Rise in Summer Heat Index over Pakistan

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Abstract:

Heat index is a serious threat to health in Southern Punjab, almost all parts of Sindh, South eastern Balochistan extending upto coast and plains of North Eastern Balochistan of Pakistan particularly during summer. The temperature is rising due to anthropogenic activities resulting in global warming. Summer season has prolonged while winters have become short in Pakistan. Summers have become hotter and thus affecting the lives of the people engaged in outdoor activities during scorching sun hours. The rise in heat index has been calculated from 1961 to 2007 during summer (May- September) in different regions of the country. The aim of this paper is to identify the spots most vulnerable to heat strokes, heat waves and sun burns due to high heat index. The results show rising trend of heat index in almost all the regions of Pakistan. The highest increase in heat index value has been observed in areas of Azad Jammu & Kashmir. The second highest increase is observed in Punjab and Sindh regions where thermal regime is already a challenge to human tolerance. Even Northern Areas, Balochistan and NWFP have also shown rising trend of heat index. The summer season analysis for the entire Pakistan has also done combining all the regions of the country to calculate the total change in heat index over the time scale of 47 years. . The average increase in apparent air temperature in Pakistan is 3°C. (276.15K). Pakistan experiences a clear shift in heat index pattern from its southern half towards northern half.

Key words: Heat index, Ambient dry-bulb temperature, Relative humidity, Heat stroke and Heat cramps.

Introduction

Pakistan lies in South Asia between latitudes 24 o N to 37 o N and longitudes 60 o E to 75 o E. The country covers such an area of land that the climate in one place is quite different from that in the other. The climate is generally arid, characterized by hot summers and cool or cold winters and wide variations between extremes of temperature at given locations (Chaudhry & Rasul, 2004). The sustained high temperature and high humidity for a certain period have long been recognized as a significant weather hazard. The high values of the heat index can pose a health risk to anyone engaged in outdoor activity over a short period of time; a greater general danger to public health exists when the heat index remains high for an extended period of time.

Heat index is a measure of the stress placed on humans by elevated levels of atmospheric temperature & moisture. As the atmospheric moisture content increases the ability of human body to release heat through evaporation is inhibited thereby causing discomfort and stress. The regions most prone to this effect include humid regions of tropics and summer hemisphere extra tropics including southeastern United States, India, Southeast Asia and Northern Australia (Delworth et al., 1999)

Heat affects every individual's performance, attitude and overall health. Projections from the climate models suggest that global surface air temperature will increase substantially in future due to radiative effects of enhanced atmospheric concentrations of gases (Delworth et al., 1999).

The rise in heat index results in higher heat related mortality rate during summer. The combination of heat and high humidity may cause discomfort, heat stroke or even death to humans and animals. These heat related incidences have been studied extensively by various authors (Keatinge et al., 2000, Guest et al., 1999, Kumar, 1998, Pan & Li, 1995, Donaldson et al., 2003, Cristo et al., 2003 & Piver et al., 1999).

The heat related-illness and casualties are likely to increase with predicted incidence of global warming and increasing duration of heat waves. The thermoregulatory control of human skin blood flow is vital to maintain the body heat storage. Heat load exceeds heat dissipation capacity which alters the cutaneous vascular responses along with other body physiological variables (Aggarwal et al., 2007). The relationship between the heat index and heat disorders has been summarized in Table 1. Tropical people

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accept as comfortable considerably higher levels of air temperature and humidity than are accepted by temperate zone groups shown in Table 1. Out door workers also tolerate higher temperatures than sedentary indoor workers. Adults at rest appropriately clothed for the environment and not exposed to solar radiation or to relative humidity above 50% have the following model comfortable dry-bulb temperatures: cool temperate zone 17°C (290.15K), temperate zone 23°C (296.15K), subtropics 25°C (298.15K), tropics 27°C (300.15K). It appears that tropical people accept some sweating as a component of comfort and thus heat index range from 27-32°C is tolerable for the people of our region (Gadiwala & Sadiq, 2008).

Heat Index	**Health Effects**
27°C – 32°C (300.15 - 305.15 K)	Fatigue possible with prolonged exposure and/or physical activity.
32 – 41 °C (305.15 - 314.15 K)	Heat cramps and heat exhaustion possible with prolonged exposure and/or physical activity.
41 – 54 °C (314.15 - 327.15K)	Heat cramps or heat exhaustion likely and heatstroke possible with prolonged exposure and/or physical activity.
> 54 °C >327.15 K or higher	Heatstroke highly likely with continued exposure.

In this study trends have been drawn among different regions of Pakistan using average heat index anomalies. The intent of this study is to calculate change in heat index in all the regions of Pakistan during summer (May-September) for a period 1961-2007. The summer season analysis has also been done for the entire Pakistan (all the regions of the country) to calculate the total change in heat index over the time scale of 47 years. Its results illustrate that enhanced level of atmospheric temperature and humidity in summer is causing significant rise in heat index. A shift in heat index patterns has also been calculated.

Methodology

The Heat Index (Steadman, 1979, 1984) is usually simplified as a relationship between ambient temperature and relative humidity versus skin (or apparent) temperature. There is a base relative humidity at which an apparent temperature ‘‘feels’’ like the same air temperature. Increasing (or decreasing) humidity and temperature result in increasing (or decreasing) apparent temperature.

In order to arrive at an equation which uses more conventional independent variables, a multiple regression analysis was performed on the data from Steadman's table. The resulting equation could be considered a Heat Index equation (Rothfusz, 1990)

$$\mathbf{HI = -42.379 + 2.04901523T + 10.14333127R – 0.22475541TR – 6.83783 \times 10\text{-}3T2}$$

$$\mathbf{-5.481717\times10\text{-}2R2 + 1.22874\times10\text{-}3\ T2R + 8.5282\times10\text{-}4\ TR2 – 1.99\times10\text{-}6T2R2 \quad (Eq.\ 1)}$$

Where,

T = ambient dry bulb temperature
R = relative humidity

Such a formula (Equation 1) is applicable only when air temperature and humidity are higher than 26ºC and 39%, respectively. Because this equation is obtained by multiple regression analysis, the heat index value (HI) has an error of ±1.3°F (1.5ºC or 274.65K). The values of heat index were then further converted in Celsius scale.

The real time data of mean monthly maximum temperature and relative humidity for a period 1961-2007 was obtained from Pakistan Meteorological Department, Islamabad in order to calculate heat index.

The average (MJJAS) heat index anomalies were obtained by subtracting the actual values of heat index with the 1971-2000 mean appropriate values during the period 1961-2007.

