An Empirical Microclimate Analysis of the Coastal Urban City and Comparison of Vicinal Urban and Rural Areas with It

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Abstract

This Paper is an innovation of microclimate analysis of Karachi (coastal-urban) accompanying comparison of Hyderabad (urban) and Badin (rural) with it. Temperature along several interrelated tenement meteorological parameters like precipitation, thunderstorm and rainy days, wind, clouds, relative humidity, and sunshine are studied, analyzed and depicted. The study is asserted by characterizing statistical parameters, correlations, different calculations, scatter & dot plots with maintaining HIE, HII, range and trend graphs. Manora station recorded highest values of minimum temperatures, relative humidity and wind speed among all stations. Masroor town experiences the highest amount of precipitation, thunderstorm and rainy days. Hyderabad is leading in sunshine hours possessing heat island effect (HIE) and hence because of heat island intensity (HII) found not only significantly warmer than Badin but more than Karachi also. Rising Trends of ranges between urban and rural area indicates the increasing anthropogenic activity in urban area. Further details of each parameter for every station are incorporated in Paper.

Key words: Microclimate, Heat Island Effect, Heat Island Intensity, Urban, Coastal-Urban, Rural.

Introduction

Karachi is located in south of Pakistan and directly north of the Arabian Sea, covering an area of 3,527 square kilometers, which is largely comprised of flat or rolling plains with hills on the western and northern boundaries of the urban sprawl (Khan, 1993). Two rivers namely Malir and Liyari Rivers pass through the city from northeast to the center and from north to south respectively. Many other smaller rivers pass through the city as well. The Karachi Harbour is sheltered bay to the southwest of the City, and is protected from storms by Kemari and Manora Islands, as well as by Oyster Rocks (Shahid, 1998). Together, these natural barriers block the greater part of the harbour entrance in the west. Karachi is delimited by the Arabian sea towards the south by a chain of warm-water beaches.

There are some important micro skin textures of Karachi, which are also helpful to understand the general pattern of weather here. As regards for Physical Geography, the hilly area in north and northwest, vault of Drigh road, Lower valley of Hab, Lyari and Malir and the coastal area are the five prominent physiographic divisions (pittahwala et.al., 1953). Precipitation, wind speed, temperature and even humidity are different in these parts. Topography of low hill areas like Bathe Island, Ghizri and Clifton has a little changed climatic conditions contrast than the interior part of the city. While Korangi, Manora, Sandspit and Hawks Bay are the chic parts of the City. The heights of the hills of Mongho Pir are not enough to catch the saturated clouds in monsoon season. This range is also fail to prevent cold and hot spells in winter and summer respectively. Generally, the almost sterile low hills in the City do not help the climate in any way instead it is the source of dust annoying.

This Waterfront City near Arabian Sea also lies between deserts of Baluchistan (in the west) and Ther-Rajputana (in the east). Sea plays significant role in temperature control of Karachi. Little balminess in winter and soothing sea breeze spells in daytime and land breeze during nights in summer are consecrations of this sea, which also counterbalance the low and high temperatures. As the reflective power of water is higher than the land, accordingly sea takes time to be heated and cooled. This factor helps to make the climate of Karachi placid and tolerable for most of the year. The river valleys in the neighborhood of Karachi are entirely dry and their beds are sandy, so that the temperatures are raised and radiation is increased even in these river valleys. At the same time, the desert also participates substantially. But for the sea and the underground supply of fresh water, in the river alluvium, Karachi would have been a desert. Always in Sind there is period of 40 days in May-June, called “Chaliho”,

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which is considered to be a terrible time for Karachi as well (Shamshad, 1988). Only cooling systems make it comfortable to some extent.

The climate of Karachi is affected by several complex factors including the above mentioned factors and since the city is now expanding more rapidly in all the ways including population, pollution and infrastructure by developing and new colonies, satellite towns, suburbs, etc., it seems necessary to inquire the micro-climates of Karachi with their causes and effects in different parts of the city. As this Metropolitan coastal city is big with respect to area structure and population, different parts of it show different climatic peculiarities, needed to study further separately (Sadiq, 2007). This inspires to analyze further divisional climatic study of Karachi by dividing the city into microclimate zones. Further we analysed the available nearest rural area Badin and urban city Hyderabad for comparison.

Data and Methodology

To accomplish microanalysis of the climate of Karachi, weather logs of several different places within the city limits would have been very useful. In the absence of such an ideal network, we have tried to make use of the meteorological data of the four available observatories of Karachi (with observatories of Hyderabad and Badin), mentioned in the following section.

The study utilizes the mean monthly and mean annual data of ten meteorological variables viz Maximum (T_x) Minimum (T_n) and Mean (T) temperatures, Precipitation (Ppt), number of rainy days (Pptd), thunderstorm days (Td), relative humidity (Rh), wind speed (Ws), Cloud amount (C), and sunshine hours (SSH). We examined Karachi as an urban-coastal city, comprises the observatories of Karachi airport (KHI), Faisal town (FST), Masroor Town (MST), and Manora Observatory (MNS). The nearest available urban area Hyderabad (HYD) further which is near to rural area of Badin (BDN) is utilized for comparison. To incorporate this comparative analysis we employ the maximum available data of different parameters for different stations (cf. Table 1).

Initially the characterization of mentioned meteorological parameters undertaken with the help of basic statistical parameters including Mean, Median, Standard Deviation, Maximum & Minimum values and the range between these values. Then after going over the compatibility and suitability through correlations, data is found appropriate to use for the undertaking of comparison.

Findings

Calculations of characterizing statistical parameters reveals that for KHI the period from 1931 to 2008 shows almost doubled standard deviation value (6.33) of minimum (T_n) to the maximum temperature (T_x) (3.20), while for HYD and BDN, T_n shows somewhat higher values than T_x (cf. Table 2). Sunshine hours and amount of clouds at BDN are greater than HYD but less than KHI. Seasonal rain and relative humidity show maximum standard deviation because of their highly variable nature.

The correlation matrix indicates the interdependence to the variables (cf. Table 3), which suggests that meteorological variables are strongly correlated to each other and compatible for comparison.

Ascertaining of the analysis with related calculations and diagrams are discussed in subsequent sections

Temperature

Maximum, minimum and average mean monthly and mean annual temperatures are drawn in figure 1 to 3 and the resulting important values regarding mean annual temperature(s) are summarizes in table 4.

Mean Monthly and Mean Annual Maximum Temperature (T_x)

In monthly analysis HYD and BDN appears with first and second highest values from March to October respectively, while among Karachi observatories MST touches the peak values for the

same months (Fig. 1a). MNS is lying with least values and KHI shows almost the same attitude like FST throughout the year.

HYD stands with highest values among all because of its heat island effect and second berth is for BDN (Fig. 1b). Among the stations of Karachi, FST has the maximum values of T_x. The widest range is covered by BDN and HYD respectively with values above than 3oC. KHI and FST acquire equal range with different values (cf. Table 4). The graph also shows that the highest value of T_x of MNS is less than initial values of KHI & FST. Most Recurring values (MRV) of T_x for all stations is also summarized in Table 4.

If we compare the Karachi observatories with the HYD (Urban), the maximum value of the T_x for Karachi stations lie almost at the minimum value of HYD. BDN has the more scattered value of maximum temperature. The T_x range of BDN is less than HYD but higher than observing stations of Karachi.

Mean Monthly and Mean Annual Minimum Temperature (T_n)

From May to September almost all stations shows singularity. The maximum difference appears in December and January (peak winter months). As Badin is a rural area with no signs of HEI so it reaches to the minimum values of T_n (Fig. 2a). MNS because of the nearness to the sea shows highest values. MST, KHI and FST are showing very slight difference, whereas HYD has greater values than BDN.

T_n for MNS has the greater values of temperature. It is because of the creek island characteristics of MNS due to which its temperature does not decrease so much as the land area. MST and FST are next to it, while FST is mostly consisting of scattered values (Fig. 2b). KHI acquire the widest range of T_n. If we compare HYD with BDN, the most common repetitive values of T_n are found higher than BDN and lower than MNS (cf. Table 4), while values of FST and MST are almost lying in the range of HYD. KHI appears with most disperse values whose initial and final values are more expanded than HYD.

The minimum values of T_n appear at rural area of BDN because of no heat island effect. The highest value of T_n for BDN is the lowest value for MNS. The temperature of HYD is higher than BDN due to HIE, which will discuss in later sections.

Mean Monthly and Mean Annual Temperature (T)

During February and November all the stations shows analogues while in May and June most distant values (Fig. 3a). The scheme of the temperature positions for all observatories is somewhat similar as for T_x (with different temperature values).

