HEAT WAVE VULNERABILITY ASSESSMENT OF FORMAL & INFORMAL SETTLEMENT IN LAHORE METROPOLITAN AREA

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ISLAMABAD

August, 2020

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A thesis submitted in partial fulfillment of the requirements for the degree of

MS Urban & Regional Planning

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THESIS ACCEPTANCE CERTIFICATE

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Declaration

I certify that this research work titled "**Heat Wave Vulnerability Assessment of Formal & Informal Settlement in Lahore Metropolitan City**" is my work. The work has not been presented elsewhere for assessment. The material that has been used from other sources has been properly acknowledged and referred to.

Signature of Student

DEDICATION

Dedicated to

My beloved sister and daughter in heaven.

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to my supervisor Dr. Irfan Ahmad Rana for his exceptional support. His encouragement and timely feedback kept my morale high throughout this challenging journey. I am forever indebted for his valuable and constructive criticism which enabled me to complete my work.

I am thankful to my family for their unwavering support and encouragement.

Laila Sikandar

ABSTRACT

The world is likely to experience an increase in the onsets of extreme temperature events with a significant increase in their magnitude, length, and intensity as a discernible consequence of climate change. The unprecedented rise in temperature will reach far beyond the habitable level particularly in South Asia by the end of this century. The increase in frequency and intensity of heat waves has already been predicted, making the occurrence of heat spells higher for urbanites than the rural residents. In doing so, if the temperature continues to rise, heat waves could become the most fatal kind of disaster. The situation is far worst in unplanned developments where the infrastructure is minimal and failing. Urban poor populations with relatively high population density and low socioeconomic conditions are fairly more vulnerable and not well adapted to climate and weather extremes. This study investigated the prevailing vulnerability in one formal and informal settlements located in Lahore Metropolitan City. The questionnaire field survey was conducted in these two settlements comprising of questions related to household characteristics and indicators of exposure, capacity, and sensitivity. 400 households were randomly selected and interviewed. It was found that vulnerability was comparatively higher in an informal settlement with very low capacity and high exposure values whereas the sensitivity dimension of vulnerability was the same for both settlements. It was concluded that the high capacity dimension of vulnerability played a significant role in reducing the vulnerability in the formal settlement.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

Globally, cities are sprawling and are undergoing a drastic transition in terms of population. The ongoing urbanization trend has significantly affected the environment by altering the climatic patterns which have intensified climate change impacts (Filho, 2015). The global climate change has already had discernible effects on the environment and the effects are visible in the form of an accelerated rise in sea level, glaciers melting and more intense heat spells. The fifth report of the Intergovernmental Panel on Climate Change (IPCC) has declared climate change a key risk for the South Asian region being detrimental for human life, infrastructure, and livelihoods. It is also exacerbating the alteration of natural processes, cycles, and the ecosystem which is threatening the food security and environment. Rapid urbanization and high population density, all together contribute to the harmful emission of greenhouse gases, leading to the rise in temperature. (Banalata Sen, 2017).The changing climate is a global phenomenon and its impacts are far-reaching. Pakistan's vulnerability to climate change is well documented and discernible (Bank A. D., 2017). In the long-term climate risk index from the year 1997 to 2016, Pakistan has been ranked 7th in the list of most affected countries due to natural disasters instigated by climate change. The overall list included the countries which are poor and developing. The results indicated that poor developing countries are far more susceptible to the risk of climate change even though huge monetary losses are faced by richer countries (David Eckstein, Vera Künzel and Laura Schäfer , 2017). The IPCC fifth assessment report sensitized over the climate change threats face by agro-based economies such as in Pakistan which would result in affecting the food productions and economic capacities of the nation. Also, it has been notified in the report that the Asian region will undergo a temperature increase that would impact the glaciers' melting rate and precipitation. Consequently, it will significantly impact the efficiency and productivity of water-dependent sectors such as energy and agriculture (Climate Change Profile of Pakistan, 2017). The unprecedented rise in temperature will reach far beyond the habitable level particularly in South Asia by the end of this century. (Worland, 2017). The increase in frequency and intensity of heat waves has already been predicted, making the occurrence of heat spells higher for urbanites than the rural residents. In doing so, if the temperature continues to rise, heat waves could become the most fatal kind of disaster. (Cole, 2017).

1.2 Justification of the study:

In Pakistan, a significant trend has been observed in the increase in mean annual temperature. An increase of 0.57 C in annual mean temperature been observed from 1901 to 2000. Although, it is considered low as compared to other south Asian regions. But a drastic increase of 0.47 C had been observed from 1961 to 2007 and the year 2004 was marked as the warmest year. Consequently, it is predicted that the trend would continue to accelerate and would be higher as compared to other parts of the region. Pakistan ranks among the top 20 countries in the world where heat waves occur frequently. According to the EM-DAT database, Pakistan has faced 12 heat waves with 1388 death tolls (Lee 2014).

The intensity as well as the frequency of heat waves are likely to increase with time, predominantly in the South Asian region. Pakistan is the part of the region, is also under the threat of devastating impacts of heat waves. In the Hong Kong Shanghai banking corporation (HSBC) report 2018, Pakistan has been ranked second in being the most vulnerable country in terms of climate change. (Gupta, 2018). The impacts of heat waves are far-reaching and under-researched in developing countries. As compared to previous years, it is predicted that the intensity of heat waves is likely to be more intense coming years.

The concept of vulnerability is multidisciplinary, and therefore diverse definitions and interpretations are existing in the scientific literature (W. N. Adger 2006; Birkmann et al. 2013). In disaster risk science and climate change adaptation, it is increasingly acknowledged to be a human-induced phenomenon and has been recognized as the root cause of severe disaster impacts (W. N. Adger 2006; IPCC 2012; UNISDR 2004). Vulnerability is considered an integral and defining part of many interpretations of disaster risk concepts. The vulnerability has been looked through the lens of multiple contexts, multiple dimensions, and Spatio-temporal scales, however, there is no universal theory or model for it. Numerous models have been developed to explain relationships, causes, and dependencies of vulnerability like The hazards of place vulnerability model (Cutter, Mitchell, and Scott 2000), the double structure of vulnerability (Bohle 2001), Pressure and release vulnerability model (Wisner et al. 2004), Turner's vulnerability framework (Turner et al. 2003), Bogardi, Birkmann and Cardona Vulnerability Framework (Bogardi and Birkmann 2004), Vulnerability Spherical Model (Birkmann 2006) and Methods for the improvement of vulnerability assessment in Europe (MOVE) framework (Birkmann et al. 2013). These models provided further confirmation of the concept of vulnerability and its assessment, as a multi-dimensional phenomenon.

Socioeconomic and unequal infrastructural development in urban areas further aggravates the disaster. This research proposes to understand the dynamics and drivers of socio-economic and infrastructural vulnerabilities of urban communities in the context of extreme heat waves. Formal (planned/regular housing schemes) and informal (slums) settlements of the Lahore Metropolitan Area have been taken as the case study area.

This research would identify the vulnerable areas, which need to be targeted to enhance adaptive capacities. Vulnerability will be assessed for both formal and informal settlements, based on a multi-dimensional model which incorporates social, economic, institutional, and infrastructural dimension. It will help to determine the target audience for future awareness campaigns and training/workshops. This research would help to identify the vulnerabilities of each dimension, enhance capacities. Moreover, this study will be the first of its kind in Pakistan exclusively focusing on heat waves in urban areas, and will not only be highly relevant in the local context but would be beneficial for South Asian developing countries as well.