In order to illustrate the normal situation of heat index during summer (May-September) in Pakistan, the mean monthly maximum temperature and relative humidity of Climate Normals from 1971-2000 were used to calculate the normal values of heat index (Fig .1).

Surfer version 8.04 was used to map the normal scenario of heat index during summer (May-September) in Pakistan.

Results & Discussion

The normal scenario of heat index in Pakistan during summer i.e. (May-September) is presented in Figure 1. Most of the country is under the effect of high heat index. The areas of Southern Punjab, South eastern Balochistan extending upto coast, low elevation and plains of North Eastern Balochistan lies within the danger zones from May till September. Almost all the areas of Sindh particularly Nawabshah, Larkana, Jaccobabad, Hyderabad, Karachi, Chhor and Padidan are under extreme danger zone where health problems such as heat strokes and sunburns are most likely to humans and animals exposed for an extended forenoon to afternoon hours. The rest of the regions lie in relatively the comfort zone, which is not beyond the human tolerance of the genetic features of inhabitants of this area.

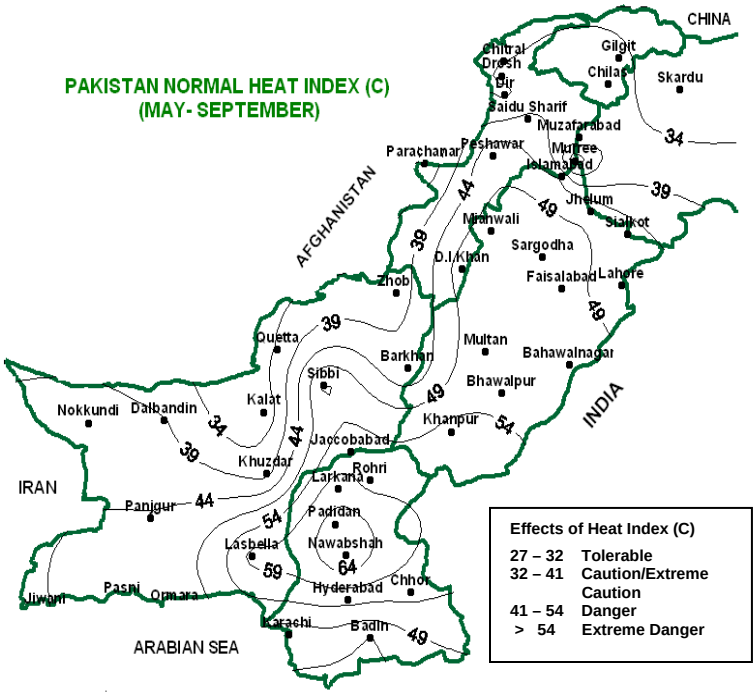

Figure 1: Normal Scenario of Heat Index during Summer (May to Sept) in Pakistan

Punjab (Bahawalpur, Faisalabad, Islamabad, Jehlum, Khanpur, Lahore, Multan, Murree, Sialkot, and Sargodha) comprises upper Indus plain, where land remains under extensive agriculture for most of the year. In summer high temperatures have been recorded in this region of Pakistan. The trend drawn with the help of average (MJJAS) heat index anomalies from 1971-2000 has shown tremendous rise in apparent temperature in Punjab during the study period. The results are shown in Figure 2 (a). The total increase calculated is 3.5ºC (277K) which is statistically significant at 95% confidence level. This rise in apparent temperature will not only add to the discomfort of humans but also greatly affect flora and fauna of the region. The highest peak is observed in 2000 when relative humidity and maximum temperature both are increasing side by side in Figure 2 (b).