Comparison of Karachi observatories reveals that MNS has the least value of T and as it is an island, so the annual variation in temperature is less as compared to the other stations (Fig. 3b). The least value of temperature for MNS is the highest value for FST. As regards MST, the values of temperature are more scattered. The most scattered values of KHI are notable.

Comparing all observatories, HYD has the highest temperature and BDN is the next one and then KHI. As HYD is an urban area and also away from the coast, so its temperature is higher due to Heat Island Effect. The minimum value of temperature for HYD starts from 27.5ºC, which is greater than maximum value of MNS (26.7ºC). The maximum value of temperature for HYD can reach up to 28.9ºC, which is the highest value.

If we compare BDN with Karachi stations, then it is clear that BDN has also the highest range of temperature than Karachi stations. The reason is that BDN is the land area, away from the coastal area. The value of temperature of BDN is less than HYD because HYD is an urban area.

Heat Island effect (HIE)

Heat Island Effect indicates a metropolitan area which is significantly warmer than its surrounding rural areas. Urban Cities consume enormous amounts of energy in heating, cooling and transportation (WMO, 1997). The released energy (heat) together with that generated by each city dweller and his or her activity, heat is reflected by the physical fabric of the city itself, bouncing from one hard surface to another and often trapped under a layer of pollution that arches over the city and prevents its from escaping (Oliver & Hidore, 2003). Added to this, building material and roads surfaces store heat; cities for typically several degree warmer than surrounding rural land (Khan & Arsalan, 2007).

The same effect for the Hyderabad for the first day of January 2008 is shown in figure 4a. In between 1200 and 1500 GMT (at about 0700 and 1000 PST) the graph lines crosses each other showing that HYD now releasing its absorbing heat less rapidly than BDN till 0100GMT. Stronger heat retention and release, including fuel consumption, construction, gives significant increase in temperature of Hyderabad (Urban) creating this effect.

Three observatories of Karachi (data of MNS not available) are also shown in the same graph. That after 1200 GMT the difference between lines of same pattern appear in which KHI releases its heat more rapidly and MST more slowly because of nearness to the sea. So the observation shows that HYD shows the prominent Heat Island Effect at night for HYD.

The situation of 1st May 2008 is shown in figure 4b. As per expectation the diurnal variations of BDN and HYD are more spectacular than the observatories of Karachi, which appears with less diurnal variation due to coastal effect. At 0000 GMT both urban and rural area shows temperature lesser coastal city observatories but HYD at about 0400 GMT and BDN at about 0600 GMT starts absorbing heat more rapidly. HYD leads BDN till night.

Heat Island Intensity (HII)

The degree of Heat Island Effect is expressed as Heat Island Intensity (Park, 1987), which is calculated for KHI, HYD and BDN in terms of urban, rural and coastal-urban areas for T, T_x and T_n. The difference between HIE factor for ΔTu-c and ΔTu-r appears most striking for T_x, relatively less prominent for T and negative for T_n (cf. Table 5). Depictions of the calculated Intensity are shown in Fig 5.

For Mean Monthly Temperature (T)

It is evident that Heat Island Intensity for T and T_x is more in between urban and coastal area (Fig. 5b) than the urban and rural area (Fig. 5a), while intensity of urban and rural areas put more effect on T_n (Fig. 5c) than T_x and T_n.

Regarding Intensities for T, urban and rural areas has maximum values of 1.4, 1.6 and 1.3 during main monsoonal months of July, August and September respectively (Fig. 5a). The contrast of temperature is maximum in the monsoon season due to HIE of HYD. Similarly, minimum values comes out for the months of December, January and February (0.4, 0.3 and 0.3 respectively) shows that this effect is minimum in the winter season. Seasonally the HII for summer is four fold as compared to the winter season.

For Mean Monthly Maximum Temperature (T_x)

ΔTu-c shows that the temperature of the KHI is less than the BDN (Fig. 5b). The greater temperature contrast (3Co) is due to the greater heat capacity of the Arabian Sea lying in the vicinity of KHI. The graph further shows that the coastal effect diminishes the Island Effect of KHI and the highest value of heat island intensity is observed in the pre-monsoon months. The notable feature is the minimum negative Heat Island Intensity for the main winter months of December & January viz. -0.6, 0.3 and -0.5 respectively. While the maximum values appear for the months of April, May & June viz. 2.5, 3.1 and 2.6 respectively express that urban land

become hotter more rapidly than the coastal area. This shows that as the summer season approaches, the temperature of urban area increases rapidly and that of the coastal area increases slowly as the specific heat of water is greater.

The most pronounced effect of HII regarding T_x found for ΔTu-c, which is even greater than ΔTu-r, while ΔTu-r acquires the highest value throughout the summer season. However the intensity for urban and coastal area is minimum during the winter as temperature of the urban area decreases rapidly and coastal-urban city shows less variation due coastal effect.

For Mean Monthly Minimum Temperature (T_n)

For T_n, the ΔTu-r is more pronounced in the winter season as compared to the summer season. It is because of HIE in winter, when T_n of urban area is higher than rural area (Fig. 5c). It shows that the temperature of rural area is marked decreasing in winter whereas in summer months due to decreasing and increasing T_n values of HYD and BDN respectively, the resulting Heat Island Intensity is also decreasing.

Three notable crests appears for ΔTu-c, showing peaks from March to April, July to August and for October to November, which indicate that during this period the temperature of urban city is exceeding from coastal urban city. It is also important that in acme of summer and winter intensity becomes analogous for urban and coastal-urban areas.

Further the mean annual temperature(s) ranges for ΔTu-r and ΔTu-c are also considered for Karachi, Hyderabad and Badin in the subsequent sections.

Mean Annual Temperature (T) Range

The notable abrupt increase in the range during late seventies and eighties (figure 6a); shows the beginning and development of industrialization in the urban area from 1975 to 1988 due to which both HIE and hence HII increases. However the linear trend model equation shows slight increase of 0.043 per decade. Figure 6(b) shows that the trend line with relatively sharp decreasing rate of 0.127 per decade. This means that the sea surface temperature is rising due to which the temperature of coastal-urban area is also increasing with time. This increment might be due to rapid growing population, sloppy structure and complex composition of Karachi city, as well as the thermal properties of coastal construction materials. Additional factors for rising temperature of Karachi includes massive transportation and pollution supportive industrialization.

Mean Annual Maximum Temperature (T_x) Range

The T_x range for urban and rural area (Fig. 7a) is found analogous to Figure 6a but with steeper slope of 0.104 increment per decade, indicates that the maximum temperature of the urban area of Hyderabad is increasing. Linear equation reveals the most steep (of decreasing tendency) trend for T_x range regarding urban and coastal areas (Fig. 7b). This means that the T_x of the coastal-urban area is increasing due to urbanization as well as due to coast effect (specific heat of water body). The temperature of the coastal-urban city sharply increasing after 1988 to 2000 is notable.

Mean Annual Minimum Temperature (T_n) Range

The T_n of the coastal area is increasing as compared to the urban area. It is important that almost from 1960 to 1990, the urban area (HYD) is warmer than the coastal-urban area (Fig. 8a). However in the last decade the temperature of KHI is increasing drastically as compared to the HYD. However the combined effect comes out as an almost straight resulting trend line. Considering ΔTu-c for T_n range (Fig. 8b), decreasing tendency of -0.065 per decade appears. From 1960 to early nineties increase in temperature of urban area and from late nineties to onwards sharp increase for coastal area is notable.

Rainfall (Ppt) & Rainy days (Rd)

Except FST and BDN which shows normally distributed attribute (and hence greatest amount of rainfall appears in July and August) all others station's show positively skewed distribution of rainfall because of which they all show highest rainfall only in the month of July (Fig. 9a). In the peak month of monsoon ascending order with respect to amount of rainfall found viz. HYD, FST, MNS, BDN, KHI and MST. From Mid of November to March bunch of BDN, HYD and KHI distinguished from the bunch consisting of MST, FST and MNS. Similarity between the KHI and BDN's deportment in the month of October and from April to July is a highlighted feature.

Mean monthly graph also shows co-effect (i.e. coastal & urban) of Karachi, leads to the increased buoyancy, convection and moisture resulting in increased Ppt at Karachi. However, the increased amount of ppt of Badin than Hyderabad in monsoon season shows that the monsoon season is much more prevalent in Badin. The annual amount of precipitation of MST and KHI is greater than FST and MNS. The value of precipitation for MST lies with in the range from 2.5 to 957 mm in 1967 (CDPC, 2005). The maximum values lie within the range from 20 to 140 mm/yr (Fig. 9b). The rainfall for KHI is more scattered and has the values within the range from 0 to 713 mm/yr.

