Socio-Economic Impacts of Heat Wave in Sindh

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Abstract

The severity and persistence of Karachi heat wave in June 2015 was a rare occurrence for the dwellers of this metropolitan hosting more than 200 people of diverse socio-economic status. The causes were combination of the environmental, meteorological and demographic phenomena. Most of the causalities did not occur due to high temperatures rather extended exposure to sun, non-ventilated housing, dehydration due to fasting, prolonged power outages and discontinuity of water supplies were responsible for such elevated death toll. Majority of victims were poor who had to earn their day to day livelihoods to feed their families despite the looming threat of heat strokes and health warnings. There was hardly any causality in posh areas of the metropolitan. The zonation of the death toll clearly indicates the direct relationship with the socio-economic conditions which could be a priority area to work on the heat waves risk reduction.

Introduction

Heat-wave is a prevalent very hot spell generated through persistence which becomes a climate related natural hazard entrapping a particular region. Heat waves are referred to as uncommon period of humid and hot and/or dry and hot condition, which reign through three to five consecutive days during a summer season. However, there is no universal definition of heat waves episodes. For the study in hand the heat wave definition by World Meteorological Organization's (WMO) has been used, it states that "heat-wave occurs when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5 °C". In maritime climates, high temperatures coupled with high concentration of the water vapour in the air increases the discomfort level to extreme sensible heat which is gauged by heat indices. For that reason, the feel-like temperatures are 5-6°C higher than the thermometer readings at the same location (Meehl, et al., 2004). A study conducted by Huygens et al., (2001) on mortality rate of Dutch population due to thermal extremes indicated that heat waves were the serious killers. Similar results were drawn by Wu et al., (2012) during an investigation in North America.

Rey et al., 2009 has analyzed the August 2003's European heat wave, which caused high mortality in France. A heat wave exposure index along with a deprivations index employed to elaborate the spatial heterogeneity of high mortality "(with Cantons Scale: 3,706 spatial units)". The study reveals that 68 percent "extra-Poisson spatial variability" explained by the heat wave exposure in the time of heat wave occurrence. Mostly, urban areas found to have high heat exposure index as compare to rural areas. While, in the densely populates areas of Paris found to have three upper quintiles of heat exposure. In the "most deprived Cantons (about 20 excess deaths/100,000 people/day)", the mortality rate had been two fold higher as compare to "the least deprived Cantons (about 10 excess deaths/100,000 people/day)". Although, there is no synergy has realized for the areas other than the Paris. At the same time, rest if France has found to expose less to heat wave and less deprived heterogeneously as well. While, all degrees of deprivation caused a remarkable increase in mortality rate due to exposure to heat waves. Therefore, deprivation proved to be "vulnerability factor" in the context of heat wave related mortality.

Russo et al., 2015 reviewed the ten highest heat wave events across the Europe from 1950 to 2015 and stated that the heat waves are not only killer of living things including human-beings, plants and animals but also paralyze the civic life halting the construction work and development activities and hence leaving far-reaching impacts on the livelihood and socio-economic activities. Mostly the victims, in all the heat wave scenarios in all vulnerable regions, are women, children, and elderly members of a family. Impacts of the heat waves are far more serious in the densely populated and congested localities due to poor housing structures, hardly ventilated houses, deprived from standard water and power supply. In case of heat wave conditions, the pressure increases on the electricity demand and in most of the cases power supply system

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failed of sustainable operation. A person struck by the heat wave remains under treatment for a long time as the recovery in severe stroke cases is quite slow. If the sufferer is the bread earner of a family in middle and lower strata of the social structure then it shakes the whole budget through stoppage of the income but increased expenditure on the healthcare. Such economic shocks have sometimes very serious consequences on the marginal income communities.