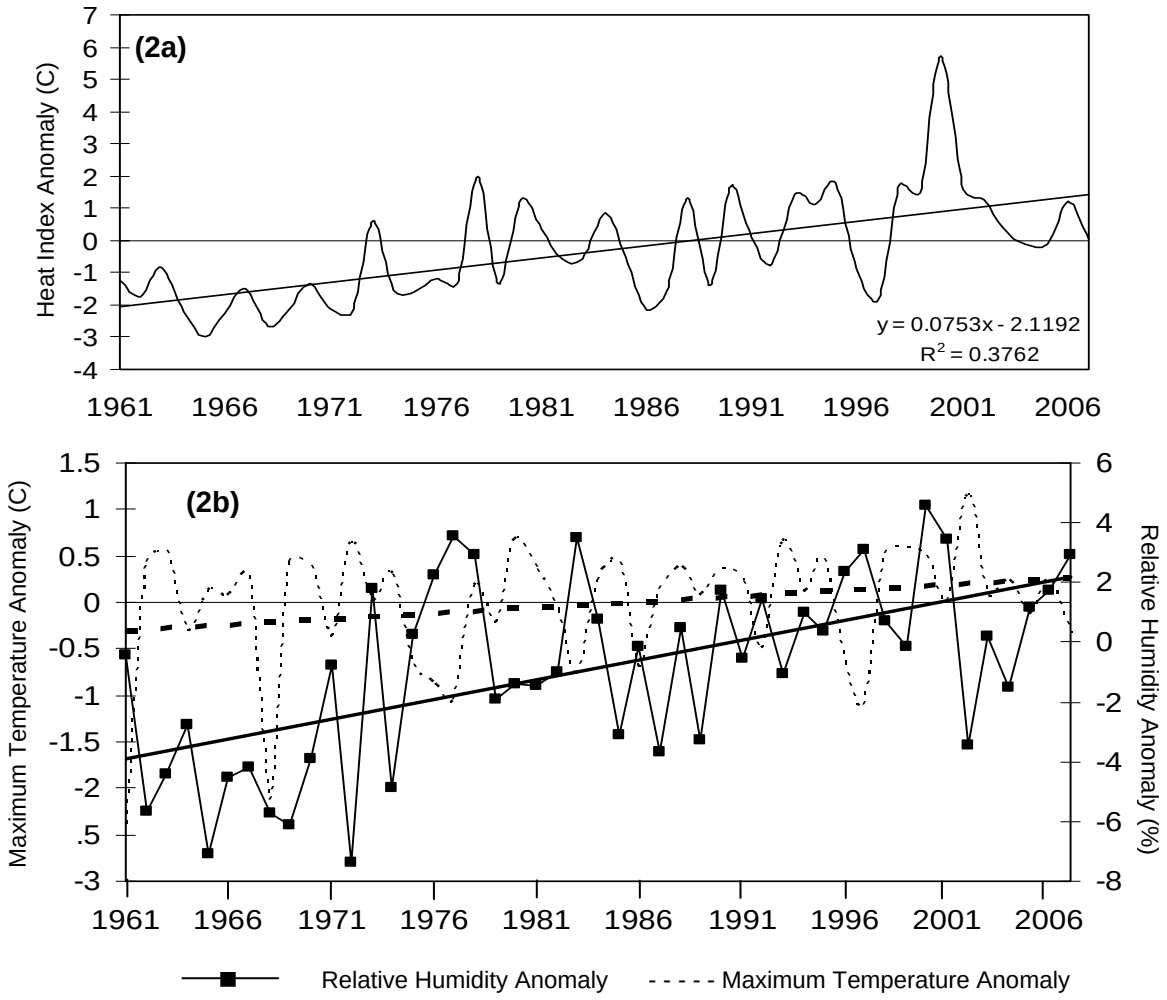

Figure 2: **a.** Heat Index Anomalies in Punjab (1961 - 2007) **b.** Maximum Temperature and Relative Humidity Profile of Punjab (1961 - 2007)

Pakistan experiences serious heat index in its south eastern parts (Chhor, Badin, Hyderabad, Jaccobabad, Nawabshah, Padidan, Karachi and Rohri) which falls under desert like hyper-arid climates. Chances of heat stroke/sunstroke are much prominent in the peak summer days (Gadiwala & Sadiq, 2008). Figure 3 (a) shows sharp increase in the rising trend of heat index in this region. The total increase calculated was 3ºC (276.15K) which is also a significant rise in apparent temperature during the 47 years period i.e. from 1961-2007. The rise in heat index started from 1980. The highest peak of heat index is observed in 1988.The mean maximum temperature at most of the stations exceeded 41ºC and high values of relative humidity are the reason for this peak. Even if the temperature is moderate still high values of humidity during summer makes life uncomfortable in this region Figure 3 b.

In most parts of Balochistan (Panjgur, Quetta, Pasni, Sibbi, Dalbandin, Jiwani, Nokundi, and Zhob) winters are extremely cold and summers are unbearably hot. Mercury drops below 0ºC (273.15K) at certain points due to invasion of cold northerly winds in other areas dry and bare mountains absorb heat during day time and retain high temperature for long. The apparent temperature is showing an increasing trend in this region as well Figure 4a. The total rise in heat index calculated for summer season is 1.34ºC (274.5K). One of the hottest spot in the world i.e. Sibbi is also part of this region. The highest peak is observed in the year 1988 because of high maximum temperature and relative humidity during summer

whose cumulative effect cause sharp rise in heat index as shown in Figure 4b. In this region Pasni, Sibbi and Jiwani, inspite of monsoon rain effects, record higher temperatures. Nokkundi and Dalbandin have no monsoon rain effect and so the temperature continues to rise up in this area of Balochistan. With increasing trend of temperature and decreasing trend of humidity heat index will decrease, because rate of evaporation increases with low humidity and high temperature. The internal body temperature remains maintained and humans do not feel heat stressed.

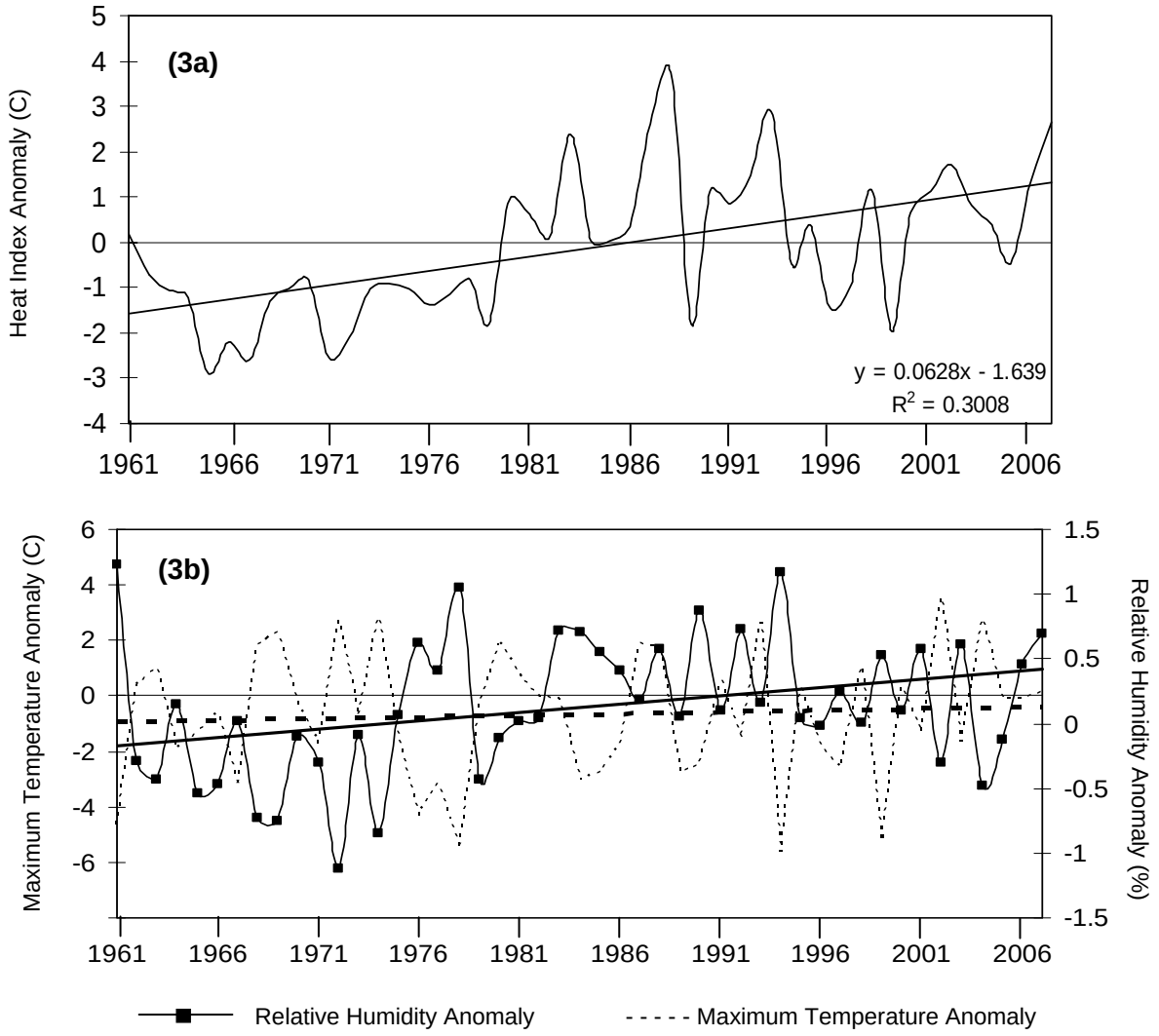

Figure 3: a. Heat Index Anomalies in Punjab (1961-2007) **b.** Maximum Temperature & Relative Humidity Profile of Sindh (1961-2007)