Preparedness and coping level of selected communities will also be judged, and possible approaches will be tested to reduce heat waves disaster risk. In the end, this study will be instrumental for disaster management institutions and local governments in developing future strategies for heat wave risk reduction. Multi-dimensional Vulnerability Assessment will show the exact social or economic sector which needs to be targeted to reduce vulnerabilities and enhance capacities for both local institutions and urban communities.

The study aims to accomplish the following objectives:

1.3 OBJECTIVES:

- To assess the climate change vulnerability of formal and informal settlements for a heat wave.
- To investigate indigenous knowledge and preparedness measures of exposed communities.
- To make recommendations for remedial steps based on the findings of this study and suggest policy measures that will help disaster managers in risk reduction.

1.3 SCOPE OF THE STUDY:

This research will have significant importance in addressing the sweltering heat waves at a metropolitan level. It will help local government, by identifying the vulnerable settlements and their existing capacities which would be strengthened and enhanced by the proposed strategies and measures. It would also help the disaster managers in defining the areas for awareness campaigns and mitigation measures.

1.5 RESEARCH GAP:

This research aims to conduct the heat wave vulnerability assessment in formal and informal settlements by identifying the socioeconomic conditions of people residing in these settlements. Despite the extensive literature, focused literature on how to assess heat wave vulnerability in these settlements could not be found. Little to no work has been done to address this issue, making it an under-researched topic. To identify and quantify the potential heat wave impact driven by demographic and climate change is an acute challenge. An extensive variety of risk and vulnerability definitions and frameworks exist depending on the type of research being conducted (SENF). IFRC (2019) defines vulnerability as "the ability of a community or group to cope up or withstand against the impact of natural or man-built hazards" Whereas UNDSIR (2017) defines "The socio-economic, physical and environmental factors to determine the conditions which tend to lead to the susceptibility of an individual or community or systems to towards the impacts of hazards." (Nations, 2016). UNDP defines risk as" the probability of harmful consequences — casualties, damaged property, lost livelihoods, disrupted economic activity, and damage to the environment — resulting from interactions between natural or human-induced hazards and vulnerable conditions" (UNDP,2010). Therefore risk can be seen as the function of hazard and vulnerability (Fussel, 2006). By assessing the quantified risk and vulnerability, it enables the decision-makers to develop strategies for future coping (SENF). Risk assessment is a process to evaluate the extent and intensity of a hazard to determine the potential harm to the exposed communities, their property, environment, and livelihoods (UNDP, 2010).

Chapter 2

LITERATURE REVIEW

2. CLIMATE CHANGE:

2.1 Definition

The International Panel on Climate Change (IPCC) defines climate change as "Any change over the period of time as an outcome of human activity or natural variability in the climatic patterns. Similarly, the World Bank defines climate change as any change in the intensity or magnitude of weather. It encapsulates a range of phenomena, including changes in mean temperature, precipitation, and in the onsets of extreme weather events. (Such as tropical storms or heat waves)" (Muthukumara Mani, 2018).

2.1.1 Global and Regional Climate Change scenario and Its Impacts:

Climate change is likely to debilitate all forms of life on earth with varying extent and vulnerability across the regions and populations residing inside them. Though the impacts will reciprocate disproportionately upon developing nations (Report, 2007). While debating on climate change, often much attention is given to extreme events and rising sea levels as they are more discernible through the profound impact they have on communities. (World Bank Group, 2018).

Global and regional Climate change have gained much attention during the last three decades. A significant percentage of the scientific community agrees with the fact of a drastic increase in temperature in the past and has predicted that it will continue to rise in the near future. As a result of these identifiable changes, it is expected that there would be an increase in extreme temperature events such as a higher frequency of cold and hot days or nights. An increase in temperature means an increase in frequency as well as the intensity of hot days and warmer nights. This proves the substantial sensitivity of extreme temperature events towards climate change (Xiaodong Liu, 2006). However, the relationship between global mean change and regional climate change is quite complex. The regional climate varies with location. So, it responds differently to deviations in global scale influences. Whereas, global mean change is an effect on the convenient summary of multiple regional climate responses.

Climate change is a pressing issue for the South Asian region as temperatures have been drastically accelerating and are projected to continue increasing for the upcoming decades under all plausible scenarios. It has been declared as highly vulnerable to climate change and variability. Therefore, it is highly susceptible to the consequences of climate change. Inhabiting a huge chunk of the population of approximately 1.3 billion people, it is been identified as a highly disaster-prone region (United Nation Environment Programme, 2003). Rising average temperatures and varying rainfall patterns are ample evidence of climate change in the region affecting agriculture. The rising sea level because of glacier melting has engraved the threat of flood over the major cities of the region which are home to more than 50 million people. Similarly, extreme temperature events, such as heat spells like 2015 took more than 3500 lives and are also a threat faced by the region. There are numerous areas and regions in South Asia that are highly vulnerable to climate change. In most cases, changes in extreme events are indicated by the variance in weather pattern (World Bank Group, 2018). The values of weather events that are far away from the mean have the least chances of occurrence (such as heat waves, droughts, and flooding). These events are called extreme events in a statistical context. It is substantial as the predictions for the future pinpointed an increase in intensity and frequency of extreme weather events like drought and floods, making a huge portion of the region vulnerable (IPCC, 2001). Economic activities and livelihoods in South Asian are significantly dependent on the natural resource base. Hence, it is highly vulnerable to climatic changes. Agriculture will be quietly threatened by a combination of hydro and thermal stresses, rising sea level, strong winds accompanied by intense cyclones, and increased flooding. Biodiversity and availability of fresh water are already under acute pressure due to population growth and land-use change, will also be adversely affected by climate change. Consequently wetter, and warmer conditions will increase the probability as well as the potential for a higher occurrence of heat-related events. The paramount dilemma for South Asian nations is that prolonged and intensive extreme climate stress can propel the processes of impoverishment which would result in diminished means of livelihoods of the poor people whereas poverty would further aggravate vulnerability to climate change by further restricting the capacities of the people (South Asian Regional Study on Climate Change: Impacts and Adaptation:Implications for Human Development, 2007). Variability in precipitation patterns and temperature and several other factors will impart effects on natural and human systems. Sectors that are sensitive to climate variances such as agriculture, water resources, and forestry, human systems which include human health, human settlements, and energy and industry sectors will be profoundly affected (IPCC, 2001).

The increase in annual mean temperatures in South Asia is alarmingly increasing unevenly across the region in recent decades. South Western Pakistan and western Afghanistan have undergone a phenomenal increase in annual temperature rising from 1 C to 3C from 1950 to 2010 whereas south-eastern India, western Sri-Lanka, northern Pakistan, and eastern Nepal also underwent through a temperature increase from 1C to 1.5C over the same period. Similarly, from 1950 till 2010 significant trends of increase in monsoon precipitation have been observed in eastern Afghanistan and central Pakistan whereas decreasing trends have been observed in the Uttar Pradesh part of India while no change in trends found in other parts of the region (Muthukumara Mani, 2018).

2.1.2 Climate Change in Pakistan:

Pakistan has long been defined as a nation with the prolific countryside. A nation, where most of the population is rural dwellers (66%) with a comparatively low proportion of urban residents (33%). However, the situation is different. The annual urbanizing rate of Pakistan is the fastest in South Asia i.e. 3%. Approximately half of the country's population will be urbanized by 2025 as estimated by The UN Population Division (Kugelman, 2014). The country's vulnerability to climate change is well acknowledged and discernible in the form of frequent heat waves, accelerating the glaciers melting, rising sea level, and droughts. Consequently, it has taken a heavy toll on both life and assets and has adversely affected the country's economy (Asian Development Bank, 2017). According to a recently published report by ADB, a 6 C temperature is projected to increase in Asian landmasses consequently, countries like Pakistan could experience a remarkable intense warm climate (Anwar, 2017).