The Ppt for Karachi stations is of similar pattern throughout the year. In early winter the amount of rainfall is greater over KHI and FST. However in March and from mid of June to mid-July, MST surmount than all other stations. In the month of April and May, the Ppt of HYD and BDN is greater from all the stations of Karachi. In the month August, FST is at the top in the graph and sharply decreases in the months of September to October as compared to the other stations. In the pre-monsoon season, BDN has the highest rainfall, which indicates that, the monsoon season lag behind the stations of Karachi and HYD. BDN has the precipitation with in the range from 0 to 913mm in 1994 (CDPC, 2005) and has accumulated values with in the range from 160mm to 360 mm/yr.

Among Karachi observatory of Masroor town acquire the maximum number of rainy days (Fig. 10a), as it lies in the west of the city near the Arabian sea where drizzle and light rain is common due to frequent appearance of stratus clouds. Annual rainy days of MST are greater than any station of Karachi. For MST the annual rainy days varies in the range of 1 to 45 days (Fig.10b). The greater amounts of rainy days over MST are due to the drizzling in the months of August and September because of the stratus clouds. The maximum values of rainy days occur in the range from 9 to 30 days. MNS has the maximum rainy days with in the range from 1 to 14 days. KHI has the maximum amount of rainy days with in the range from 3 to 12 days.

The minimum rainy days occur in May and October when land breeze invade in the southern part of the country while maximum rainy days usually occur in July & August. Pptd of BDN are less than HYD in winter season while in summer BDN acquire somewhat greater values than HYD. The possible reason is that in winter the temperature of BDN is less than HYD (due to Heat Island Effect) and so there is no convection of air available for the development of clouds. If HYD is compared with Karachi stations, it has the lower amount of rainy days. HYD has the maximum rainy days within the range from 1 to 8 days. BDN is the station, which has the least amount of rainy days with in the range from 0 to 23 days. The maximum values of rainy days lie in the range from 3 to 9 days for BDN. The notable feature is that all the stations have minimum rainy days in the months of May and October.

Thunderstorm Days (Td)

These days are maximum at MST through out the year except in the months March, April and May when HYD has the maximum Td (Fig.11a). The annual Td is maximum over the MST with minimum value of 0 and maximum value of 30 days. The maximum value of thunderstorm occurs within the range from 3 to 7 days.

Among the stations of Karachi, MNS has the least thunderstorm activity in all the months. All the stations appear with least Td during the months of May & October because of less convection and due to transitional period between winter & summer. The least values of Td over MNS are due to the possible reason that the station is located very near to the Arabian Sea and there is no enough heating for the development of convectional clouds, as a result and only stratus clouds are frequently developed. In winter (November, December, January & February) HYD possess less Thunder activity and in the months of March, April, May and June has stronger activity. BDN has the least Thunderstorm activity in the winter season as its temperature drops and no convectional clouds are developed.

Considering mean annual thunderstorm days among the stations of Karachi, MNS has the least value within the range from 0 to 5 days (Fig. 11b). Comparison of HYD with Karachi stations brings out that HYD has Td less than MST & KHI and more than MNS. Td of HYD also comes out as more than BDN. It might be because of the fact that area where the temperature is higher has the high probability of development of convectional clouds (cumulonimbus and towering cumulonimbus), which are main source of thunderstorm. HYD has the maximum values of Td within the range from 2 to 6 days and has maximum values as high as 20 days. The least amount of Thunder storm over MNS is due to the fact that the temperature of MNS cannot increase as much as necessary for the convectional clouds.

Wind speed (Ws)

All Karachi stations are windier than Hyderabad (Urban) and Badin (rural) except KHI for June to September when BDN's wind is equal or greater than KHI (Fig.12b). As the area of MST is comparatively more open, Ws here is much greater than FST & KHI throughout the year; also greater than MNS but both become equal in December & January. From October to March Ws of FST becomes less than MNS, which is otherwise dominating in other months. Similarly from June to September HYD's wind is dominating to KHI's, which is otherwise lesser in other months. In general HYD's wind is greater than BDN throughout the year except February when both become equal to each other.

Considering mean annual values BDN's wind ranges from 2.5 to about 10.1 knots while MST's range start form 9.6 kt to about almost 17.1kt. A notable feature of HYD wind is the absence of 9.6 to 12.6 kt wind. While its first range is from 4 to 10 kts and other is 12.5 to 14.8 kts (Fig. 12b). HYD acquire most scattered values of Ws, lies in the range from 3.8 to 14.8 kts. The highest values of wind speed lies in the range from 3.5 to 6.0 kts. BDN has the lowest wind speed than all other the stations, ranges from 4.5 to 9.0 kts.

Regarding coastal city, MST experiences highest values of wind speed (9.6 to 17.1 kts) as it is more open and less friction area as compared to the other stations. Its highest values of Ws lie within the range of 11.5 to 14.5 kts. The lowest speed at KHI is due its location, as now it is comparably more inside the city so friction area for wind is more.

Relative Humidity (Rh)

This important factor is undertaken because in-coupled with temperature it may affect changes in cooling rates and therefore heat island development (Jauregui, 1996). The lowest values for Karachi stations exist for the winter months while for BDN and HYD least values found in March and April (Fig. 13a). HYD observed less humid than BDN as Badin lying in south of Hyderabad. Mean monthly pattern also shows highest value for summer months as the moisture holding capacity of sea breeze increases due to increasing temperature while peak value appear for the month of August (peak monsoon in this region) for all stations. As per expectation MNS (as it is creek island in southwestern side of the city) and KHI (lies in north eastern part of the city) are found most and least humid Karachi stations respectively. Mean annual dot picture also establish higher amount of relative humidity for the stations lying nearest to coast. For MNS the relative humidity lies in the range from

60.5% to 78.2%. Most of the values are accumulated in the range from 63% to 70% (Fig. 13b). MST is second to MNS whose values lie in the range from 50% to 63.7%.

Karachi stations have the decreasing trend of humidity as the distance from the coast increases. As KHI has maximum distance among the Karachi stations so it has the lower relative humidity among these stations. Likewise if Karachi stations are compared with HYD, the HYD has least relative humidity due to higher temperature, distance and elevation from the coastal area. For HYD the relative humidity lies in the range from 28% to 42%. Most of the values are accumulated in the range from 30% to 40%. Comparing HYD with BDN, the relative humidity of BDN is greater than HYD because BDN is a rural area, has comparably lower temperature and nearest to the Run of Kutch area of India.

Clouds (C)

In summer MNS is most cloudy than any other station of Karachi as total amount of clouds are more in the summer & monsoon season at all Karachi stations. The overall cloudiness over Karachi stations (KHI, MST, FST, MNS) is more (Fig. 14a) than HYD & BDN in all seasons because of sudden and frequent cloud (mostly stratus) appearances here. As the HYD & BDN is comparably far from the coastal area, so the total amount of clouds over these stations is comparably less. However comparison of HYD and BDN shows, that the cloud amount over HYD is greater in winter season and lesser in summer than BDN. In monsoon season, as the BDN station is near to the coastal area than HYD, so there are many clouds over BDN than HYD and hence more thunder storm, rainy days and precipitation over BDN.

Mean annual graph shows that all the stations of Karachi are covered with high amount of clouds almost in the range from 2.0 to 4.0 oktas (Fig. 14b). The clouds are more scattered at MNS. Over KHI the clouds are mostly accumulated within the range from 2.4 to 2.8 oktas. The least amount of clouds is found over BDN with scattered values. Over HYD, the clouds are greater than BDN and are mostly accumulated within the range from 1.4 to 2.2 oktas.

Sun shine hours (SSH)

Hyderabad acquire maximum sunshine leading to Badin while Karachi get the least value with a common (but with different amounts) attitude that the minimum hours are observed in peak monsoon period (July and August) and maximum increasing tendency found in seasonal shifting from winter to summer, where as in monsoon period there is sharp decrease observed (Fig. 15a). Karachi appears with least values because of its coastal attitude as clouds are very common here which block the isolation and this behavior is at peak in July and August (monsoon season) when the absorption, scattering and reflection of solar radiation is maximum. The graph also shows that the sunshine hours for Hyderabad (urban) is maximum in the summer and minimum in winter than KHI & BDN. Mean monthly sunshine hours (for annual and monsoon) and its percentage is summarizes in table 5.

As regards the values of total annual sunshine hours of KHI, it lie within the range of 2477 hrs/yr to 3168 hrs/yr while maximum hours lies with in the range from 2840 to 2980 hrs/yr (Fig.15b). Sunshine hours for HYD is greater than KHI and BDN may be because of relatively far distance of HYD from the coastal area and hence fewer amounts of clouds reached there, hence increases the amount of sunshine hours. The values of total annual sunshine hours for HYD lie with in the range from 230 hrs/yr to 3501 hrs/yr. The maximum value of sunshine lies with in the range from 2960 to 3380 hrs/yr.