Tan et al. (2007) studied heat wave associated mortality for Shanghai, China for two points of time i.e. 1998 and 2003 to identify the causes of high death toll. The heat waves of these two years i.e 1998 and 2003 found to share the same meteorological characteristics but the death toll was higher during 1998 event. In order to capture the heat wave related human mortality differences for both of the years, a wide range of pollution, social and more importantly meteorological variables have been taken into account for the scientific analysis. The data have been collected during summer i.e. from June 15th to September 15th during both years and then examined comprehensively. A multivariate analytic approach employed to examine the casual relationship of heat waves and mortality rate by considering timing and duration of heat waves and air pollution levels during summer. The study explained the heat wave caused mortality during the summer for both of the years. They further explored that during the both of the years meteorological conditions and air pollution level were same. But, improvements in social variables i.e. high living standards, spacious residential areas, increased no of open green spaces in the city, expanded air conditioning use along with improvements in non-structural social variables i.e. increased numbers of heat waves' awareness programs and heat wave early warning systems' effective implementation were attributed to reduce mortality rate in 2003 in comparison with 1998 heat wave event's mortality rate. Klinenberg (2002) studied Chicago heat wave and concluded it an autopsy of disasters. Coley et al. (2012) explained the impacts of building and structural architectures on the intensity of the heat waves and found a significant increase in heavily constructed zones.

Daniel et al. (2011) reviewed a thirty recently published studies on mortality and morbidity of aged people due to heat waves. All of these research studies published during January 2008 to December 2010. Among these studies, six are focused on "temperature-morbidity" relationship while rests of the twenty four studies are related to "temperature-mortality" relationship. The mortality related studies reported that a quick rise in respiratory and cardiovascular mortality in the time of heat wave occurrence. However, morbidity studies are not much in number. Among both temperature-mortality and temperature-morbidity related studies, very few studies has captured the medical, environment, and social susceptibility factors. They further figured out that climate change is predicted to have occurrence of increased number of extreme climate events, including heat waves. They further forecasted that intensity and frequency of heat waves would increase around that the globe because of climate change. Moreover, with a simultaneous increase in global life expectancy is changing demography around the world in every society across the world. Therefore, the increase in heat waves occurrence along with their intensity and frequency would lead to a direct effect on health of human population. Many past studies have already indicated the elderly population of a society would be susceptible to the heat waves. Most of the studies suggested to envelope detailed factors extended demographic parameters such as urban environment, housing conditions, and availability of civic utilities as well as gender proportionate for future research. Zampieri et. al.(2016) investigated that the recurrence of intense heat waves surged in different parts of the world. While, human health is at risk due to increase in these parts of the world.

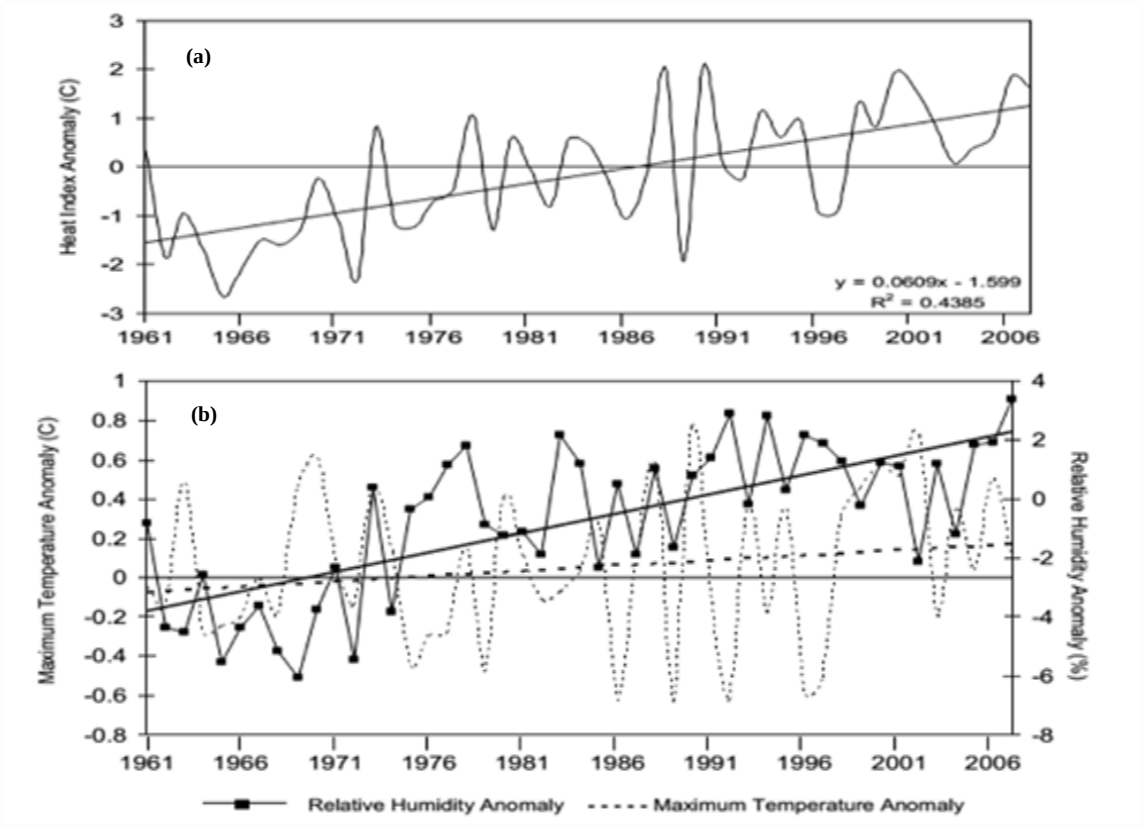
In summer 2015, a weeklong extreme heat wave has hit Karachi from June 17 to June 24 June and caused death of 1200 human lives leaving thousands impaired by heat stress. The heat index considered to be a good tool to measure the effects of heat wave to a person in a distinct area by enveloping the aggregate impact of temperature, wind rate and direction, air pressure and humidity.