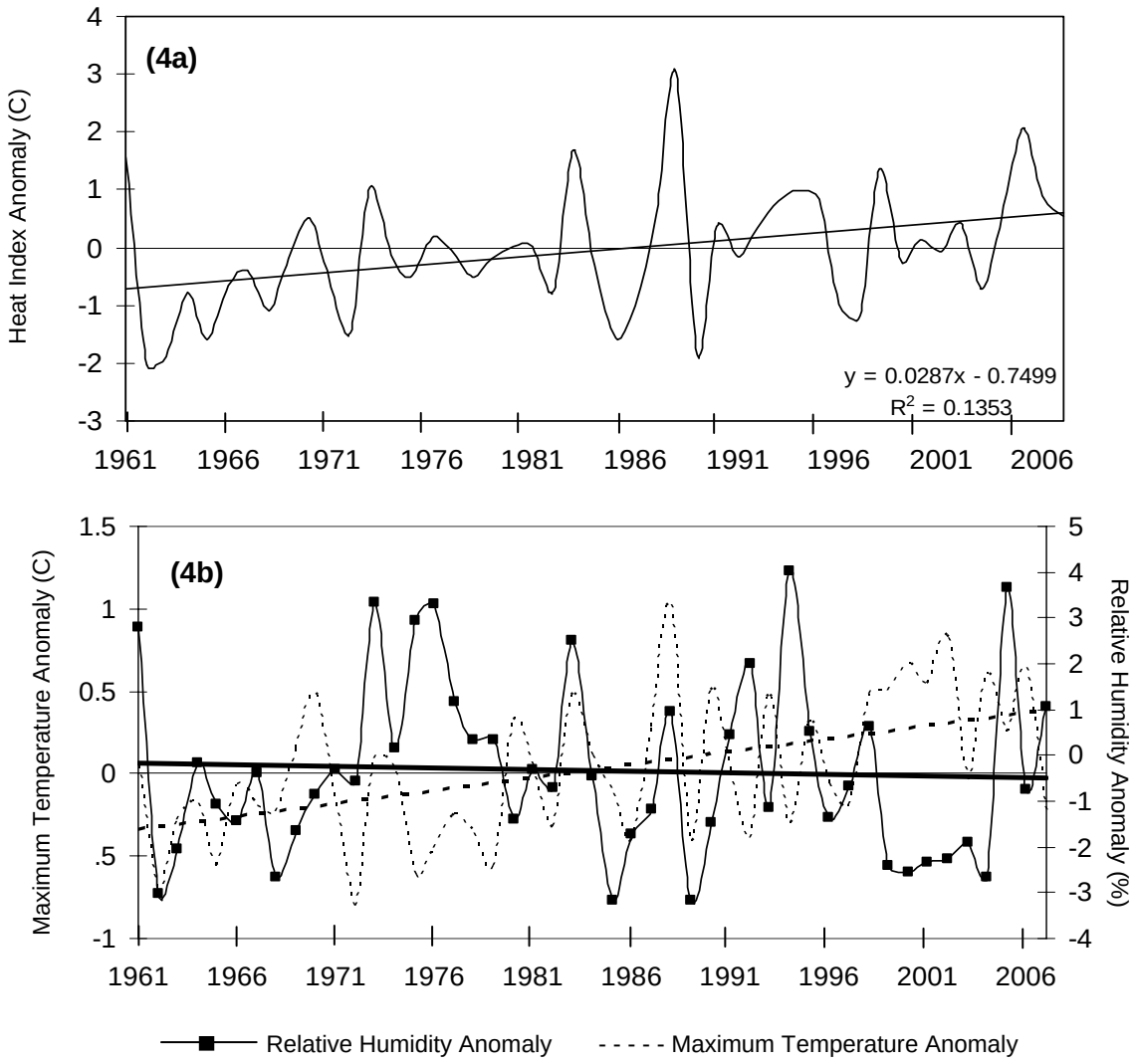

Figure 4: a. Heat Index Anomalies in Balochistan (1961-2007) **b.** Maximum Temperature & Relative Humidity Profile of Balochistan (1961-2007)

The atmosphere and lands are very dry in Northern Areas (Bunji, Chilas, Gilgit, Skardu, and Astore) of Pakistan. This region claims some of the world's highest mountain peaks like K2, Nanga Parbat and Raka Poshi. There is a big difference in temperature between exposure in the sunshine and in the shade. Nights are very cold and days are comparatively warm. Figure 5a shows that there is a gradual rise in heat index values. The total increase calculated in this region is 2 ºC (275.15K) over the time scale of 47 years. The highest peak is observed in 1990 due to high values of humidity and ambient air temperature shown in Figure 5b. Summer rainfall or cloudiness is most appropriate reason for rising trend of humidity and decreasing trend of maximum temperatures in Northern areas.