Conclusion

Undertaken analysis comprises of the microclimate of coastal-urban city (Karachi) and further comparison of urban (Hyderabad) and rural (Badin) areas with it. The anthropogenic activities make some substantial changes to the climatic parameters of urban areas especially in respect of temperature, so this parameter studied in more detail with other selected meteorological variables.

The pattern of average and maximum mean monthly temperature is found with similar pattern (with different values). Hyderabad (highest) and Badin (2nd highest) acquire the values greater than Karachi stations while MNS acquire the least values among all. Very slight values of MST are observed greater than FST in-coupled with KHI. As far as minimum temperature is concern, MNS is at the top and then MST, FST, HYD and BDN for winter months respectively. Urban area (HYD) shows marked Heat Island Effect when comparing with rural area (BDN) and Karachi. HII is greater for HYD and KHI regarding mean and maximum temperatures while marked less for minimum temperature, which indicates the rapid climatic changes regarding Karachi climate due to Pollution, population, industrialization, transportation etc. Intensity also shows the marked decrease in temperature of BDN during winter as there is no existence of HIE for it. The maximum effect of HII observed on mean annual maximum temperature ranges, which shows the most steeper (upward and downward) trends of urban & rural and urban & coastal.

Among all stations MST get highest and HYD get the least amount of precipitation in monsoon while FST gain the least amount among Karachi stations. For considered areas, very less amount of rainfall due to western disturbance (in winter) appear as compared to monsoon. For all stations least rainfall occur in the months of April, May, October and November.

During monsoon MST and MNS came out with most and least values for rainy days within Karachi stations. Looking at all stations, MST and HYD last with maximal and minimal rainfall days respectively. Least rainy days appear for the months of May, October and November, while in winter minimum rainy days occur for BDN.

Considering all stations during monsoon the highest and least thunderstorm days occur at MST and MNS respectively. Second highest values acquire by KHI and then BDN.

Throughout the year MNS remain most windy whereas HYD posses least values of wind indicating that urbanization (due to modified structure) reduces the wind speed and HYD observed with peak and bottom values of winds. MST is at second position while FST is analogous to KHI with somewhat higher values and then BDN came out with a marked difference.

The pattern of relative humidity demonstrates that the examined stations are inversely related to the distance between sea and observatory location being highest for MNS and lowest for HYD.

Concerning cloud amount all observatories of Karachi shows a close bunch with (more cloudy than BDN and HYD) very little difference in between but marked difference with BDN and HYD. Values are closer in October and far in monsoon. A notable feature of HYD's cloud amount is found that from October to April its values become very closer to Karachi stations.

Percentage of HYD sunshine is 16 and 23 percent greater than BDN and KHI while annually it is only 4 and 8 percent higher.

The pressure of continuous growing population and pollution is emerging as a serious long-term threat by increasing in diseases and death rates in the urban area, which needs to be further investigated.

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Table 1: Available meteorological data of different parameters verses observatories

Station	Lat/Lon	Elev	T, T_x,T_n	SSH	Rh	Ppt_d	Ppt	T_d	C	Ws
KHI	24º 70′N & 67º13′E	21m	78 Yrs 1931-08	62 Yrs 1947-08	78 Yrs 1931-08	48 Yrs 1961-08	78 Yrs 1931-08	48 Yrs 1961-08	78 Yrs 1931-08	64 Yrs 1945-08
MST	24º 90′N & 66º93′E	11m	52 Yrs 1957-08	-----	52 Yrs 1957-08	48 Yrs 1961-08	52 Yrs 1957-08	48 Yrs 1961-08	52 Yrs 1957-08	52 Yrs 1957-08
FST	24º 88′N & 67º12′E	6m	38 Yrs 1971-08	------	38 Yrs 1971-08	38 Yrs 1971-08	38 Yrs 1971-08	38 Yrs 1971-08	38 Yrs 1971-08	38 Yrs 1971-08
MNS	24º 48′N & 66º59′E	2m	57 Yrs 1931-87	------	57 Yrs 1931-87	26 Yrs 1962-87	57 Yrs 1931-87	26 Yrs 1962-87	55 Yrs 1933-87	46 Yrs 1942-87
HYD	25º 38′N & 68º42′E	40m	78 Yrs 1931-08	40 Yrs 1969-08	76 Yrs 1933-08	48 Yrs 1961-08	78 Yrs 1931-08	48 Yrs 1962-87	76 Yrs 1933-08	67 Yrs 1942-08
BDN	24º 63′N & 68º90′E	10m	78 Yrs1931-08	35 Yrs 1974-08	72 Yrs 1937-08	48 Yrs 1961-08	78 Yrs 1931-08	48 Yrs 1961-08	72 Yrs 1937-08	67 Yrs 1942-08

Table 2: Characterizing statistical parameters

Variable	Station	Mean	Median	St.Dev	Maximum	Minimum	Range
T	KHI	26.18	28.20	4.60	31.50	18.10	13.40
	HYD	27.61	30.20	5.80	34.10	17.60	16.50
	BDN	26.81	29.25	5.45	33.00	17.30	15.70
T_x	KHI	31.80	32.30	3.20	35.30	25.60	9.70
	HYD	34.42	36.35	5.57	41.70	24.50	17.20
	BDN	33.73	34.40	4.52	40.10	25.70	14.40
T_n	KHI	20.54	21.75	6.33	28.10	10.60	17.50
	HYD	20.79	22.30	6.26	28.00	10.70	17.30
	BDN	19.92	21.70	6.72	27.50	9.00	18.50
Rh	KHI	51.43	46.90	13.90	71.50	36.00	35.50
	HYD	34.85	30.20	11.20	54.90	22.50	32.40
	BDN	39.44	34.15	13.07	62.30	25.00	37.30
Ws	KHI	8.33	8.75	2.30	11.30	4.90	6.40
	HYD	7.63	6.80	2.97	11.70	4.10	7.60
	BDN	6.192	6.00	2.29	9.30	3.00	6.30
SSH	KHI	240.0	264.5	54.0	290.3	133.4	156.9
	HYD	265.13	266.75	27.27	305.70	209.10	96.60
	BDN	252.5	269.7	49.1	299.6	148.8	150.8
C	KHI	2.58	1.90	1.65	5.70	0.80	4.90
	HYD	1.72	1.65	0.82	3.40	0.60	2.80
	BDN	1.60	1.15	1.41	4.50	0.40	4.10
T_d	KHI	0.50	0.30	0.58	2.00	0.10	1.90
	HYD	0.55	0.45	0.56	1.70	0.00	1.70
	BDN	0.48	0.15	0.64	1.80	0.00	1.80
Pptd	KHI	0.93	0.65	1.03	3.30	0.00	3.30
	HYD	0.76	0.50	0.71	2.30	0.20	2.10
	BDN	0.67	0.30	0.80	2.40	0.10	2.30
Ppt	KHI	17.93	8.15	26.59	89.40	0.70	88.70
	HYD	14.54	4.25	21.27	59.50	1.50	58.00
	BDN	19.03	4.30	30.06	87.20	1.50	85.70

Table 3: Correlations

Variable	Station	T	T_x	T_n	Rh	Ws	S.Sd	C	T_d	Pptd
T_x	KHI	0.92								
	HYD	0.98								
	BDN	0.94								
T_n	KHI	0.98	0.83							
	HYD	0.98	0.92							
	BDN	0.97	0.85							
RH	KHI	0.83	0.56	0.92						
	HYD	0.41	0.22	0.57						
	BDN	0.46	0.15	0.64						
Ws	KHI	0.88	0.70	0.92	0.87					
	HYD	0.85	0.76	0.90	0.68					
	BDN	0.78	0.67	0.81	0.51					
S.Sd	KHI	-0.37	-0.04	-0.52	-0.76	-0.48				
	HYD	-0.00	0.17	-0.15	-0.75	-0.35				
	BDN	-0.29	-0.01	-0.46	-0.83	-0.53				
C	KHI	0.44	0.09	0.58	0.81	0.60	-0.97			
	HYD	0.13	-0.00	0.24	0.61	0.45	-0.84			
	BDN	0.31	0.03	0.48	0.84	0.51	-0.93			
T.d	KHI	0.35	0.05	0.48	0.69	0.49	-0.94	0.93		
	HYD	0.65	0.52	0.74	0.77	0.83	-0.65	0.78		
	BDN	0.48	0.20	0.64	0.91	0.62	-0.94	0.96		
Pptd	KHI	0.27	-0.03	0.41	0.64	0.42	-0.96	0.94	0.98	
	HYD	0.39	0.23	0.52	0.84	0.62	-0.84	0.89	0.93	
	BDN	0.41	0.13	0.58	0.90	0.54	-0.89	0.97	0.97	
Ppt	KHI	0.34	0.05	0.46	0.67	0.45	-0.91	0.89	0.98	0.96
	HYD	0.42	0.25	0.55	0.86	0.64	-0.82	0.85	0.93	0.98
	BDN	0.40	0.12	0.56	0.88	0.52	-0.89	0.96	0.96	0.98

