data of Karachi South station in 1986-2007. including station pressure, sea level pressure, wet bulb temperature, dry bulb temperature, dew point temperature, relative humidity, wind direction, wind speed, low cloud cover, total cloud cover, daily maximum temperature, daily minimum temperature and daily precipitation;
- Monthly extreme maximum and minimum temperature of both stations in 1961-1980;
- Other extreme meteorological data in1986-2017, including the number of the days of occurring dust, fog, fog, hail and thunderstorm for each month;
- Report and images of wind direction and wind speed of both stations in 1978-1980, from which the data of maximum wind speed in three years of from 1978 to 1980 can be found;
- Tropical cyclones in 1975-2018.

2.2 Problems existed in the original data

According to the data detailed in above section 2.1, during the data process and analysis a number of problems were found as the follows:

- Data input errors, including more than one decimal point, decimal dislocation, entering multiple data in a cell, numerical errors of mistakenly appearing letters, wind direction error, such as NN and NS, and so on;
- Some errors found according to the dry bulb temperature, wet bulb temperature and relative humidity analysis, including that the wet bulb temperature is greater than the dry bulb temperature, and dry bulb temperature, wet bulb temperature and relative humidity do not conform to the actual law, and so on;
- Only tropical cyclones case or annual report provided, through which the minimum air pressure and the maximum wind speed value affecting the coastal area can not be found out.

The information of data acquisition of each element for both stations is shown in Table 2.

Table 2: Information of Data Acquisition of Each Element for Both Stations.

Element	Karachi Airport		Karachi South	
	Time interval	Acquisition rate	Time interval	Acquisition rate
Station pressure	Three-hourly data (1986-1993), Hourly data(1994-2018)	96.33	Three-hourly data (1986-2007), Hourly data(2008-2018)	92.61
Sea-level pressure		98.39		98.71
Dry-bulb temperature		97.47		95.50
Wet-bulb temperature		95.30		94.05
Relative Humidity		96.08		94.33
Wind speed		99.00		99.25
Wind direction		99.14		99.49
Low cloud		97.74		98.10
Total cloud		98.00		98.58
Dew point temperature	Hourly data (1994-2018)	97.99	Hourly data (2008-2018)	98.87
Wet-bulb less than dry-bulb	30 years	98.95	33 years	98.99
Dew-point less than wet-bulb	Calculated value	98.44	Calculated value	98.09

2.3 Methods of dealing with the original data error

According to the actual situations of errors, the following measures are taken.

- Correction through judgments for finding more decimal point, one cell with two numerical values, etc.;
- Considering the data as the missing data because the data was mistakenly entered as symbols and could not be correctly identified;
- The data series with no correction. Although the series looks reasonable, the validity of data can not be judged.
- The data of tropical cyclones, is downloaded from the website of tropical cyclone center of India Meteorological Department (IMD) and the Joint Typhoon Warning Center (JTWC), from which the minimum central pressure and the maximum wind speed of influencing region is collected. There is no data before 1990 in IMD, the tropical cyclones data after 1990 is taken from IMD, and the data between 1978 and 1990 is downloaded from JTWC to supply the data of minimum central pressure and the maximum wind speed. The data before 1978 cannot be used because it is short of the data of center pressure and wind speed.

2.4 Comparative analysis of terrain

Pakistan coast is about 1120 km long (Ministry of petroleum and Natural Resources, 2004). The coastal meteorology and hydrography of Karachi, the biggest city of Pakistan, is controlled by the seasonal change in the north Arabian Sea (Saied et al., 2015). Two stations are located in the desert zone, where the terrain around the Karachi south station in the 16 km east of the coast is more similar to that around the coast, as shown in Fig. 2. The observation environment of Karachi airport station in the east of the city may be greatly affected by city, which is about 36 km from the Karachi Coast.

Figure 2: Terrian Around Two Met. Stations

2.5 Determination of representative meteorological station for coast

Considering the location of the meteorological station, Karachi South is nearer from the coast which is in keeping with the geographical features around the coast, but the Karachi Airport station is closer to the urban district with more influence of city. The data from both stations near the coast has reliability and consistency, where the representation of the Karachi South station is better for the coastal area.

Taking into consideration of the type and history of station, geographic location, topography and landform as well as the results of three-character analysis, the Karachi South Station is selected as the representative meteorological station for the Karachi coast.

3. RESULTS AND DISCUSSION

The three focused topics of the study (Routine, Extreme and Engineering Meteorology) are described one by one in this section.

3.1 Routine Meteorology

The Statistical analysis of routine meteorological data in investigation region i.e., Karachi coast, is based on the routine meteorological data from Karachi South station during 1986-2018. All meteorological parameters are discussed below one by one.