On Karachi's heat index scale during 2015 heat wave event, the maximum temperature was recorded as 44.8°C. However, on the peak heat wave day of 20 June, the heat index reached as high as 66°C due to reduced wind speed and air pressure along with soaring humidity. The hardships were further exaggerated when power supply system of Karachi metropolitan could not sustain the increased load and ultimately

water supply was also suspended in poor and congested areas as pumping of water to the roof-tops stopped without electricity. The victims were mostly elderly people (>50 years age) especially labourers followed by the children and women. The major causes of deaths identified by various health units were heat cramps, heat exhaustion, heatstroke and de-hydration (Chaudhry, et al., 2015). That heat wave also coincided with the holy month of Ramadan and adult men and women.

Thermal Profile of Pakistan

In Pakistan, summer season persists from April to September and heat-wave events commence from month of May and extend up to September. However, central and northwestern parts of Pakistan receive monsoon precipitation from July to September which keeps the temperature in moderate limits. Therefore, the probability of the occurrence of the heat waves is higher in monsoon shadow zones (where monsoon rains seldom reach) as compared to monsoonal areas. Seasonal heat index profile of the whole of the Pakistan reveals that during the last few decades apparent annual temperature has increased significantly. Figure 1 (a) shows overall increase in heat index captured during the summer season is 3°C. While figure 1(b) reveals the humidity along with maximum temperature profile of Pakistan. The both parts of the figure 1 show that there is remarkable increasing trend of both of the factors. The heat index value of Pakistan is offspring of this rising trend. For the period of 1961-2007, in Pakistan, the overall change in humidity is 6.2 percent. While, overall change in mean maximum temperature is 0.25°C. These findings of the heat index indicate that the heat waves will be more probable in pre-monsoon season which coincides with May and June as well as the post-monsoon season during September and October, in case of early retrieval of monsoon air mass from Pakistan (Zahid and Rasul, 2010).



Source: Muhammad Zahid and Ghulam Rasul (2010) "Rise in summer heat index over Pakistan". Pakistan Journal of Meteorology. 6(12), 85–96.