Table 4: Analytical values for mean annual temperature(s)

Variable	Station	Minimum Value	Maximum Value	From	Range	MRV
Tx	KHI	30.9	33.1	30.9 to 33.1	2.2	31.0 to 32.4
	HYD	32.8	35.9	32.8 to 35.9	3.1	33.4 to 35.2
	BDN	32.3	35.6	32.3 to 35.6	3.3	32.4 to 34.8
	MST	30.2	32.4	30.2 to 32.4	2.2	30.6 to 32.0
	FST	31.9	32.7	31.9 to 32.7	2.1	31.2 to 32.8
	MNS	28.4	31.0	28.4 to 31.0	1.6	29.0 to 30.8
Tn	KHI	19.4	22.5	19.4 to 22.5	3.1	19.6 to 20.8
	HYD	19.7	22.1	19.7 to 22.1	2.4	20.0 to 22.3
	BDN	18.8	21.0	18.8 to 21.0	2.3	19.2 to 20.2
	MST	20.1	22.1	20.1 to 22.1	2.0	20.9 to 21.7
	FST	20.0	22.7	20.0 to 22.7	2.7	20.6 to 21.0
	MNS	21.4	23.3	21.4 to 23.3	1.9	21.9 to 22.6
T	KHI	25.3	27.5	25.3 to 27.5	2.2	25.6 to 25.9
	HYD	27.6	8.9	27.6 to 28.9	2.3	27.1 to 28.0
	BDN	25.8	27.7	25.8 to 27.7	1.9	26.5 to 27.5
	MST	25.4	27.2	25.4 to 27.2	1.8	25.8 to 26.2
	FST	25.8	27.7	25.8 to 27.7	1.9	26.0 to 26.5
	MNS	25.1	26.7	25.1 to 26.7	1.6	25.6 to 27.1

Table 5: Mean, Maximum and Minimum Temperatures and their respective differences for Karachi, Hyderabad and Badin.

S.No	Station	T (^oC)	ΔT (C^o)	T_x (^oC)	$\Delta T(C^o)$	T_n (^oC)	$\Delta T(C^o)$
1	HYD	27.61	ΔT_{u-c} = 1.41	34.41	ΔT_{u-c} = 2.6	20.8	ΔT_{u-c} = 0.3
2	KHI	26.2	ΔT_{u-r} = 0.81	31.8	ΔT_{u-r} = 0.7	20.5	ΔT_{u-r} = 0.9
3	BDN	26.8					

Table 6: Mean monthly sunshine hours and percentage

	Station	Hours	Percentage
Annual	HYD (Urban)	265.1	74
	BDN (Rural)	252.5	70
	KHI (Coastal Urban)	240	66
July & August	HYD (Urban)	217.5	60
	BDN (Rural)	160.8	44
	KHI (Coastal Urban)	135.3	37

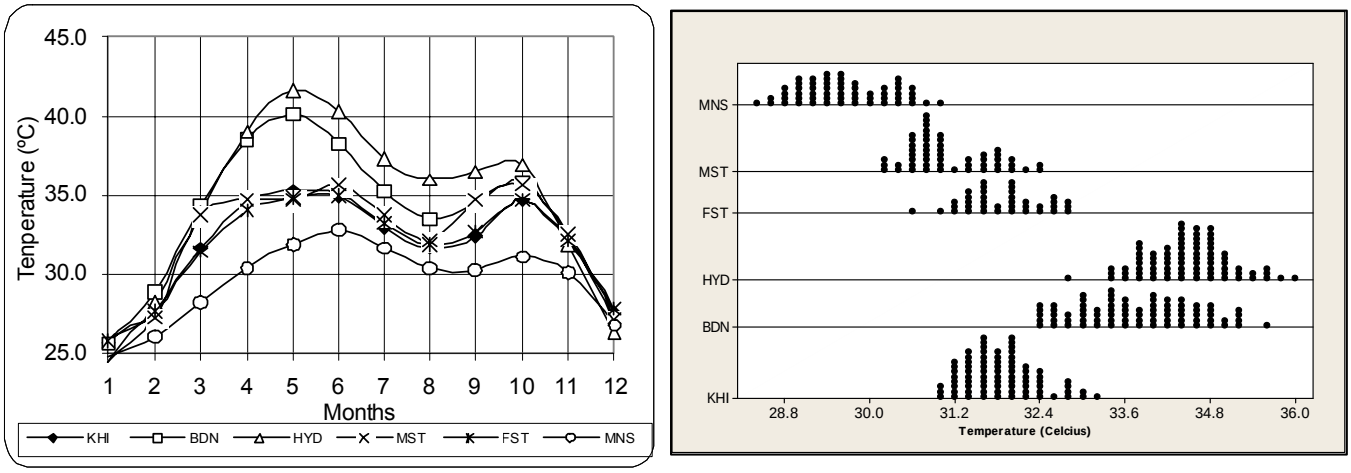


Figure 1: Mean Monthly and Mean Annually Maximum Temperatures for Urban, Rural and Coastal Urban

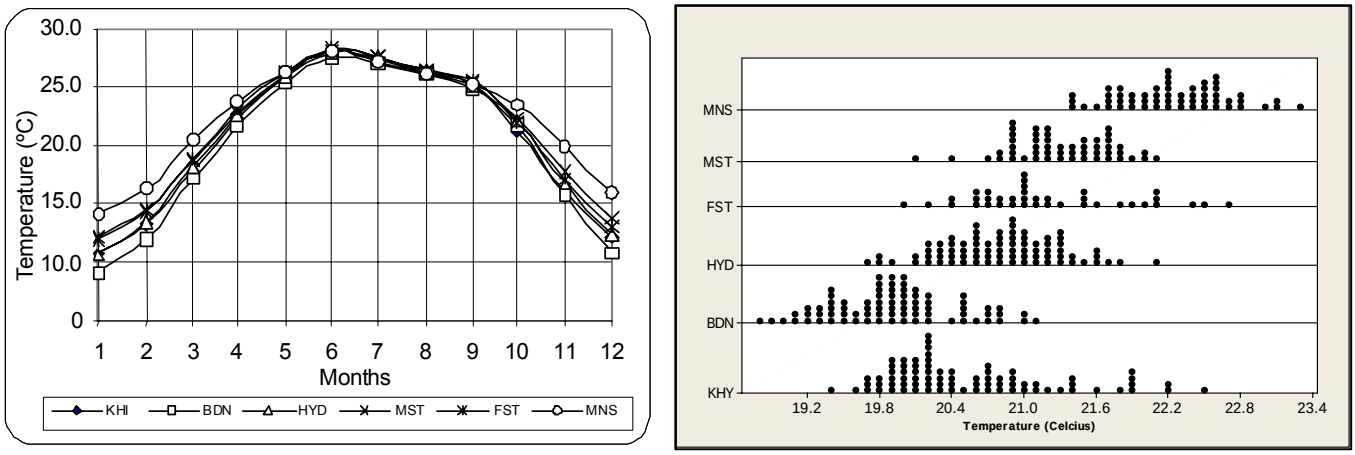


Figure 2; Mean Monthly and Mean Annually Minimum Temperatures for Urban, Rural and Coastal Urban

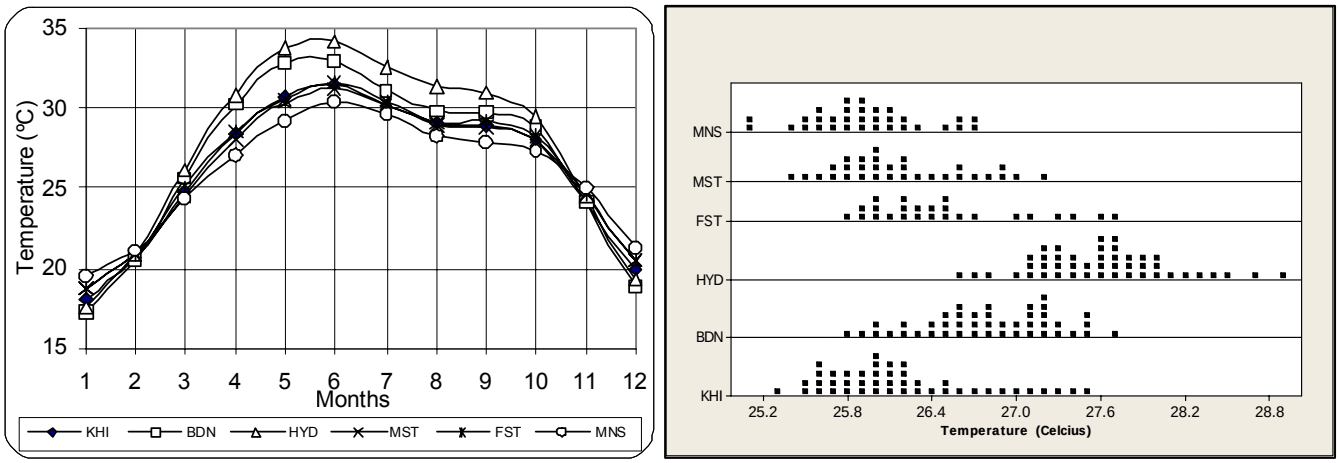


Figure 3: Mean Monthly and Mean Annually Temperatures for Urban, Rural and Coastal Urban