3.1.1 Atmospheric pressure

For the representative meteorological station, the average atmospheric pressure of 1006.4hpa, the annual average minimum pressure of 1004.6hpa in 2010, the annual average maximum pressure of 1007.7hpa in 1997; the minimum of monthly average air pressure of 997.0hpa in July; the maximum of monthly average air pressure of 1014.5hpa in January; the extreme maximum pressure of 1023.6 hpa, the extreme minimum air pressure of 973.9 hpa is observed.

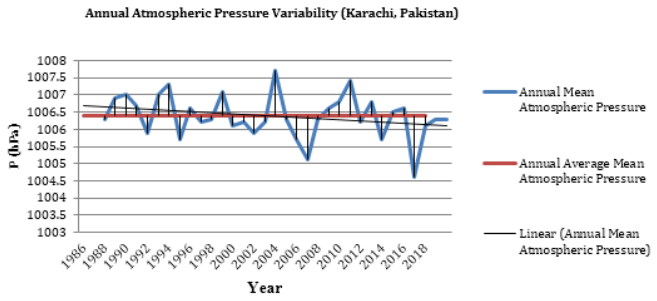

Figure 3: Annual Mean Atmospheric Pressure Variability (Karachi Coast, Pakistan)

Annual mean atmospheric pressure variability is shown in Figure 3. The trend of annual mean atmospheric pressure is decreasing which shows increase in temperature with the passage of time.

3.1.2 Temperature

During the course of the twenty-first century, scientific evidence points to global-average surface temperatures that are likely increasing by 2^0C~4.5^0C. The current rate of global warming is 2^0C per century (Salinger, 2005). The global mean temperature will rise by at least 1.5^0C by 2050. It is unlikely to rise by less, but it could rise by much more (Tickell, 1990). For the representative meteorological station (Karachi South), the annual average temperature of 26.2 ^{0}C, the annual mean minimum temperature of 25.3^0C , the annual average maximum temperature of 27 ^{0}C (2009); the extreme maximum temperature of 45.5 ^{0}C (on June 11, 1988), the extreme minimum temperature of 4.5 ^{0}C(on January 1, 2007) is observed. Annual mean Temperature variability and annual mean wet bulb Temperature variability is shown in Fig. 4 and Fig. 5 respectively. The annual average

wet bulb temperature of 21.4 ^{0}C, the annual average maximum value of 22.3^{0}C, the annual average minimum value of 20.5 ^{0}C, the maximum of monthly average value for years in succession of 26.9 ^{0}C with occurring in June and the minimum of 13.5 ^{0}C in January is observed. From Figure 4, it is evident that Temperature of Arabian Coast at Karachi is increasing with time.

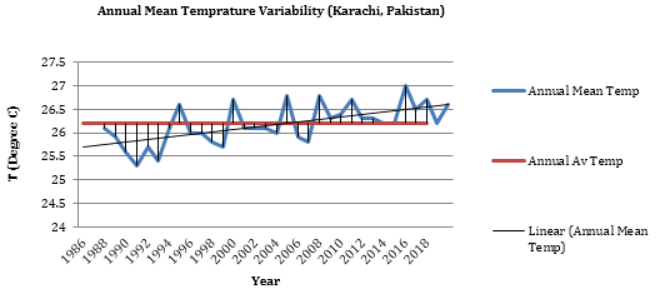

Figure 4: Annual Mean Temperature Variability of Karachi Coast

The extreme maximum temperature of Karachi airport is 46 ^{0}C. The extreme minimum temperature is 1.3 ^{0}C. 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).

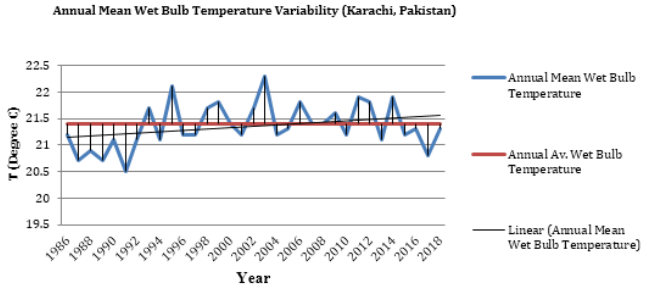

Figure 5: Annual Mean Wet Bulb Temperature Variability

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.