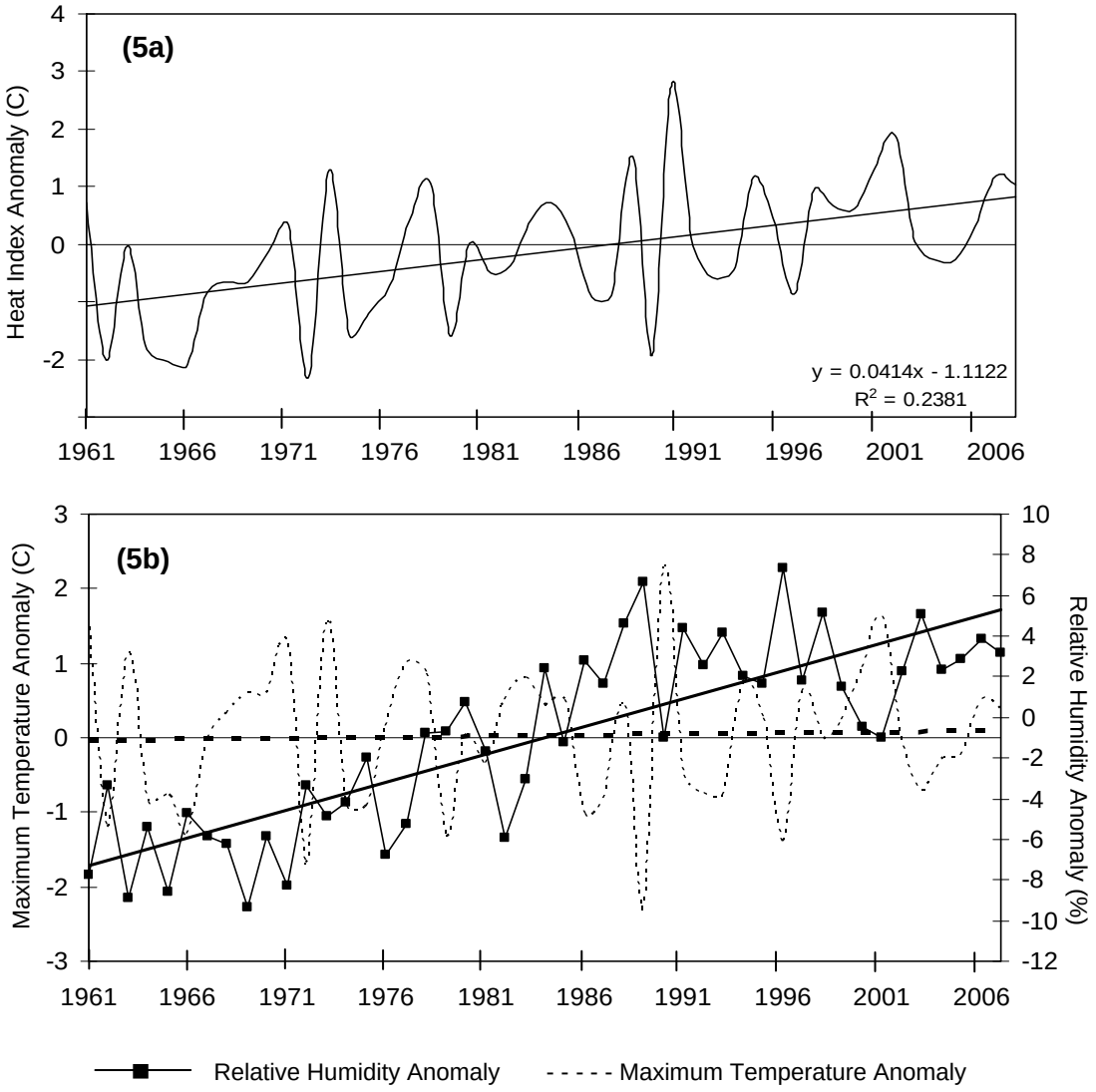

Figure 5: a. Heat Index Anomalies in Northern Areas (1961-2007) **b.** Maximum Temperature & Relative Humidity Profile of Northern Areas (1961-2007)

Northern half of North-West Frontier Province (NWFP) (Balakot, Cherat, Chitral, Drosh, Parachinar, and Peshawar) receives substantial amount of rain in summer and winter therefore a good vegetation cover the soil during the year. Southern half is, however, dry and experiences temperatures and humid conditions like central Punjab. Semi arid to arid climates of the province get heated touching the extreme daytime temperature above 40ºC (313.15K). NWFP is also showing an increasing trend in heat index Figure 6a. The total increase in heat index is almost 1ºC (274.15K) in this region which is statistically a significant change. The trend of relative humidity in NWFP have shown sharp increase during the study but at the same time maximum temperature is decreasing therefore there is a very slight increase in heat index in this region Figure 6 b.