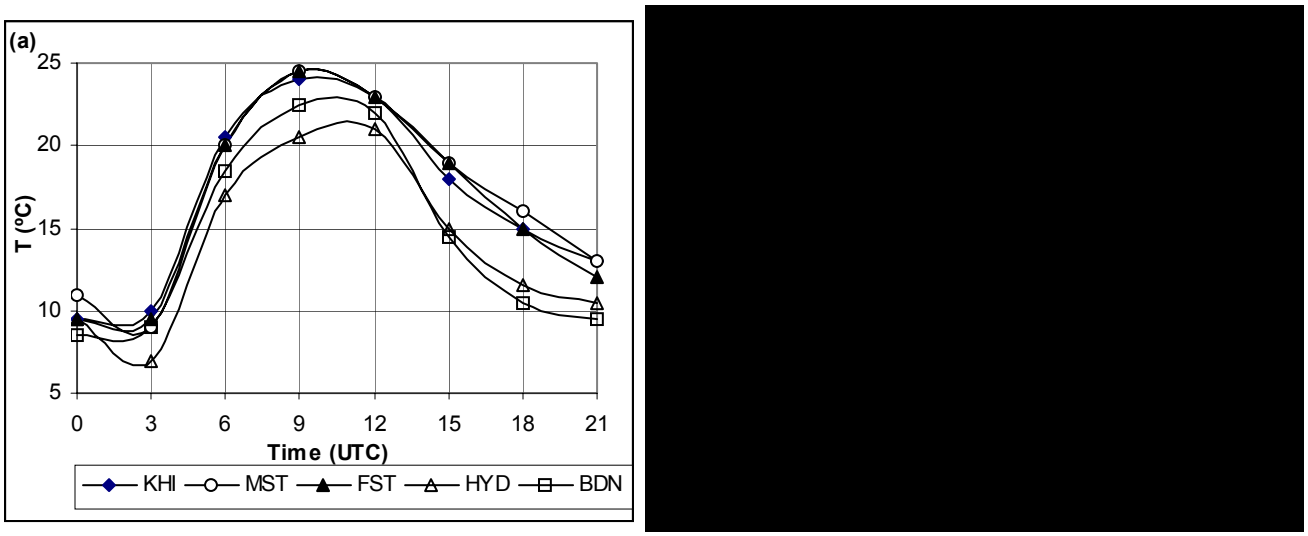
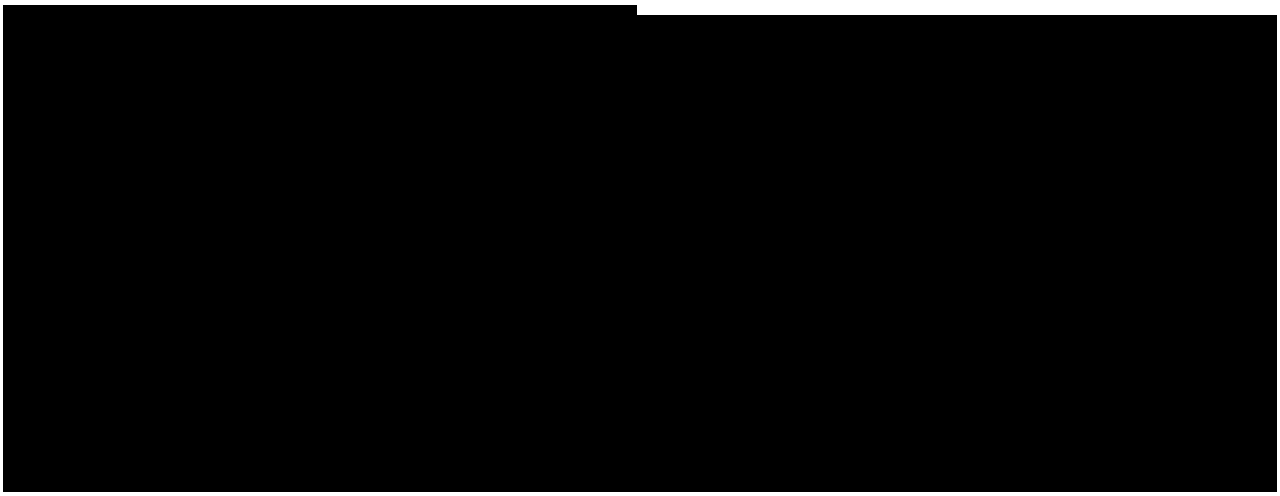


Figure 4: Diurnal Variations of Temperature for 1st January and 1st May 2008



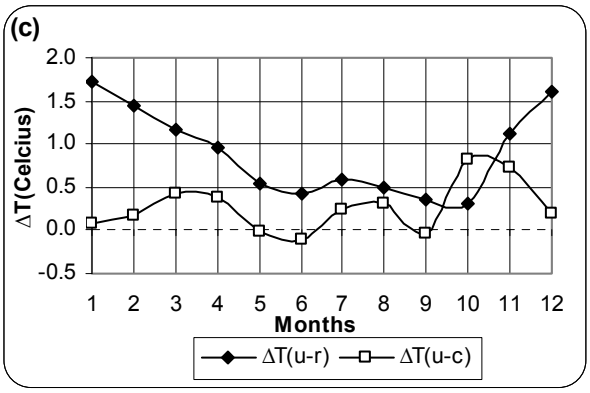


Figure 5: a. Mean Monthly Temperature Heat Island Intensity **b.** Mean Monthly Maximum Temperature Heat Island Intensity **c.** Mean Monthly Minimum Temperature Heat Island Intensity

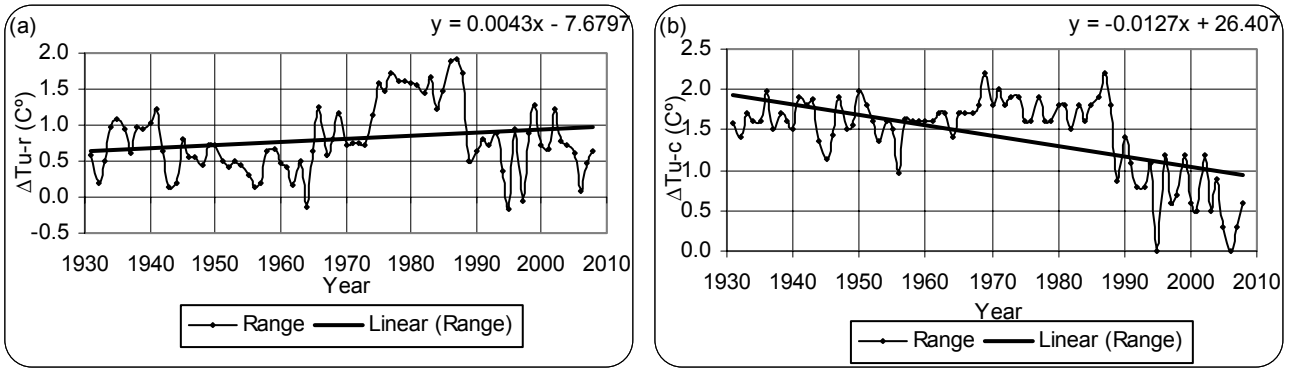


Figure 6: a. Mean Annual Temp. Range between HYD & BDN **b.** Mean Annual Temp. Range between HYD & KHI