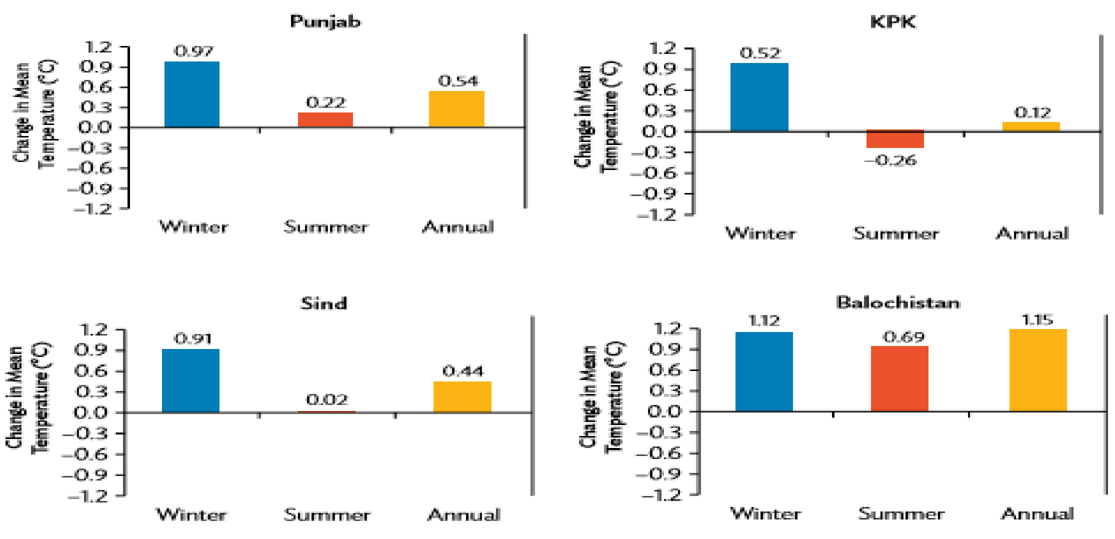
2.1.3 Climate Change Trends in Pakistan:

Following are some of the climate change trends in Pakistan:

Increase in Temperature:

In the past, a considerable warming trend with a 0.57C increase in the annual mean temperature was observed from 1901 to 2000 in Pakistan. Although this increase is less as compared to that of the whole Asian region. An increase in the warming trend of 0.47C was observed from 1961 to 2007 resulting in the highest increase during winters with the temperature increase from 0.52C to 1.12C. Till 2007, the warmest year recorded was 2004. The overall annual temperature increased by 0.87°C (maximum) and 0.48°C (minimum) from 1960 to 2007. The figure shows the overall increase in temperature during summers and winters.

Figure 3: Region-Wide Increase in Winter (Blue), Summer (Red), and Annual (Yellow) Mean Temperatures from 1960 to 2007



KPK = Khyber Pakhtunkhwa.

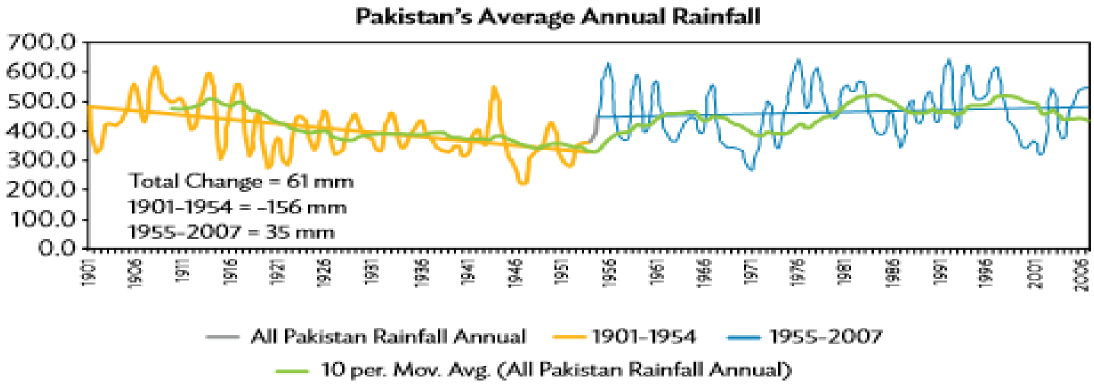
Source: Q. Z. Chaudhry et al. 2009. *Climate Change Indicators of Pakistan*. Technical Report. No. 22. Islamabad: Pakistan Meteorological Department.

In the future, Pakistan's projected temperature increase will continue to rise and will be higher than the global average. Therefore, a significant increase in the frequency of hot days and hot nights is expected.

Precipitation Patterns:

From 1951 till 2000, a decrease of 10%–15% in rainfall in arid plains and coastal areas during summer and winter was observed whereas an increase of 18%–32% was observed in the summer rainfall during the monsoon region of the country. The figure shows the annual average change in precipitation patterns.

Figure 5: Time Series Annual Average Precipitation, 1901–2007
(in millimeters [mm])



In the future, no significant change has been observed in precipitation patterns. However, an increase in summer and a decrease in winter precipitations is observed in southern Pakistan.

Extreme Temperature Events:

A substantial increase in the number of heat wave days per annum has been observed with a rate of 11 days per decade from 1980-2007. Especially, in the province of Sindh, a sharp increase in the trend of heat waves with temperature ≥45°C for 5, 7, and 10 days. A significant increase in the frequency of heat wave events had been noticeable from 1990 to 2011 all over the country. With the rising temperature, the prevalence of heat waves will be more frequent and intense in the long run in Pakistan. Similarly, an increase in cold waves has been observed in the north-western parts of the country whereas a decrease in Punjab and southern areas of Sindh province. However, no significant future trend has been observed regarding the increased frequency and intensity of cold waves (Asian Development Bank, 2017).

2.2 HEAT WAVES

2.2.1 What is a heat wave?

In several cases, the onset of extreme temperature events can often be explained through the changes in average weather patterns. As a practical example, over the last three decades, there has been an increasing number of heat-related mortalities in South Asia. This increase has been invigorated by the frequent, longer, and more intense heat waves during the summer (Muthukumara Mani, 2018). A heat wave is relative to a specific area therefore no universal definition exists for defining the heat wave. An average temperature of one region might be considered as a heat wave in another. Generally, when the temperature soars to 10 C above the normal for a longer span (10 or more days), it is considered to be a heat wave. Moreover, a heat wave is generally defined as “An unusual period of time with soaring high temperatures, higher than the average temperature registered.” (Martinez et al., 2016).

2.2.2 Formation of heat waves:

When the maximum daily temperature exceeds the average maximums by 5C or more, there is a lengthy spell of humid and hot weather and are declared as a heat wave. They normally occur when high pressure dominates an area (Gibbons, 2018). This high-pressure system develops an umbrella-like shape over the area where it traps the heat which would otherwise rise into the air to cool off to circulate back to the air surface. This causes a reduced chance of precipitation to occur and results in a continual build-up of heat. During summer, high-pressure systems are often slow to change which means the heat gets trapped and linger on and on for a longer duration in the affected area and temperatures may not cool off at night (Patrick, 2018).

2.2.3 UHI as a triggering Factor for Heat waves:

The impacts of heat waves are far more aggravated in urban areas increasing the vulnerability of ecosystems and urbanites. Urban development alters the land surface which leads to the creation of distinct urban climates. Infrastructures and buildings have increased thermal storage capacity due to urbanization which has led to the transformation of the ecosystem. These built structures are impervious and have the potential to absorb and radiate heat which leads to warming up of the boundary layer of the atmosphere producing an urban heat island (UHI) effect (Yaella Depietri, 2011).