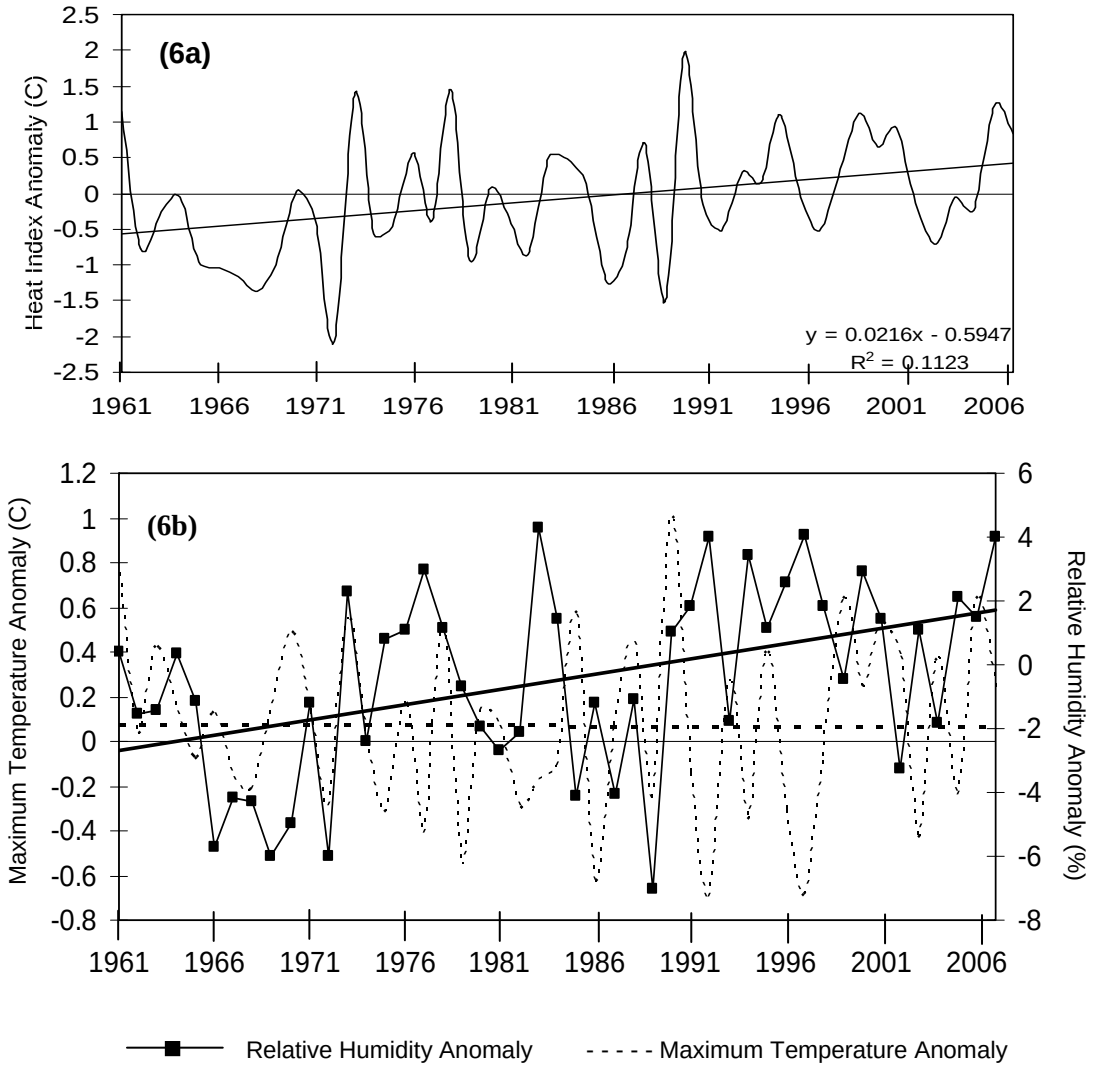

Figure 6: a. Heat Index Anomalies in NWFP (1961-2007) **b.** Maximum Temperature & Relative Humidity Profile of NWFP (1961-2007)

Climatic conditions of Azad Jammu & Kashmir (Muzaffarabad, Kotli and Garhi Dupatta) have great similarities to that of upper NWFP. The area enjoys both summer and winter precipitation and falls within sub humid climatic zones. There is quite a major boost in heat index values during summer season in Azad Kashmir during the study period. Figure 7a is showing gradual increase in the trend of heat index and the total change calculated in this region is 6 ºC (279.15K). The maximum change calculated in this region is due to an increasing trend in temperature and humidity both as shown in Figure 7b. Kashmir is the land of pastures so the rate of evapotranspiration is also maximum here making the atmosphere more humid.

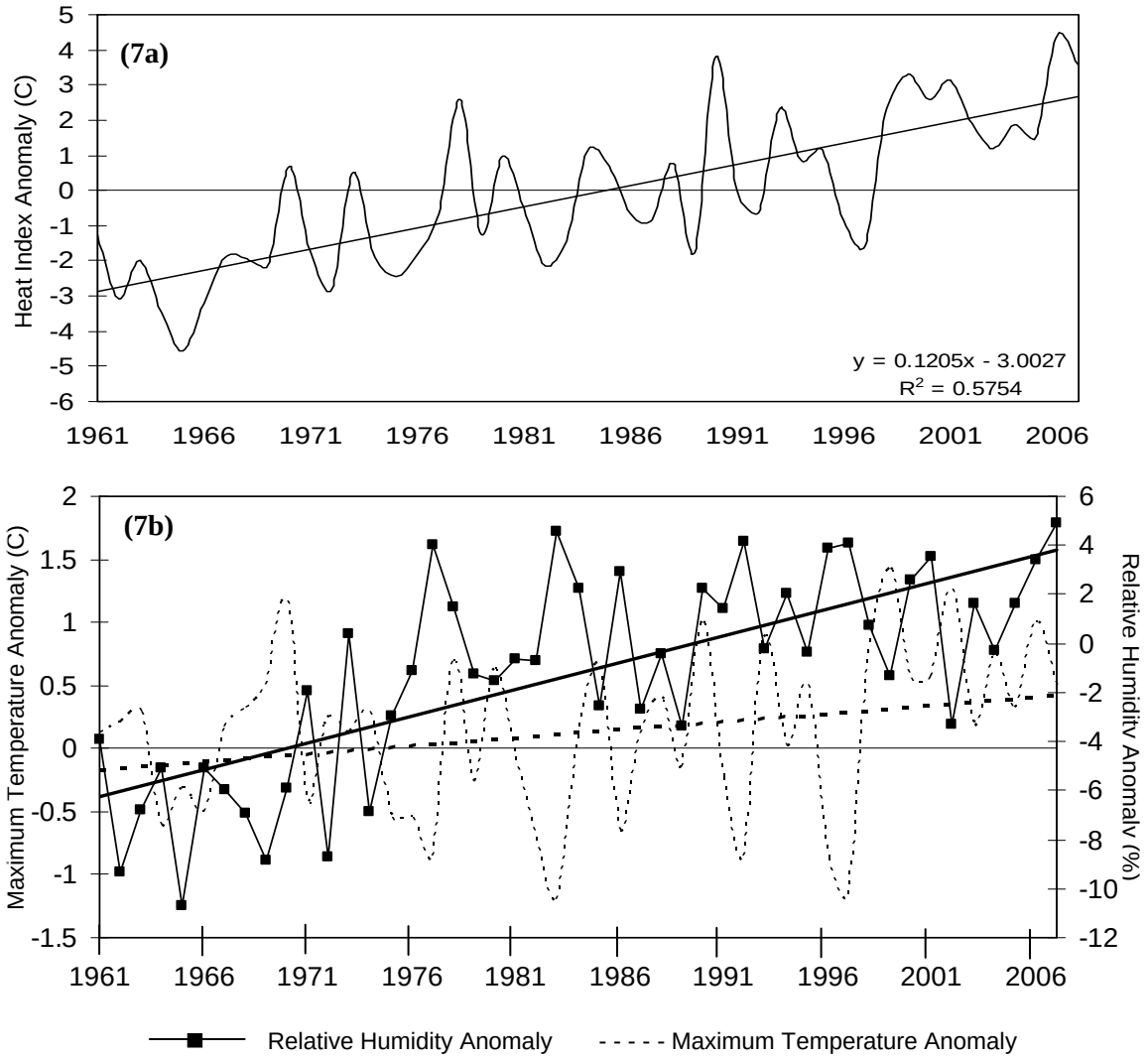

Figure 7: a. Index Anomalies in Azad Jammu & Kashmir (1961-2007) **b.** Maximum Temperature & Relative Humidity Profile of Azad Jammu & Kashmir (1961-2007)

In Pakistan normally heat index and its possible effects starts from May and extends upto September. Seasonal analysis of heat index for the entire Pakistan depicts that there is significant increase in apparent temperature for the last 47 years i.e. 1961-2007. The total increase in heat index calculated during the season is 3°C (276.15K) Figure 8a. The maximum temperature and relative humidity profile for the whole Pakistan is presented in Figure 8b. There is a significant rising trend of both the factors which is the ultimate cause of sharp increase in heat index values in Pakistan. The total change in humidity calculated during summer from 1961-2007 for entire Pakistan is 6.2% and total change in maximum temperature is 0.25°C (273.4K).