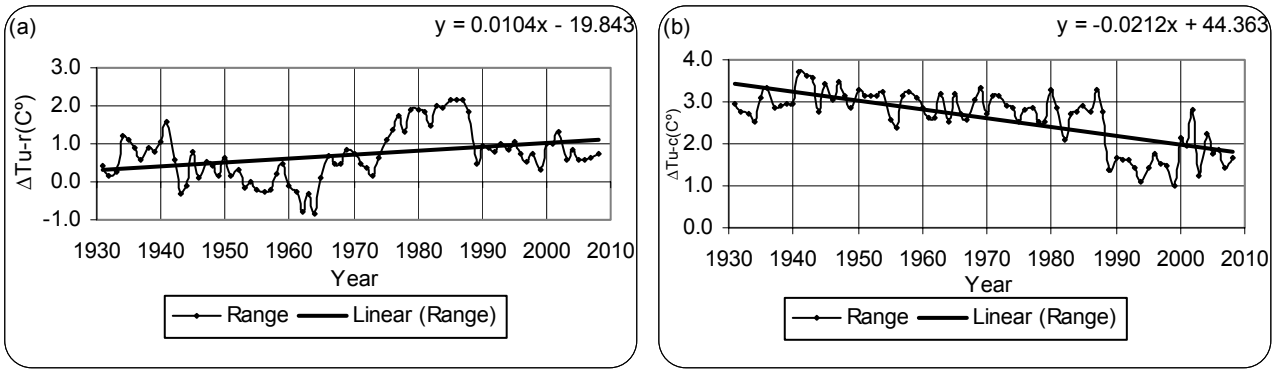


Figure 7: a. Mean Annual Max. Temp. Range between HYD & BDN **b.** Mean Annual Max Temp. Range between HYD & KHI

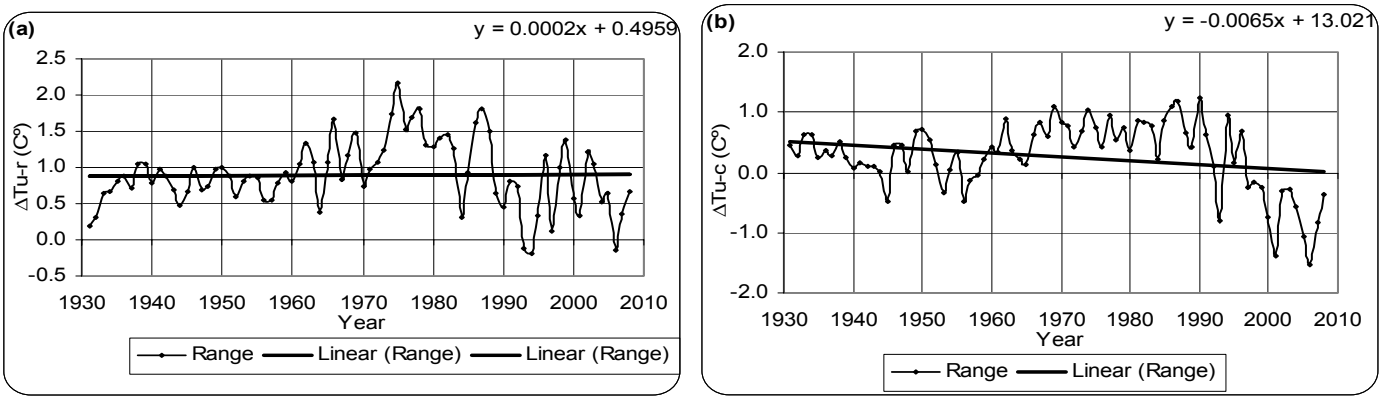


Figure 8: a. Mean Annual Min. Temp. Range between HYD & KHI **b.** Mean Annual Min Temp. Range between HYD & BDN

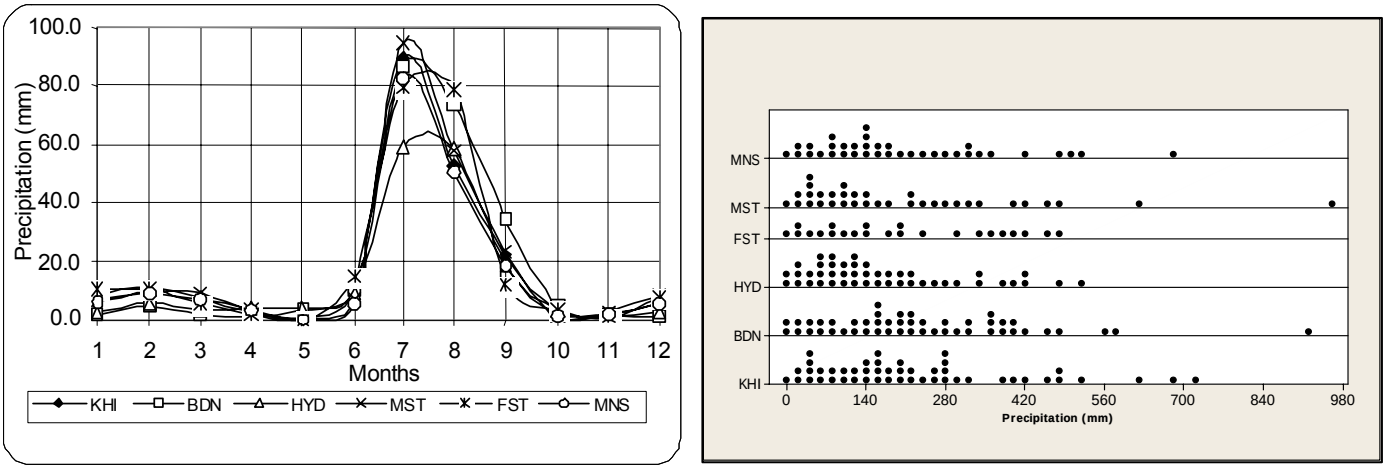


Figure 9: Mean Monthly and Mean Annually Precipitation for Urban, Rural and Coastal Urban

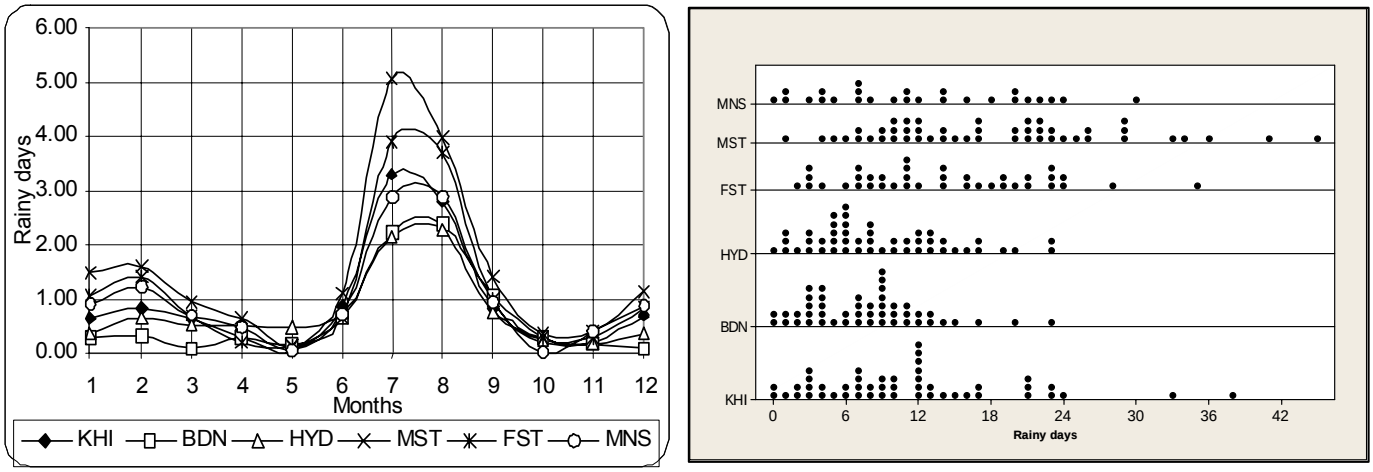


Figure 10: Mean Monthly and Mean Annually rainy days for urban, rural and coastal urban

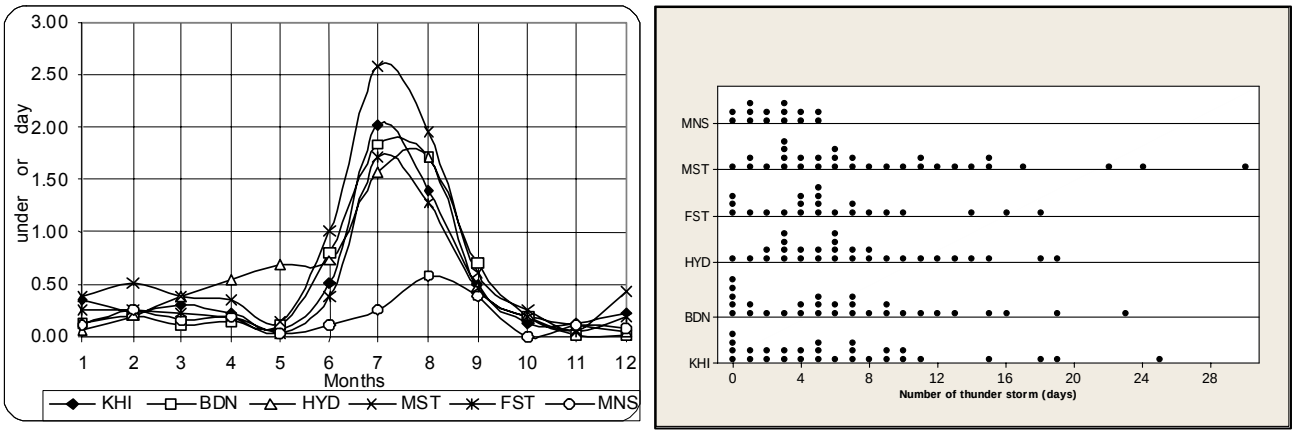


Figure 11: Mean Monthly and Mean Annually Thunder storm of Karachi stations (KHI, MST, FST, MNS), Hyderabad and Badin