2.2.4 Classification of Heat waves in Pakistan:

A heat wave is a relative phenomenon specific to an area, therefore no universal definition exists to define it (Cousineau).

In Pakistan, the standard criteria to identify heat waves is laid down by Pakistan Meteorological Department (PMD) as following:

- When the maximum temperature of the under-study meteorological station goes higher than 45°C for plains and higher than 40°C for hilly areas, it would be identified as a heat wave.
- When the maximum temperature observed is 42°C for the under study station then the rise of 5°C to 6°C for 8 and more consecutive days is regarded as heat wave.
- When the average maximum temperature of the under study station is greater than 45°C for more than 8 consecutive days regardless of the normal temperature trend, is identified as heat wave.

Moreover, another method PMD uses for classification of heat waves into the following three categories as stated in the research by (Ghulam Rasul, 2008).

Severe Heat Wave=Five consecutive Days with Daily Maximum Temperature ≥ 40°C

Moderate Heat Wave= Five consecutive Days with Daily Maximum Temperature ≥ 35°C and

Mild Heat Wave= Five consecutive Days with Daily Maximum Temperature ≥ 30°C and <35°C.

2.2.5 Heat waves in Pakistan:

Pakistan is situated in a climatically warm geographic region therefore, it is not exempted from extreme climatic events. It has substantial vulnerability towards extreme events such as heat waves, droughts, and floods. The temperature increase in this region tends to be higher than the global average variations (Wajid Nasim, 2018).

In Pakistan, heat waves usually develop during pre-summer i.e. March and April, and pre-monsoon i.e. May and June. During the pre-summer period, the heat wave conditions were often less during the 90s however due to climate change they are now more frequent in this particular period which has resulted in a longer summer season in Pakistan (Ghulam Rasool, 2012). An increase in heat index has been reported from 1961 to 2007 in the country (Wajid, 2018). The heat index is defined as "a measure of the stress placed on humans by elevated levels of atmospheric temperature & moisture" (Rasool). During heat wave of 2015, an estimated more than 200 people died of heat wave within a week in Pakistan (Wajid Nasim, 2018). Pakistan is highly under the effect of the high heat index. Areas such as Southeastern Baluchistan, Southern Punjab, and plains of north-western Baluchistan including all the areas of Sindh province are under the danger of high heat index (Rasool). Future projections show an increase of 4 C rise in temperature for 2100. To identify heat wave events, 29 weather stations (from Sindh, Punjab, and Baluchistan) were taken to analyse the daily maximum temperature from the historical data set (1997-2015). They were used to visualize the daily temperature variations for all the selected stations in the form of years and months. Maximum temperature variance has been observed from 1997 to 2015 in Pakistan. The table below shows the frequency of heat wave events in all three provinces:

Table 2.1 shows the list of heat events occurred in the Province of Punjab:

Table 1
List of heat wave events over provinces (Punjab, Sindh and Baluchistan) of Pakistan for different spatial and temporal (1996–2015) scales.

Punjab								
Mianwali	13–24 May; 1–11 June 2008	13–24 May; 19–30 June 2009	4–29 June; 10–21 May 2011	8 May–7 July 2012	5–19 June 2014			
Lahore	13 May–14 June 2010	13 May–6 June 2011	16 May–7 July 2012	4–22 June 2014				
Sargodha	13–25 May; 1–11 June 2008	13–25 May; 19–31 June 2009	21 May–4 June 2010	10–21 May; 8–28 June 2011	8 May–7 June 2012	5–19 June 2014		
Bhawalnagar Bahawalpur Multan	13 May–11 June 2008	13 May–14 June 2009	17 June–7 July 2010	24 Apr–28 June 2011	9 June–8 July 2012	17–27 May 2013	4–21 June 2014	
Toba Tak Singh	2 Apr–8 May 2008	14–31 May 2009	9 May–3 June 2010	24 Apr–28 June 2011	6 May–9 July 2012	17–26 May; 1–12 June 2013		
Rahim Yar Khan	25 Apr–8 May; 13 May–8 June 2008	8 May–25 June 2009	9–20 Apr; 6 May–10 July 2010	1 May- 8 July 2011	5 May- 7 July 2012	15–27 May 2013	26 May–11 June 2014	16–28 May 2015
Chakwal	13–24 May; 1–12 June 2008	14–31 May 2009	21 May–4 June 2010	4–28 June 2011	9 June–8 July 2012	5–21 June 2014		
Gujranwala	14 May–15 June 2009	21 May–5 June 2010	9–26 May; 4–27 June 2011	24 May–6 July 2012	4–21 June 2014			

Table 2.2 shows the list of heat waves events in the province of Baluchistan:

Baluchistan					
Barkhan	21–28 May 2010	4–28 June 2011	16 June–6 July 2012		
Nokkundi	28 May–17 June; 1–21 July 2008	15 July–19 Aug 2009	18–30 June 2010	3–17 June; 4–17 July 2011	27 June–20 July; 6–25 Aug 2012
Panjgur	8–18 May 2009	19–27 May 2010	6–24 May 2011	21 May–9 June 2012	

Table 2.3 shows the list of heat waves events in the province of Sindh:

Sindh								
Khairpur	27 Apr 13 June 2008	7 May- 17 July 2009	9–20 Apr 2010	1 May- 17 July 2011	15 May–12 June 2012	15 May–12 June 2013	26 May–25 July 2014	16–27 May; 17–30 June 2015
Jacobabad	27 Apr–14 June 2008	7 May–17 July 2009	9–20 Apr; 11 June–6 July 2010	5 May–9 July 2012	15 May–11 June 2013	26 May–26 July 2014		
Hyderabad	11–29 May 2009	11–31 May 2010	22 May–4 June 2012					
RCW Rohi	26 Apr–14 June; 1–21 July 2008	8 May–11 July 2009	9 Apr–7 June 2010	2 May–17 July 2011	5 May–9 July 2012	14 May–11 June 2013	27 May–24 July 2014	15–29 May 2015
Dahu	12–31 May 2008	8–30 May; 3–21 June 2009	29 May–10 June 2011	19 May–6 June 2012				

Seasonal heat index profile of Pakistan

shows that apparent annual temperature has considerably risen over the past few decades.