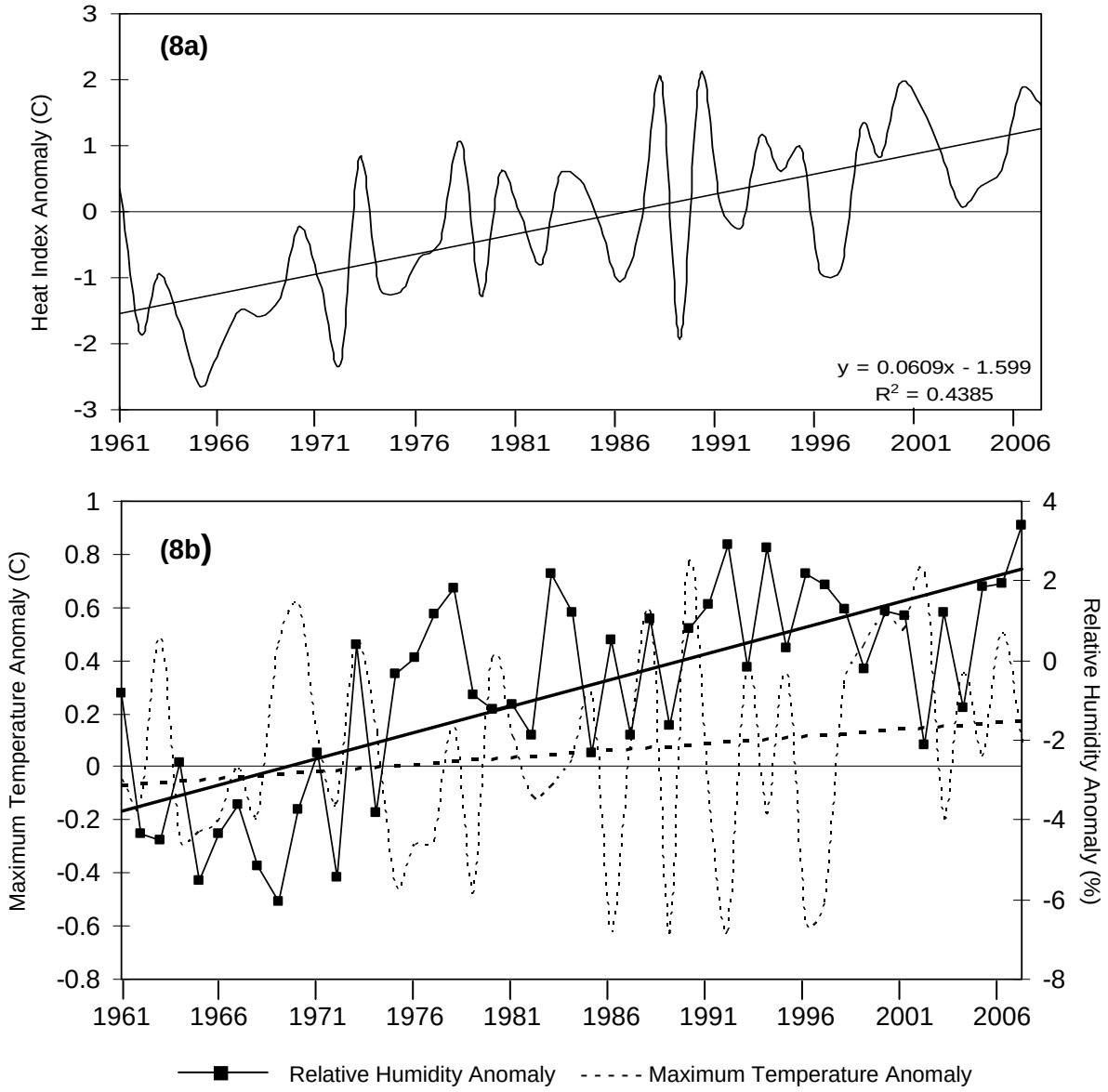

Figure 8: a. Heat Index Anomalies in Pakistan (1961-2007) **b.** Maximum Temperature & Relative Humidity Profile of Pakistan (1961-2007)

Shift in Heat Index Pattern

Pakistan has experienced an obvious shift in heat index pattern from its Southern half towards Northern half. This shift has been studied by comparing the heat index values of 1961-1990 with 1971-2000. Fig (9a) shows that in 1961-90 Nawabshah, Padidan, Rohri, Moenjedaro, Hyderabad, Chhor and Jaccobabad and Sibbi lies within extreme danger level of heat index whereas D.I Khan, Peshawar, Kotli, Karachi, Badin, Jiwani, Nokundi, Pasni, Ormara, Panjgur, Barkhan and all parts of Punjab lies within the dangerous level of heat index. The slight effect of heat index have been observed in Muzaffarabad, Garhi Dupatta, Saidu Sharif, Dir, Zhob, Quetta, Dalbandin, Khuzdar and Chilas and rest of the areas including Northern areas, Kalat and Parachinar lies within the comfort zone. Fig (9b) clearly shows that the areas within extreme danger level of heat index have been extended upto some parts of southern Punjab.

Muzaffarabad, Garhi Dupatta and Saidu Sharif which were under the slight effects of heat index are now lies within the dangerous zone of heat index. Some parts of Northern Areas & Northern NWFP (Gupis, Giligit, Bunji, Chitral and Drosh) which were previously a part of comfort zone now comes under the slight effect of heat index.