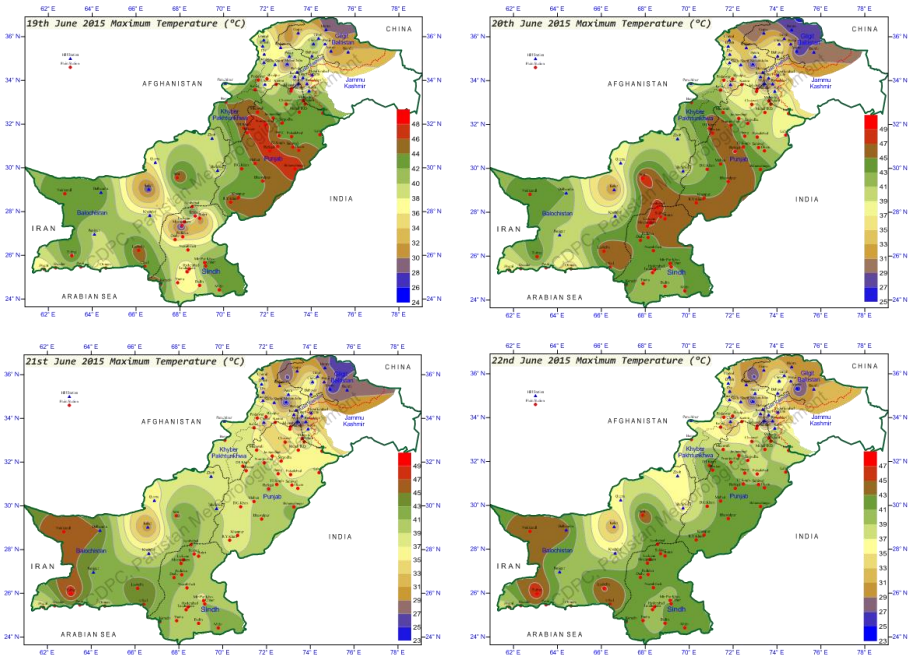
Figure 1: (a) Pakistan' s Heat Index Anomalies **(b)** Pakistan's Maximum Temperature and Relative Humidity Anomalies for the Period of 1961 to 2007.

Heat Wave Impacts

The heat waves affect directly and/or indirectly all spheres of life and sectors of the economy. It affects general public, industry, energy production and consumption, infrastructure, trade, health sector and agriculture. No sphere of life and sector of the economy could stand immune to it. Following are the direct and indirect impacts of heat waves:

1. Reduced labor productivity
2. Health Sector: Increased Mortality and Morbidity
3. Loss of Live Stock and Reduced livestock productivity
4. Increased energy Consumption and decreased Energy(Power) production
5. Loss of Crops
6. High Demand for Water
7. Outdoor activities including Work, Sporting and Recreation
8. Changes in Tourism Preferences

Zahid and Rasul (2010) found that continuous high temperature along with soaring humidity for sustained long period of time have been perceived as a serious hazard. The high heat index values could lead to serious health risk/s to outdoor workers or anybody involved in outdoor activities even for a short time span. While, on the other hand heat index remain high for a continuous long period of time, the public health could be on high risk. The heat wave of 2015 of Karachi caused an estimated death toll of 1200. During this heat wave, Karachi experienced one of the highest temperatures throughout the meteorological history of Pakistan since 1979. Although, during the 2015 heat wave, almost all of the regions of Pakistan experienced very high temperature i.e. Larkana 49 °C, Southern parts of Punjab 40 °C, Sibbi 49 °C and Turbat 49 °C, but several other factors are responsible of high death toll in Karachi apart from high temperature. Figure 2 depicts the main temperature records for various parts of the country for the time period of June 19th to June 22, 2015.



Source: Various Issues of Pakistan Meteorological Department

Figure 2: Maximum temperature of Different Regions of Pakistan on June 19-22, 2015.

It can be deduced from Figure 2 that almost whole of the country affected by brutal heat wave with maximum temperature of 45°C on average for the country. However, high death toll caused by heatstroke

mostly reported from Karachi only. Some of the heatstroke cases were reported from southern parts of the country i.e. Hyderabad, Noshero Feroz, Dadu, Badin, Thatta and Tharparkar.