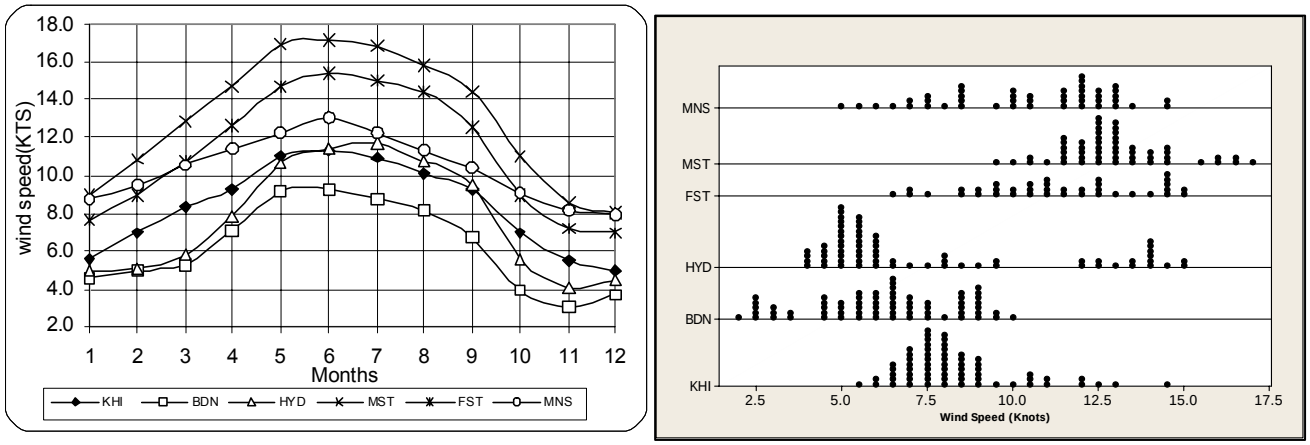


Figure 12: Mean Monthly and Mean Annually wind speeds for urban, rural and coastal urban

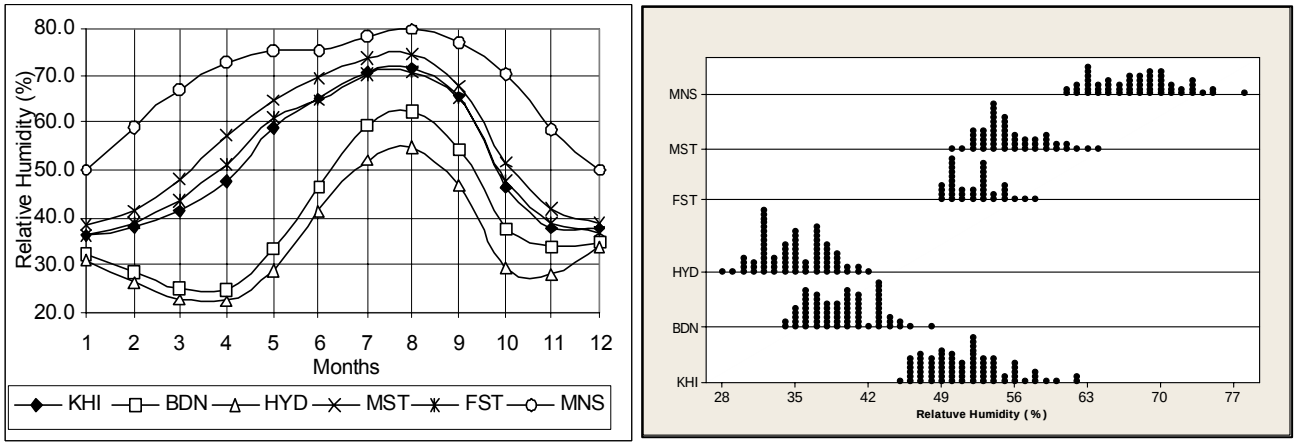


Figure 13: Mean Monthly and Mean Annually relative humidity for urban, rural and coastal urban

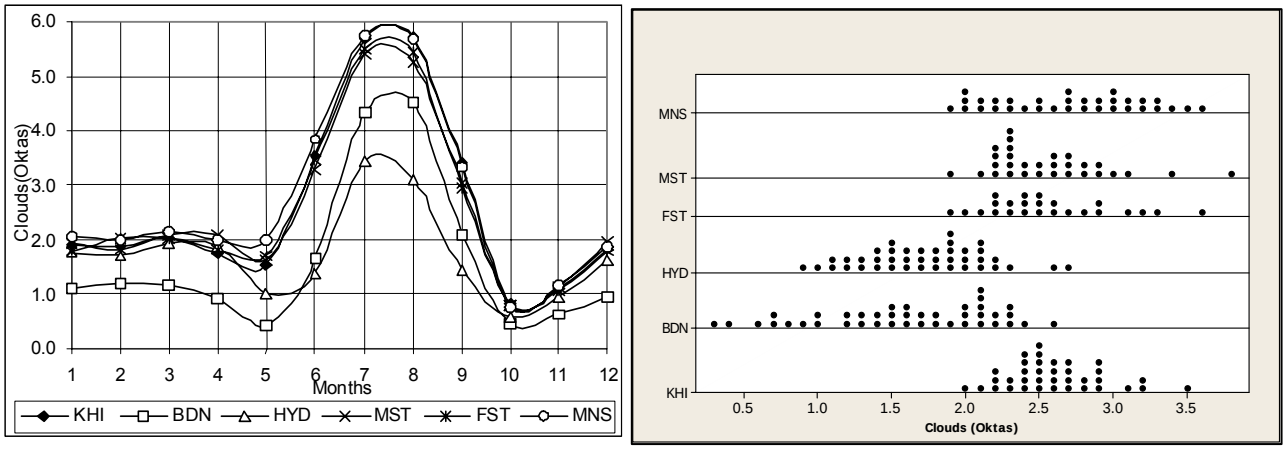


Figure 14: Mean Monthly and Mean Annually Total Clouds of Karachi stations (KHI, MST, FST and MNS), Hyderabad and Badin

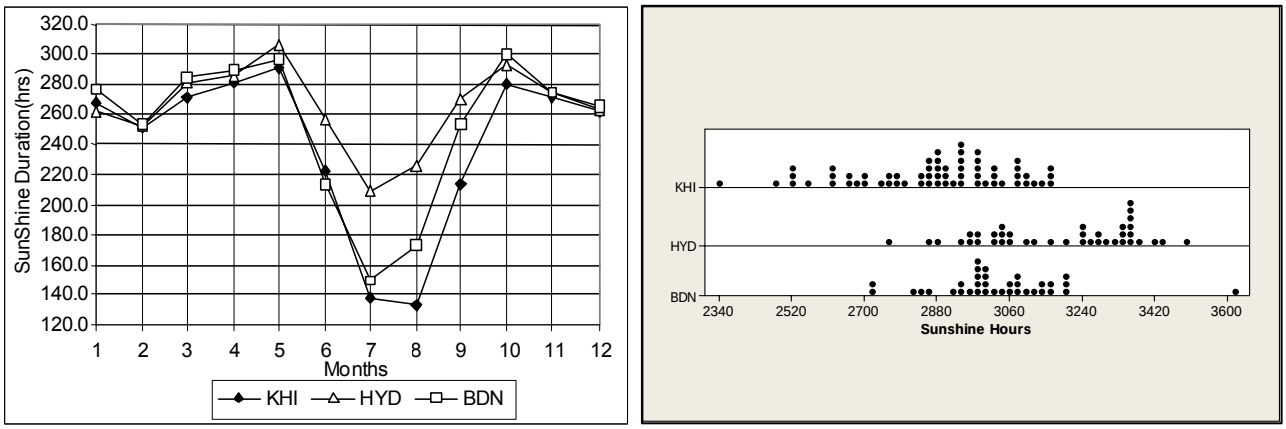


Figure 15: Mean Monthly and Mean annually sunshine for urban, rural and coastal urban