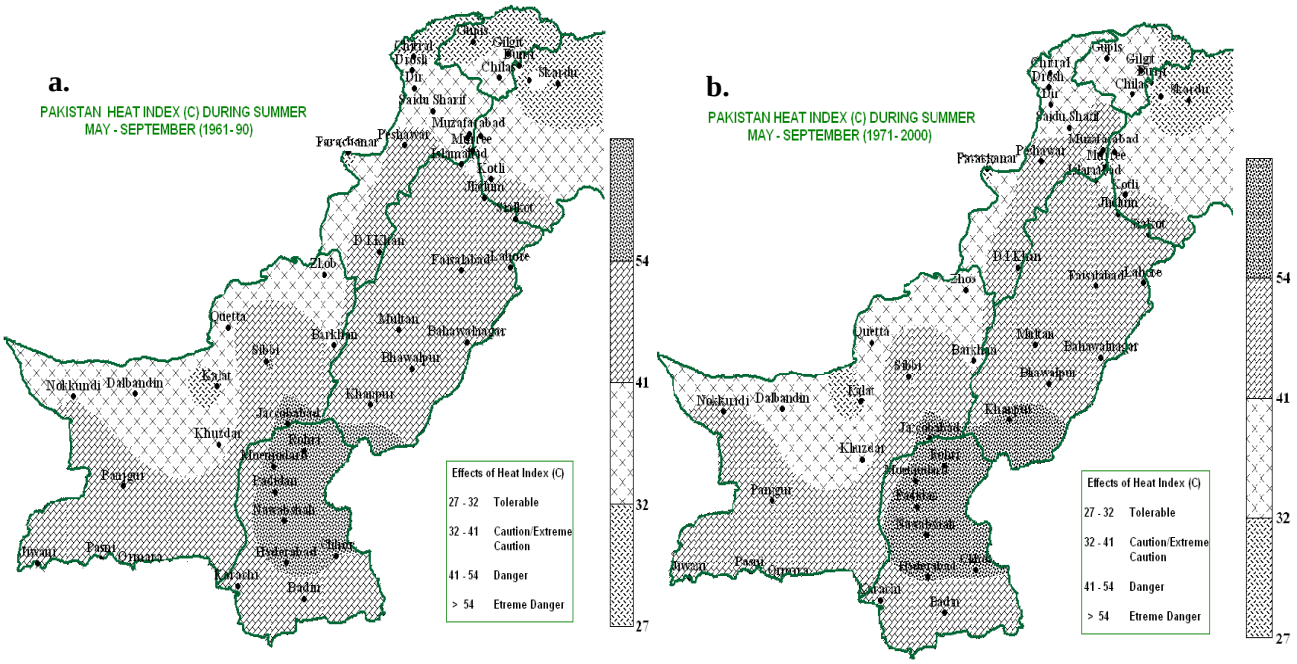

Figure 9: Pakistan Normal Heat Index (C) May – Sep **a.** (1961-1990) **b.** (1971 – 2000)

Conclusion

On the basis of discussed results it is quite obvious that the trend of heat index (apparent temperature) has shown significant increase during the summer season from 1961-2007 in different regions of Pakistan. Almost all the regions have shown rising trend. Change in heat index is associated with two factors. The first one is daytime temperature and the other is relative humidity. Climate change is not only contributing to rise in temperature but also shifting rainfall patterns. In summer season we receive monsoon rain which is the ultimate cause of enhanced level of humidity in almost all regions of the country. The highest change in heat index is calculated in Azad Jammu & Kashmir areas (6ºC/279.15K). Punjab (3.5ºC/277K) and Sindh (3ºC/276.15K), have also revealed remarkable increase in heat index where thermal regime is already a challenge to human tolerance. Northern Areas (2ºC/275.15K), Balochistan (1.34ºC/274.5K) and NWFP (1ºC/274.15K) have also shown increase in heat index. These areas are not only having high temperatures during summer but the trend of humidity is also showing sharp increase with the exception of Balochistan, where humidity have shown decreasing trend in comparison to all other areas included in the study. So it is concluded that the increase in humidity is responsible for the considerable fraction of total increases in heat index. Thus evaluating the impact of heat index on human health and comfort it must be stressed that changes in surface air temperature is not the only reason but instead changes in humidity also plays a significant role. The summer season analysis for the whole Pakistan has also done which showed that the total increase in heat index for a period i.e. 1961-2007 is 3ºC (276.15K). An obvious shift in heat index pattern has been observed from Southern half towards Northern half of Pakistan.

References

Aggarwal, Y., B. M. Karan., B. N. Das., and R. K. Sinha., 2007: Prediction of Heat-Illness symptoms with the prediction of human vascular response in hot environment using rescuing condition. J Med Syst (2008) 32:167-176.

Chaudhary, Q. Z., and G. Rasul., 2004: Agro-Climatic Classification of Pakistan. Science Vision, Vol.9 No. 1-2 (Jul-Dec 2003) & No. 3-4 (Jan-Jun 2004), 59-66.

Climate Normals (1971-2000) of Pakistan., 2005: Pakistan Meteorological Department Karachi.

Cristo, R. Di., A. Mazzarella and R. Viola., 2006: An analysis of heat index over Naples (Southern Italy) in the context of European heat wave 2003. Nat hazard (2007) 40:373-379.

Delworth, T. L., J. D. Mahlman., and T. R. Knutson., 1999: Changes in heat index associated with CO2-indused global warming. Kluwer Academic publishers Netherland, 369-386.

Donaldson, G. C., W. R. Keatinge., and S. Nayha., 2003: Changes in summer temperature and heat related mortality since 1971 in North Carolina, South Finland, and Southeast England. Environ Res 91:1-7.

Gadiwala, M. S., and N. Sadiq., 2008: The apparent temperature analysis of Pakistan using bio-meteorological indices. Pakistan Journal of Meteorology, Vol 4 Issue 8: 15 -26.

Guest, C. S., K. Wilson., A. Woodward., K. Hennessy., L. S. Kalkstein., C. Skinner., and A. J. McMichael., 1999: Climate and mortality in Australia: retrospective study, 1979-1990 and predicted impacts in five major cities in 2030. Clim Res 13:1 – 15.

Keatinge, W. R., G. D. Donaldson, E. Cordioli., M. Martinelli., A. E. Kunst., J. P. Mackenbach., S. Nayha., and I. Vuori., 2000: Heat related mortality in warm and cold regions of Europe: observational study. Br Med J 321: 670 – 673.

Kumar, S., 1998: Indian heat wave and rains results in massive death toll. Lancet 351:1869.

Pan, W. H., and Li, L. A., 1995: Temperature extremes and mortality from coronary heart disease and cerebral infarction in elderly Chinese. Lancet, 345,353-356.

Piver, W. T., M. Ando., F. Ye., and C. J. Portier., 1999: Temperature and air pollution as risk factors for heat stroke in Tokyo. July and August 1980-1995, Environmental Health Perspectives Vol 107 No 11:911 – 916.

Rothfusz, L. P., 1990: The heat index equation. Technical attachment, Scientific Services Division NWS Southern Region Headquarters, Fort Worth, TX, SR 90-23.

Steadman, R. G., 1979: The assessment of sultriness. Part I: A temperature humidity index based on human physiology and clothing science. Journal of Applied Meteorology, 18, 861- 873.

Steadman, R. G., 1984: A universal scale of apparent temperature. Journal of Climate and Applied Meteorology, 23, 1674 - 1687.