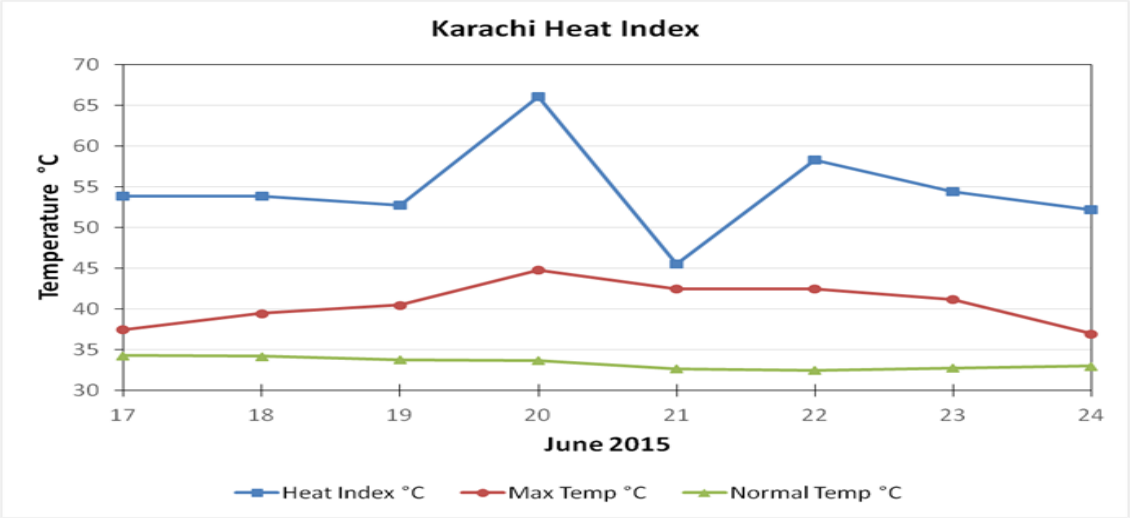
Heat wave in Karachi

Usually in summer season, Karachi displays high and/or occasionally high temperature during daytime. The gigantic city's maximum temperature data profile for the month of May and June reveals very high maximum temperature on May 09, 1938 i.e. 47.8 ºC and 47 ºC on June 18 1979.

In the study in hand, for the purpose of comparison, meteorological data of maximum temperature, humidity and wind speed and direction for the month of June against the normal period of 1981 to 2010 has analyzed. Along with, the same data for the month of June against the time period of 2013 to 2015 has analyzed as well to study the year 2015 heat wave phenomenon in the urban center of Karachi.

According to Pakistan meteorological department records, the sever heat event has continued for successive five days i.e. June 19 to June 23. While, day-to-day maximum temperature anomalies has recorded greater than 5 ºC for these successive five days. Figure 3 indicates the flight of maximum temperature from its normal range of 5.3 ºC to 11 ºC in the time of sever heat wave. On June 20, 2015, the highest maximum temperature of Karachi recorded as 44.8 ºC with a flight of 11.1 ºC.

After 2000, it was highest recorded temperature for the month of June. In the terms of constancy, the heat wave was unprecedented. Following are the heat wave indices of Karachi, where the temperature exceeds from +5 ºC or more and it continued for one to two successive days.



Source: Various Issues of Pakistan Meteorological Department

Figure 3: Karachi Heat-wave Days Maximum Temperature and Heat Index Time Series June 17-24, 2015 in Karachi.

During the half of the June 2015, the extended period of very hot conditions developed in the areas of Southern Punjab, Sindh and in partly Balochistan. Nevertheless, on June 19 and June 23, these conditions became particular grave, as level of peak heat was intolerable. The highest maximum temperature on these days found mostly more than 45 ºC and it persisted more than one to two days.

The figure 3 represents maximum temperature time series along with index of heat in the time of heat wave days in Karachi. The temperature has started to soar from June 17, 2015. While, maximum temperature was 44.8 ºC on June 20, 2015. By giving a careful look to the figure 3, indicates that temperature has been more than 50 ºC on average during the entire period of heat wave.

According to the health experts, heat exhaustion could be a aftermath of continued exposure to heat for a long time a long time during a heat index between forty 41 ºC to 54 ºC. Moreover, the environment with heat index greater than 54 ºC can cause heatstroke.

In Karachi, on June 20 and June 22, the heat index escalated up to 66.1 ºC and 58.3ºC respectively. While on June 21, a sharp downturn in het index observed due to persisted dry and hot easterly winds there. Which remarkably reduced the reliant humidity. On the other hand, heat index jumped up to 58.3 ºC on the next day.

Atmospheric Conditions

In Karachi June, 2015 afternoons, particularly on June15 and June 16 displayed a normal precipitation quantity, which transported to the area from the Arabian Sea. But, atmospheric conditions anomalies after a "ridge (extension of high pressure area)" was speeded over Baluchistan and its adjacent parts, in including Karachi". The development of this ridge paved the way to cripple the Sea wind transportation: from Arabian Sea to Karachi city and consequently decreased the level of humidity down to its normal range on June 17, 2015 afternoon.