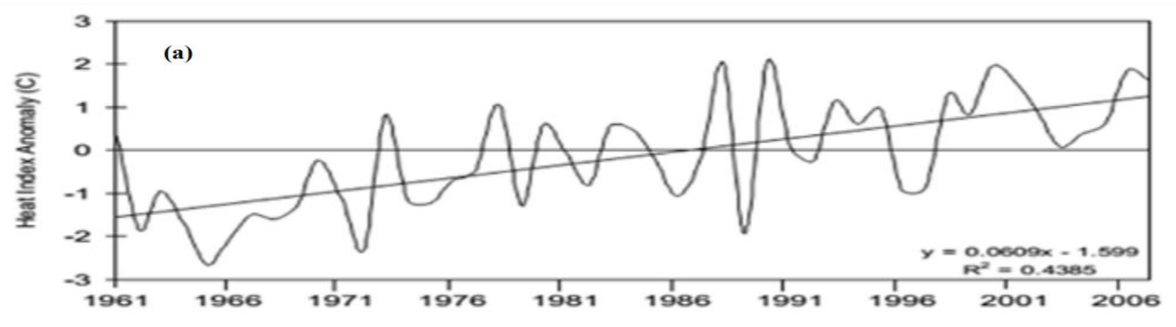
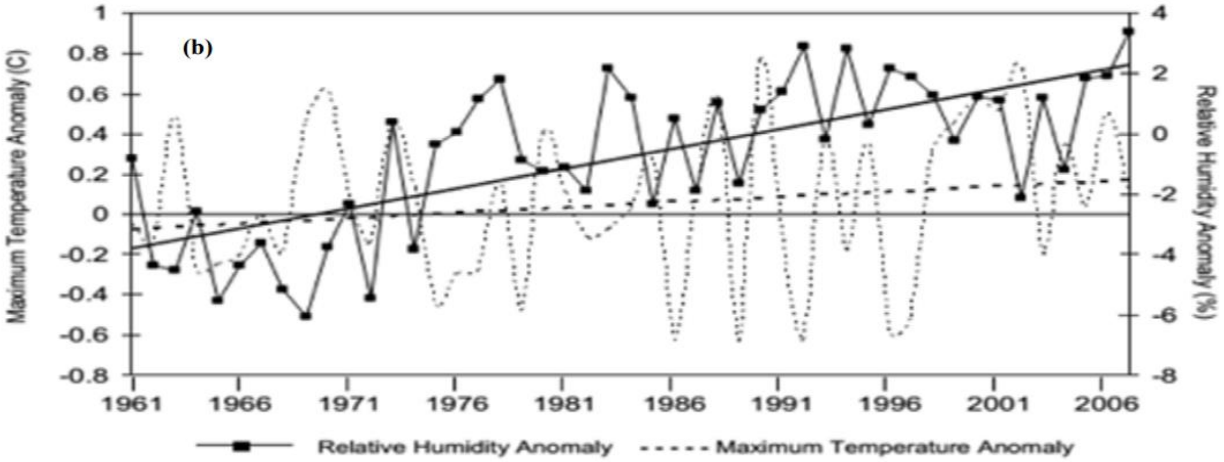


Figure 1(a) shows a total heat index increase of 3 ° C in the summer season. Figure 1(b) shows humidity along with the temperature profile of Pakistan.



Both figures illustrate a remarkable increase in both factors. As a result, the heat index value is the unfortunate outcome of this rising trend. From 1961- 2007, 6.2 percent is the overall humidity whereas the overall mean change in maximum temperature is 0.25°C. These findings point out the increased probability of the onset of a heat wave during the pre-monsoon season starting from May till June as well as the post-monsoon season starting from September till October (Hanif, 2017).

2.6 LOCAL STUDIES CARRIED OUT ON HEAT WAVES IN PAKISTAN:

Research paper title	Aims of the research Paper	Findings/ Results	Source/ authors
Future risk assessment by estimating historical heat wave trends with projected heat accumulation using SimCLIM climate model in Pakistan	Identified the historical heat waves events in temporal and spatial context in Punjab, Sindh and Baluchistan provinces. Identified future projections for heat accumulation in regions selected in the three provinces. Used these projections to identify hotspots and heat accumulation patterns in the selected regions.	Several heat waves identified from 1997 to 2015 for the provinces: Punjab 73 HW events Sindh 33 HW events Baluchistan 15 HW events. High risk of drought and heat wave in Sindh and southern Punjab.	(Wajid Nasim, 2018)
Socio-Economic Impacts of Heat Wave in Sindh	Analyse the socio-economic impacts of HW 2015 in Karachi.	Human health is at risk with an increase in the occurrences of HW. Severe and intense HW can be outcomes of climate change in the future. Lack of the provision of the water and electricity supply increased the sufferings during HW.	(Hanif, 2017)

2.3. FORMAL AND INFORMAL SETTLEMENTS:

2.3.1 Definition:

UN-HABITAT defines informal settlements as a group of housing which is constructed on land to which the occupant has no legal claim, built without any compliance to building codes and standards. Slums arise from the inability of the marginalized people to have affordability as well as accessibility for adequate housing. They are self-built usually by the market or the people when increasing numbers of people are unable to have adequate housing. Slum conditions are worsened by the inequitable distribution of wealth and resources, failing economy, bad governance, and inadequate planning policies. Inequality, being the major factor, not only responsible for poverty but it also makes it difficult the economic growth to have a positive contribution to poverty eradication.

Informal settlements or slums are often characterized by dense metal housing with minimal vegetation and scarce access to public amenities and government services. These informal settlements have a low, dense house built from iron sheets, mud, and wood with inadequate access to amenities such as clean drinking water. The population residing in these informal settlements are substantially vulnerable to heat exposure due to insufficient knowledge and awareness about heat wave occurrence and entails considerable potential risk. The inadequate provision of potable water and medical facilities along with poor household ventilation system pose a high risk in these settlements. A study conducted in three different slums of Nairobi supported the fact that the air temperature is subsequently warmer in these stations as compared to formal stations selected as study area (Anna A. Scott1, 2017).

3.2 Impact of Climate Change on Informal Settlements:

In recent years, the scale and extent of urban poverty as well as the exposure of the urban poor to climate change and disasters have increased significantly. Therefore, it has led to increased vulnerability to changes in mean climate and extreme weather events (Satterthwaite, 2008) .

3.3 Studies Conducted on Climate change in Informal settlements:

Title	Author	Aim	Conclusion
Urban poverty and vulnerability to climate change in Latin America	(PANDIELLA, 2015)	To find out who within the urban population is at higher risk from the likely impacts of climate change in the upcoming future in Latin America.	Those vulnerable groups such as women, children, and the elderly residing in informal settlements would be at greater risk form the likely impacts of climate change.
Unjust waters: climate change, flooding and the urban poor in Africa	(IAN DOUGLAS, 2008)	To alleviate flooding and its causes. And also to address the consequences of climate change.	Climate change has aggravated the problems for African urban poor in the form of flooding affecting the residents of marginalized and risky areas having little to no access to adaptation.
Responding to climate change in cities and in their informal settlements and economies	(David Satterthwaite, 2018)	To build resilience for billion urban dwellers living in informal settlements exposed to the consequences of climate change	It is the responsibility of the city government with the support of the National government to address climate change adaptation strategies and ensure city-wide infrastructure to enhance resilience for informal dwellers as well.

Vulnerability of informal settlements in the context of rapid urbanization and climate change	(DAVID SAMUEL WILLIAMS, 2019)	To identify the vulnerabilities of the urban poor aggravated by the rapid urbanization and climate change	Structural inequality has been identified as a driving risk for informal settlements and it needs to be tackled by global and international policies, legislations, and programmes.
Climate Change, Disaster Risk, and the Urban Poor Cities Building Resilience for a Changing World	(Bank, 2011)	To understand the link between climate change, urban poor, and disaster risk. Identifying good practices and proposing policies and measures to lessen the risks of urban poor exposed to the consequences of climate change.	Cities are facing enormous challenges around the globe confronting the risk induced due to climate change and natural hazards but understanding these challenges is the first step in overcoming these obstacles.

CHAPTER 3

METHODOLOGY

3.1 SELECTION OF STUDY AREA:

The study intended to assess the heat wave vulnerability in the formal and informal settlements of the Lahore Metropolitan Area. To carry out the field survey for the data collection, one formal and one informal settlement has been selected. The study area was divided into Faisal town (formal Settlement) and Kotha Pindh (informal settlement) where the socio-economic and infrastructural field survey was conducted to collect data for the indicators of sensitivity, exposure, and adaptive capacity.

KOTHA PINDH **FAISAL TOWN**

Source: Google Map, 2020

3.2 PROFILE OF LAHORE:

Lahore is the provincial capital of Punjab province and is the second-largest metropolitan city of Pakistan. The City has a complex social fabric with people from diversified ethnicities. Also, it has a rich history with several historic landmarks and archaeological sites. Lahore is an economic hub of Punjab, playing a pivotal role in the economic productivity of the state.