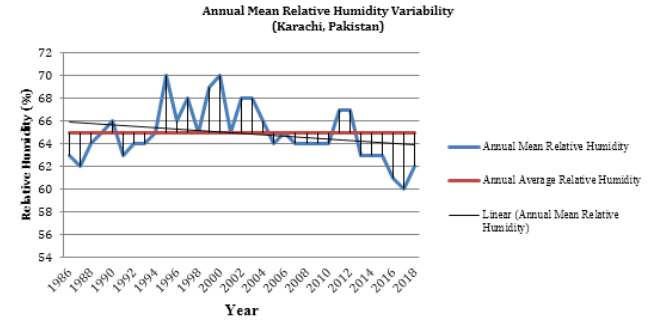

Figure 6: Annual Mean Relative Humidity Variability

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.

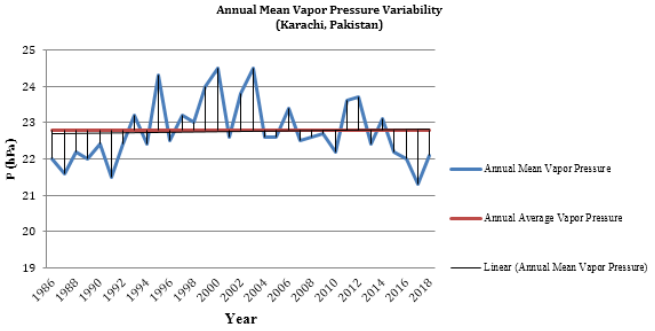

Figure 7: Annual Mean Vapor Pressure Variability

For the representative meteorological station, the annual average dew point temperature of 17.7 ^{0}C; the annual average minimum value of 16.7 ^{0}C in 1986, the annual average maximum value of 19.5 ^{0}C in 1998; the minimum of monthly average dew point temperature of 7.6 ^{0}Cin January, the maximum of 24.7^{0}C in June is observed.

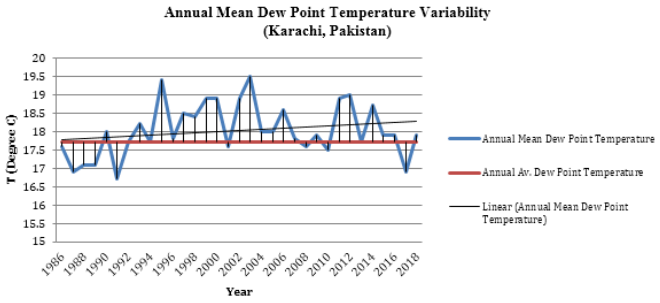

Figure 8: Annual Mean Dew Point Temperature Variability

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.

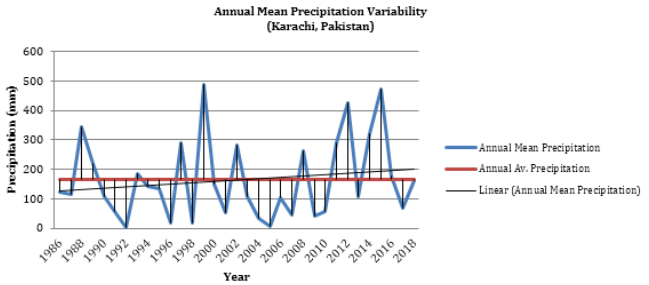

Figure 9: Annual Mean Precipitation Variability

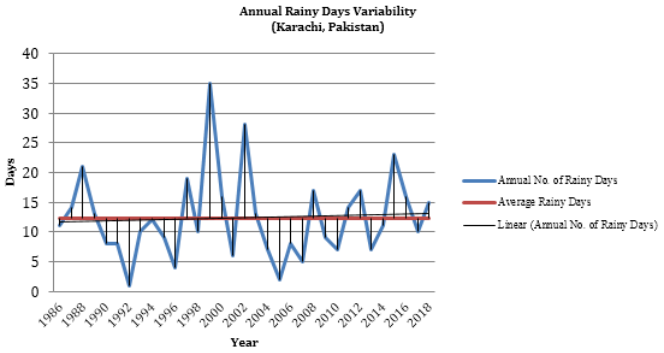

Figure 10: Annual Rainy Days Variability

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.