The ridge further accentuated on June18 and paced more into Southern and easterly regions of the country. On the June 18, 2015, a cyclonic system begins to form up over the Arabian Sea, which thickened into depression on June 22 and got weak on June 24 over the low-pressure areas. The persistence low-pressure system in the neighborhood of Sindh-Makran coastal areas further decreased the wind current form the sea.

The atmospheric conditions were the main culprit of extreme heat wave. Other factors, including soaring unplanned urbanization, inadequacy of open and green spaces, lack of heat early warning systems and awareness, faulty architecture and construction material along with polluted transportation system added fuel to the fire and given birth to the Heat Island Effect, which in turn supplemented to sever temperature.

While, during the occurrence of heat wave, prolonged and frequent power shut down along with intermittent water supply exacerbated the situation. This situation reduced the inhabitants' capacity to cope up with the adverse impacts of heat waves, which led to unprecedented high death toll in Karachi.

Urban Heat Island Effect (UHI)

The term "heat island referred to as built up areas that are hotter than nearby rural areas". While, an urban heat Island Effect (UHI) referred to as a "city or Metropolitan area that I significantly warner than its surrounding natural areas due to certain anthropogenic activities". (United Nations Environment Protection Agency, 2017). Moreover, the difference, in temperature found usually high at nighttime as compare to daytime. The UHI is noticeable mostly in summer and winter season. It is estimated that for a city having one million or more population size could have average yearly 1 to 3 °C hotter air temperature than its neighborhoods. This difference can reach to its high limit as 12°C in the evenings. The UHI induce inhabitants to increase energy demand for cooling of their homes, workplaces, shopping areas, and indoor activities centers etc. Which, in turn, give rise to Green House Gas Emission and air pollution. Moreover, public and private health expenditure increases due to heat related morbidity and mortality.

The city of Karachi is most populous city of Pakistan, it ranks 7th most populous city of the world. The city is house of 14.91 million population and its population grew with the rate of 59.65 percent since 1998 to 2017 (Pakistan Bureau of Statistics, 2017).

While in 1947 the population density of Karachi area estimate as 233Km^2 which was increased to 3,566 233Km^2(Qureshi et.al, 2008). Figure 4 shows the "marginalized difference built Index" for Karachi for the years 2000 and 2008. It can safely deduced that rapid urbanization along with impact of global warming has triggered the UHI effect in Karachi. UHI effect is the exclusive characteristics of the June 2015 heat wave of Karachi. Around the globe, including Karachi, UHI could pose a big heath threat to the vast majority of mega city's population due to increasing level of global warming coupled with weak resilience strategies (Khan and Omer, 2008).

Source: Jibran Khan and Tahreem Omar (2008) Impacts of Urbanization on Land Surface Temperature: The Case Study of Karachi, Pakistan, University of Karachi

Figure 4: Comparison of Rate of Karachi's Urbanization & Infrastructure for the Years 2000 (left) and the Year 2008 (right): Normalized Difference Built Index

Impact of Karachi Heat Wave

Initially the change of wind direction from sea to land was taken as a routine variability which was expected to persist temporarily. Temperature started rising in humid environmental conditions, power outages became common and water lifting to the roof-top water tanks was not possible in the absence of electricity. In addition to the meteorological and demographic conditions, June was the fasting months and Muslims don't eat and drink from dawn to dusk. This coupled effect resulted into surge in death toll which increased day by day due to multiplying adversities.

Table 1: Number of Deaths caused by heat wave in different hospitals in Karachi 17-24 June 2015

S. No.	Name of Hospital	Male	Female	Total
1	Jinnah Hospital	341	133	474
2	Abbasi Shaheed Hospital	253	78	331
3	Civil Hospital	194	82	276
4	Cardiology Hospital	110	21	131
5	Qatar Hospital	42	17	59
6	Metropolitan Hospital	57	14	71
7	Korangi Hospital	39	18	57
8	Lyari Hospital	35	16	51
Total				**1350**

More than 80,000 people were affected by the heat wave and brought to the nearby hospitals for treatment or first aid. Most of them were relieved after preliminary medication and precautionary advice but the most critical cases were admitted for intensive treatment. The survival ratio was quite low for those victims who suffered severe stroke and could not get proper treatment within 24 hours and brought to the hospital in critical condition. Most of such cases were reported from densely populated localities of Karachi where people live in high-rise building, low-cost houses, one to two bed accommodations with poor ventilation and ill-structured houses. From Defence Housing, no resident's causality was reported, however, 16 labourers were brought to the hospital and 3 of them could not survive. All of them were fasting and digging the ground for cabling to earn their livelihood.