3.3 JUSTIFICATION FOR SELECTION OF STUDY AREA:

Lahore is the second-largest city of Pakistan and without a doubt an economic hub of Punjab Province housing approximately 12 million people as per the 2017 census report. Due to inadequate provision of affordable housing, many people are driven to settle in slums resulting in the formation and augmentation of slums and squatter settlements. They are often found in Shahdara along Ferozepur Road as well as Johar Town being a newly developed area. These settlements generally emerge near open sewage channels or along with the hazardous bank of River Ravi etc. Hence, it is also called the city of slums and shanties (Khan, 2017). The Lahore Development Authority (LDA) reported that almost 30% of all legal and on record settlements in the city fall under the category of slums (Abubakar, 2016). According to the LDA report, bricked structures are considered legal for slums registration and there are 876 registered slums from Shahdara to Ravi in Lahore whereas there are hundreds of unregistered slums all over the city (Abdul Wahab, n.d)

The city of Lahore has been selected to conduct the heat wave vulnerability assessment as it is the second-largest metropolitan city of Pakistan. Lahore has 3% of areas as green spaces, which is significantly very low when compared to the world's standards i.e. the minimum space of 25%-30% of an urban area. The Lahore Canal and the River Ravi are the two water bodies that add some cooling effect to the urban landscape. In recent years, the city has undergone an immense land-use change. Inconsistent government policies, inadequate land-use planning, and rapid urbanization attribute to this drastic change (Kazmi, 2016). Figure 3.1 below shows the table showing the drastic change in the built-up area, vegetation cover, and water bodies for the years 1992, 2001, and 2009.

LULC categories[a]	1992	2001	2009	% change 1992–2001	% change 2001–2009	% change 1992–2009	% annual change
Built-up[a]	911.14 (51.42 %)	1012.11 (57.12 %)	1268.85 (71.61 %)	100.97	256.74	357.71	21.04
Vegetative cover	645.06 (36.40 %)	417.51 (23.56 %)	249.7 (14.09 %)	−227.54	−167.81	−395.36	−23.26
Open areas	174.69 (9.86 %)	288.1 (16.26 %)	179.26 (10.12 %)	113.41	−108.84	4.57	0.27
Water bodies	15.95 (0.90 %)	25.31 (1.43 %)	34.95 (1.97 %)	9.36	9.63	19	1.12
Mixed	25.16 (1.42 %)	28.96 (1.63 %)	39.25 (2.21 %)	3.8	10.28	14.08	0.83
Total	1772	1772	1772				

Figure 3.1 Change in the built-up area, vegetation cover, and water bodies from 1992 to 2009
Source: (Shirazi, 2012)

Over the last few decades, Lahore has undergone rapid urbanization and urban growth increasing the built-up area which has negatively impacted the local climate of the city. The greenhouse gases, emission of co_2 particularly increased in the temperature of Lahore city. The Increasing built-up area has led to cause a reduction in the vegetation and green area in the city, resulting in the formation of urban heat islands (Nasar-u-Minallah, 2018). Figure 3.2 below shows the increase in the land surface temperature of Lahore City:

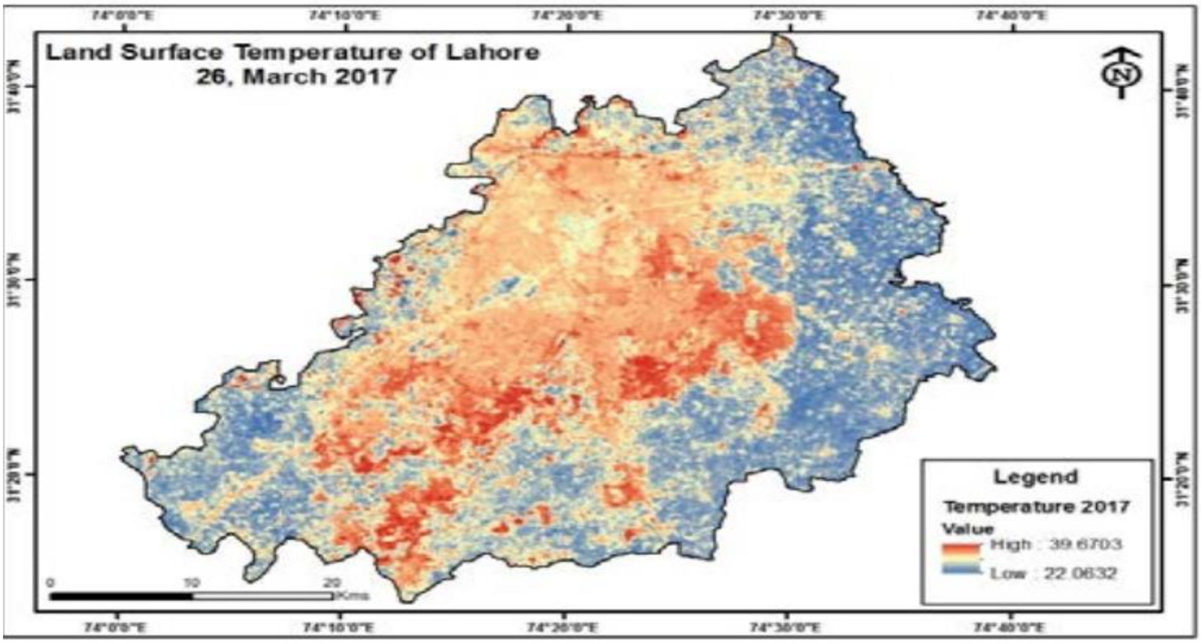


Figure3.1: Land Surface Temperature of Lahore in 2017 *source: (Nasar-u-Minallah, 2019)*

In the report "Identifying Asian Hotspots" by World Bank, the author identified Sindh province as the most vulnerable hotspot followed by Punjab particularly some of the densely populated cities that are identified as hotspot districts of Punjab namely Lahore, Multan, and Faisalabad. Also, it highlights the need to address long term climate vulnerability in these districts (mani, 2018).

3.4 DATA COLLECTION METHOD:

The study is qualitative as well as quantitative in nature (mixed research method). Both primary and secondary data were used for the study. To find the vulnerability, indigenous knowledge, and adaptive measures of both Faisal Town and Kotha Pindh, a semi-structured questionnaire with mainly close-ended questions were constructed for the residents in these settlements. The first part of the questionnaire comprised questions related to socio-economic and infrastructural conditions of the households situated in these settlements whereas the second part comprised of the open-ended questions to find out the indigenous practices and adaptive measures adopted by the households for coping with a heat wave. Households were selected through random techniques.

Due to the unavailability of existing data about the population distribution in Faisal Town and Kotha Pindh, the proportionate sampling technique was adopted for selecting the sample size. 400 households were selected for the questionnaire survey, 200 from each settlement. The fieldwork was conducted in 4 days (18 to 21 February 2020). 6 undergraduate students from the University of Engineering and Technology Lahore (UET) were entrusted with the task of enumerators. Before the field survey, the questionnaire was thoroughly briefed and discussed with the enumerators for a better understanding of the purpose of the study. Most of the respondents were males as it is customary in Pakistani society that females don’t respond to unknown people. The purpose of the study was explained to each household and their consent was sought for this purpose. Due to diverse study areas, questions were constructed in simple wordings for a better understanding of the respondents but the enumerators were instructed to translate questions for the easy understanding. The filled questionnaires were scrutinized and few questions were rephrased for better understanding.