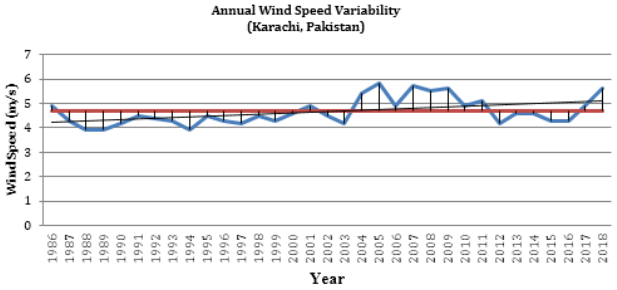

Figure 11: Annual Wind Speed Variability

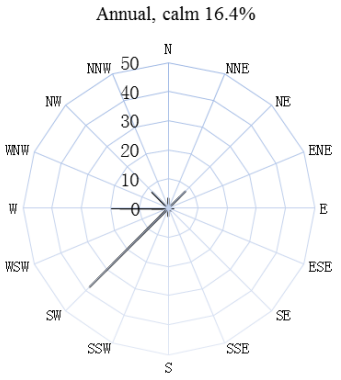

Figure 12: Observed Annual Wind Rose

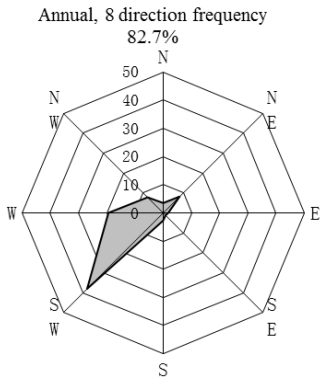

Figure 13: Rose Diagram of 8 Wind Direction

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.

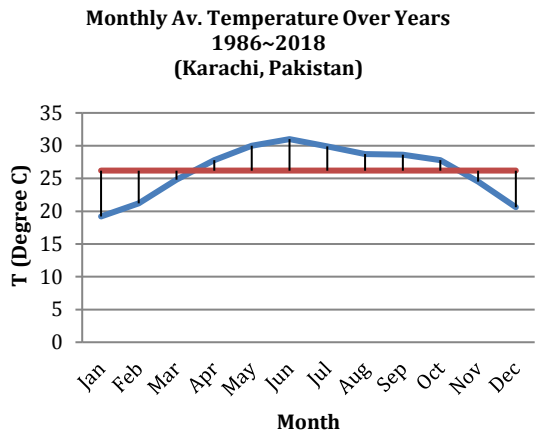

Figure 14: Monthly Average Temperature of Karachi (South) Coast

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.

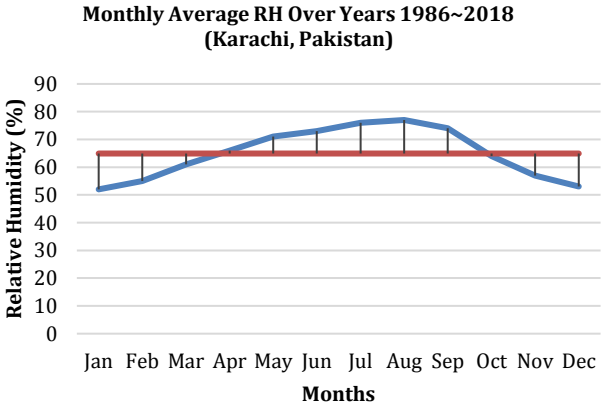

Figure 15: Monthly Average RH of Karachi (South) Coast

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.

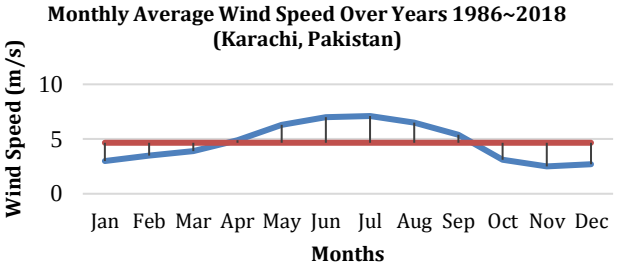

Figure 16: Monthly Average Wind Speed of Karachi (South) Coast

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.

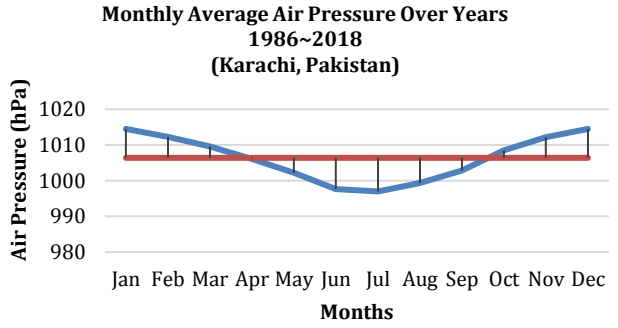

Figure 17: Monthly Average Air Pressure of Karachi (South) Coast

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 ^{o}C, which is crossing the Intergovernmental Panel on Climate Change (IPCC) predicted/estimated limit of 2^{o}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.

ACKNOWLEDGEMENT

The authors are thankful to incognito reviewers of the journal for their valuable feedback on this article. It is acknowledged that the study is part of PhD research of corresponding author.

Nomenclatures

^{o}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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