In Muslim communities, availing the month of Ramadan is considered as a blessing and most of the adult males and females fast from dawn to dusk without water and food. Elders are religiously more

strict and do not give up the fasting practices despite their health status although postponement is allowed under serious conditions. Most of the male elders became victims of heat stress, heat strokes and dehydration which led them to final fate. In most of the cases, the family heads and bread earners lost their lives as they could not stop working under the harsh weather conditions because of the economic compulsions. Thousands of the poor survivors went through long medical treatment for rehabilitation costing heavily on their pockets. Their health conditions did not allow them to go for work to earn the livelihood for their families whose dependence was on day-to-day earnings. This heat wave had not only hit hard on the health conditions of poor and marginal communities but also laid off their jobs.

Conclusions

1. In terms of continuity and severity, the heat wave of 2015 has no precedence. Settling of the depression for a long time on the Arabian Sea terminated the sea wind and elevated high pressure ridge which enveloped not only Karachi but also parts of Baluchistan and Sind. Clear skies intensified heat in the lower strata under high humidity level.
2. Considerable reduction of trees, increased number of vehicles adding to emissions and reduced greenery and exploded population over the past decades had played their part in harshness of the heat by producing UHI. The rapid urbanization over the recent years had also contributed to the severity of the heat by generating Urban Heat Island Effect. Trees and vegetation regulate surface and air temperatures acting as sink to carbon dioxide, pumping water through evapotranspiration and providing shade to the pedestrians.
3. Adverse impact of electricity and water outrages in the time of heat wave of 2015 cannot be overlooked, nevertheless, there is insufficient evidence based data to investigate the role of electricity and water shortages played to increase the death toll in Karachi. Most of the victims belonging to the densely populated areas of Karachi had indicated that the lack of the sustainability of the water and power supply increased their sufferings despite the poor housing conditions.
4. June 2015 tallied with the holy month of Ramadan when most of the adult Muslims do not eat and drink from dawn to dusk. Practicing fasting during the month of Ramadan is considered as blessing from religious point of view yet there is a provision of postponement in case of poor health or other life risk moments. Most of the causalities reported on the fasting males above 50 years of age followed by the laborers engaged in construction work without any precautionary measures. They were directly exposed to the blazing sun for most of the day time during work.
5. Sever and frequent heat waves can also be expected in future in the consequence of climate change. The environmental degradation, urbanization, urban heat island effect is likely to further exaggerate the situation.

Recommendations

In the light of above mentioned conclusion, the situation calls for an efficient and effective heat wave reliance and coping up policy and strategy in mega cities of Pakistan. It is, therefore, suggested to the stakeholders to establish a heat wave early warning system along with heat wave awareness programs. To get the desirable goal a comprehensive survey could be conducted to figure out and scale up the heat wave vulnerable areas, people coupled with coping strategies for the dense cities.

1. Before and during the onset of heat wave season, resilience and coping capacity of people could be enhanced through heat wave early warning systems and awareness program.
2. In schools and university curriculums, the study material on natural disasters e.g. heat waves' season, nature, and characteristics along with coping strategies could be included to live with heat waves in future.
3. Land use laws should b strengthen and implemented effectively to maintain and increase green open spaces in the cities. In this regards. Local governments should involve to monitor and implement land use laws in all areas of the mega cities.
4. Dense architecture and building material should be revised and reoriented to reduce the UHI.

5. Green roof topping should be another method to adapt to reduce UHI in the big cities.
6. For new building in the towns, applicable twin planning strategies, rules and regulations should be observed.
7. During the onset of the heat wave even, "cooling centers" equipped with safe drinking water, fans, air conditioning may be built along the main avenues to provide the safe heavens to the people.
8. Heat and/or sunstroke are an avoidable situation. Preventive measures should be taken by health authorities to reduce the adverse impacts of heat and/or sunstroke among people.

References

Basu, R., and J. M. Samet, 2002: "Relation between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence". Epidemiologic Reviews. Johns Hopkins Bloomberg School of Public Health.24 (2): 190–202. doi:10.1093/epirev/mxf007.

Bureau of Statistics, 2017: Pakistan Population Census.

Chaudhry, Q. Z., and G. Rasul, 2004:'Agro-Climatic Classification of Pakistan', Science Vision, vol. 9, no. 1-2, pp.59-66.

Chaudhry, Q. Z., G. Rasul, A. Kamal, M. A. Mangrio, and S. Mahmood, 2015: Task Force/ Fact Finding Mission by GOP on "Causes of Severe Heat Wave in Karachi. Technical Report, 2015.

Coley, D., T. J. Kershaw, and M. Eames, 2012: "A comparison of structural and behavioural adaptations to future proofing buildings against higher temperatures". Building and Environment. 55: 159–166.doi:10.1016/j.buildenv.2011.12.011.

Daniel, O. Å., F. Bertil, and R. Joacim, 2011: Heat wave impact on morbidity and mortality in the elderly population: A review of recent studies. Elsevier, Volume 69, Issue 2, June 2011, Pages 99–105. http://dx.doi.org/10.1016/j.maturitas.2011.03.008.

Huygens, M. T. E., P. Martens, D. Scram, M. P. Weinberg and A. E. Kunst, 2001: "The Impact of Heat Waves and Cold Spells on Mortality Rates in the Dutch Population". Environmental Health Perspectives. National Institute of Environmental Health Sciences. 109 (5): 463–470. doi:10.2307/3454704.

Jibran, K., and T. Omar, 2008: Impacts of Urbanization on Land Surface Temperature: The Case Study of Karachi, Pakistan.

Klinenberg, E., 2002: Heat Wave: A Social Autopsy of Disaster in Chicago. Chicago: University of Chicago Press. ISBN 0-226-44321-3.

Meehl, G. A., Tebaldi, Claudia, 2004: "More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century". Science. 305 (5686): 994-7.Bibcode:2004Sci.305.994M.doi:10.1126/science.1098704. PMID 15310900.

Qureshi, I. A., H. Lu, S. Ye, 2008: Urban transportation and equity: a case study of Beijing and Karachi. Trans Res Part A 42:125–139.

Rey, G., A. Fouillet, Bessemoulin, P. Eur, and J. Epidemiol, 2009: Heat exposure and socio-economic vulnerability as synergistic factors in heat-wave-related mortality. European Journal of Epidemiology. September 2009, Volume 24, Issue 9, pp 495–502. 24: 495. doi:10.1007/s10654-009-9374-3.

Russo, S.; J. Sillmann, E. M. Fischer, 2015: "Top ten European heatwaves since 1950 and their occurrence in the coming decades". Environmental Research Letters. 10 (12): 124003. doi:10.1088/1748-9326/10/12/124003. ISSN 1748-9326.

Tan, J., Y. Zheng, G. Song et al., 2007: Heat wave impacts on mortality in Shanghai, 1998 and 2003. International Journal of Biometeorology. January 2007, Volume 51, Issue 3, pp 193–200. 51: 193. doi:10.1007/s00484-006-0058-3

Zahid, M., and G. Rasul, 2010: Rise in summer heat index over Pakistan. Pak. J. Meteorol., 6(12), 85–96.

Zampieri, M., R. Simone, D. S. Silvana, M. Melania, S. Enrico and G. Silvio, 2016: "Global assessment of heat wave magnitudes from 1901 to 2010 and implications for the river discharge of the Alps". Science of The Total Environment. 571:1330–1339. doi:10.1016/j.scitotenv.2016.07.008.

Zhiwei, W.; et al., 2012: "Heat wave frequency variability over North America: Two distinct leading modes". J. Geophys. Res. 117 (D02102). Bibcode: 2012JGRD.11702102W. doi:10.1029/2011JD016908.

http://www.encyclopedia.com/environment/energy-government-and-defense-magazines/heat-waves

https://www.epa.gov/heat-islands

http://www.whichcountry.co/largest-cities-in-the-world-by-population/