3. 5 METHODOLOGY:

To analyse the data collected from field surveys, tools, and techniques were applied to the raw data. The study used the Statistical Package for Social Sciences (SPSS) for data entry and analysis. All entries for the indicators of sensitivity, exposure, and capacity were separately analysed by using the normalization technique. All values were transformed into 0 or 1 for simplified data analysis. After that, Indices were constructed for sensitivity, exposure, and capacity. Using these values vulnerability indices for each household were calculated using the IPCC framework for vulnerability assessment which is represented as:

$$\mathbf{V.I = \Sigma\ S.I + \Sigma E.I\ /\ \Sigma\ C.I}$$

Where,

V.I is the vulnerability Index

Σ S is the summation of the sensitivity index

Σ E is the summation of the exposure index

Σ C is the summation of capacity index

Where sensitivity index is represented by:

$$\mathbf{S.I = \Sigma\ S\ /\ N}$$

Where,

S.I is the sensitivity Index

Σ S is the sum of all indicators of sensitivity

N is the total number of indicators of sensitivity

Where exposure Index is represented by

$$\mathbf{E.I = \Sigma\ E/\ N}$$

Where,

E.I is the exposure Index

Σ E is the sum of all indicators of exposure

N is the total number of indicators of exposure

Where capacity Index is represented by

$$\mathbf{C.I = \Sigma\ C\ /\ N}$$

Where,

C.I is the capacity Index

Σ C is the sum of all indicators of capacity

N is the total number of indicators of capacity

Similarly, the adaptive measures adopted by respondents the Faisal Town and Kotha Pindh, were analysed using the descriptive tool in SPSS

Chapter 4

SOCIO-ECONOMIC PROFILE OF RESPONDENTS

4.1 INTRODUCTION:

This chapter displays the personal details of the respondents based on their frequency distribution and the percentage analysis:

4.2 AGE OF THE RESPONDENTS:

The age of the respondents plays a significant role in the reliability and validity of research data. The quality of research varies with the age of respondents and the results obtained from data responded by aged respondents somewhat provide less precision as compared to data obtained from young respondents (Herzog, 2014).

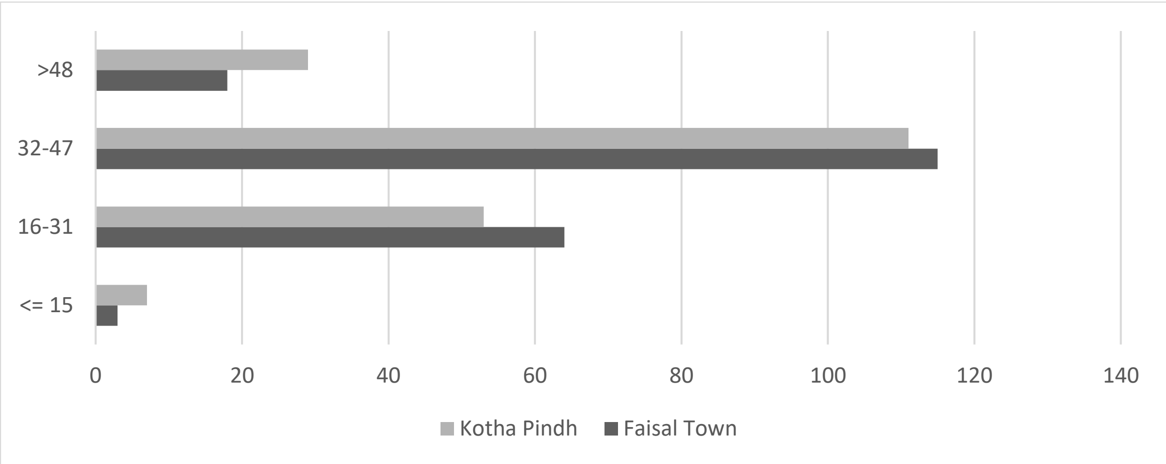
In this study, the Faisal Town respondents include 57.5 % of the respondents belonging to the age group ranging from 32 to 47, 33% belonged to the age group 16-31and 9% belonged to the age group >48. Whereas for Kotha Pindh, 55.5% of respondents belonged to the age group ranging from 31 to 44, 26.5% to the age group 17 to 30, and 14.5 % of respondents belonged to the age group > 45. Hence, a major percentage of respondents belonged to youth or middle-aged groups making our data significantly reliable. Table 4.1 below shows the percentage analysis of the ages of the 400 respondents of the study:

Table 4.1 Age of Respondents

Age group	FAISAL TOWN Frequency	FAISAL TOWN Percentage	Age group	KOTHA PINDH Frequency	KOTHA PINDH Percentage	Total Frequency	Total Percentage
<=15	3	1.5	<= 16	7	5.5	10	2.5
16-31	64	32	17- 30	53	26.5	117	29.25
32-47	115	57.5	31 – 44	111	55.5	126	31.5
>48	18	9	>45	29	14.5	47	11.75
Total	200	100	Total	200	100	400	100

Source: Field survey, 2020

Graphical Representation of Age of respondents:



4.3 GENDER:

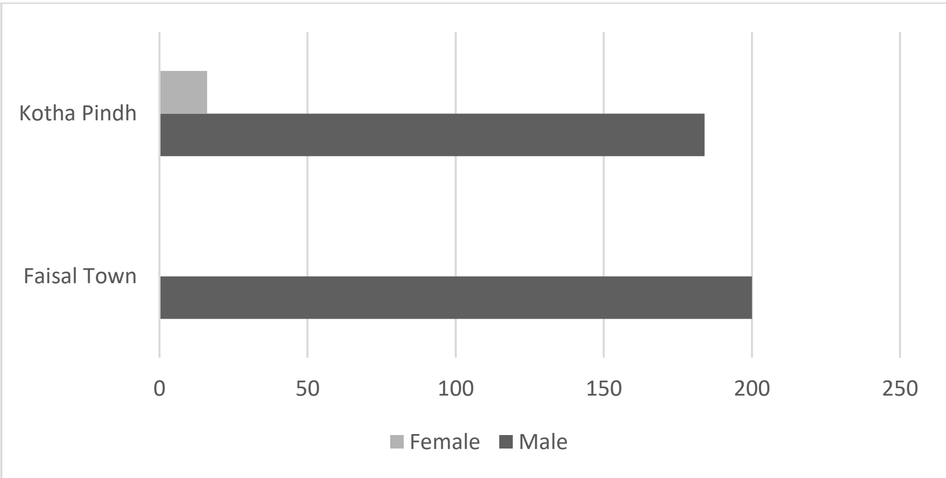
Gender consideration is crucial in implementation research. Failing to do so, might neglect an important determinant of knowledge use and it can reduce the effectiveness of the proposed interventions (Cara Tannenbaum, 2016). This study is independent of gender biases and households were interviewed based on who responded to the data collectors on the field. The majority of the respondents of Faisal Town were males i.e. 100% whereas only 92% of the respondents of Kotha Pindh were females with 8 % female respondents. The main reason for the minimal females’ participation in the survey is due to our cultural barrier. Table 4.2 shows the frequency distribution of genders in these settlements:

Table 4.2 Gender of Respondents

Gender	FAISAL TOWN		KOTHA PINDH		Total	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Male	200	100	184	92	384	96
Female	0	0	16	8	16	4
Total	200	100	200	100	400	100

Source: Field survey, 2020

Graphical Representation of Gender Distribution of Respondents:



4.4 EDUCATION:

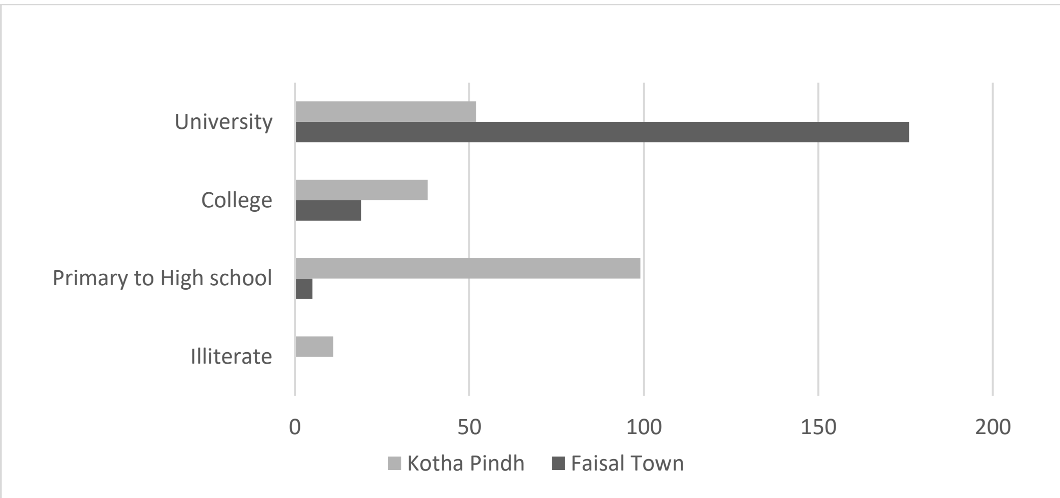
Education plays a significant role in influencing the lifestyle, behaviour, awareness, and attitude of the respondents. The education profile reveals the educational attainment of respondents. Data shows that 88% of the respondents attained university-level education and 9.5% of the respondents have attained college-level education for Faisal Town respondents whereas Kotha Pindh respondents, 26% have university-level education, 49.5% primary to high school, and 11% are illiterate. The data shows that the majority of the respondents of the study belonged to high education class in Faisal Town whereas Kotha Pindh respondents have mixed education levels. Table 4.3 below shows the percentage distribution of the education level of the respondents:

Table 4.3 Education Level of Respondents

Education level	FAISAL TOWN		KOTHA PINDH		Total	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Illiterate	0	0	11	5.5	11	2.75
Primary to high school	5	2.5	99	49.5	104	26
College	19	9.5	38	19	57	14.25
University	176	88	52	26	228	57
Total	200	100	200	100	400	100

Source: Field survey, 2020

Graphical Representation of Educational Level of Respondents:



4.5 INCOME:

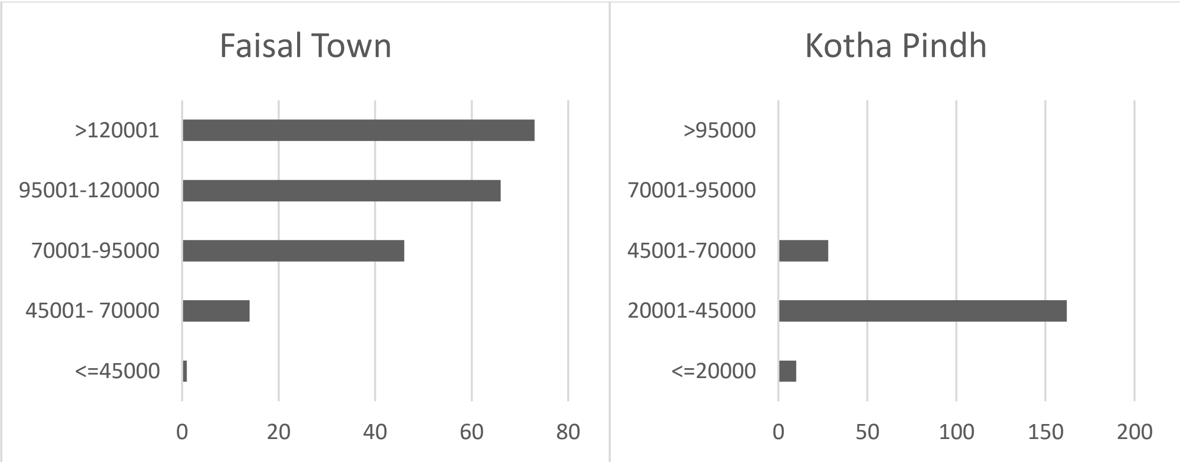
The income of the respondents shows the financial status and their affordability. Data shows that 36.5% of respondents have income greater 120000, 33% have an income ranging from 95001 to 120000 and 23% have income between 70000- 95000 in Faisal Town whereas in Kotha Pindh, 81% of respondents have income between 20000 to 45000. Table 4.4 below shows the income for respective respondents:

Table 4.4 Income Level of Respondents

Faisal Town			Kotha Pindh			Total	
Income	Frequency	Percentage	Income	Frequency	Percentage	Frequency	Percentage
<= 45000	1	.5	<= 20000	10	5	11	2.75
45001- 70000	14	7	20001- 45000	162	81	176	44
70001- 95000	46	23	45001- 70000	28	14	74	18.5
95001- 120000	66	33	70001- 95000	0	0	66	16.5
>120001	73	36.5	>95000	0	0	73	18.25
Total	200	100	Total	200	100	400	100

Source: Field survey, 2020

Graphical Representation of Income Level of Respondents:



4.6 FAMILY TYPE:

Family type means is the household nucleus, joint or single. 33% of respondents were living in a joint family system, 37% in the nucleus, and 30% in single-family type in Faisal town whereas in Kotha Pindh, 41% were living joint family system, 35% in the nucleus, and 24% in single-family type. Table 4.5 shows the following statistics about the family type of respondents:

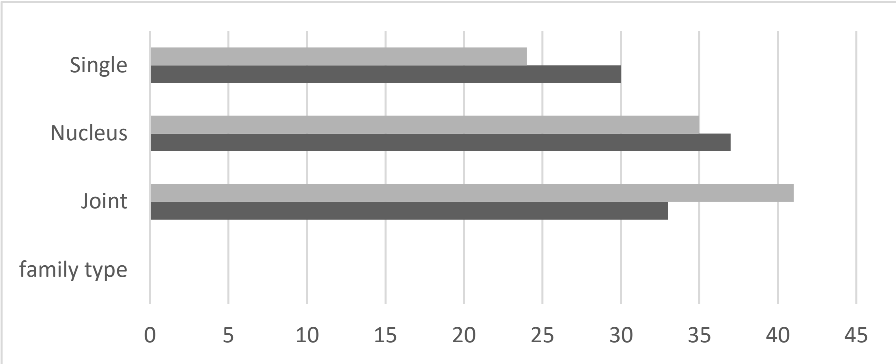
Table 4.5 Family Type of Respondents

FAISAL TOWN	Family type	Frequency	Percentage
FORMAL SETTLEMENT	Joint	66	33
	Nucleus	74	37
	Single	60	30
	Total	200	100
KOTHA PINDH INFORMAL SETTLEMENT	Joint	82	41
	Nucleus	70	35
	Single	48	24

	Total	200	100

Source: Field survey, 2020

Graphical Representation of Family Type of Respondents:



CHAPTER 5:

VULNERABILITY ASSESSMENT

Heat wave vulnerability is often regarded as a product of the effects of sensitivity, exposure, and adaptive capacity. It is often linked to buildings, urban structures, and characteristics of individuals. Some of the factors that influence heat vulnerability include the built environment, quality of housing, income levels, households' lifestyles, employment patterns, self-perception of risk, tenure patterns, and social networks. These factors impact an individual's sensitivity and exposure to risen temperatures as well as also impact their capacities to respond, anticipate, and adapt to conditions of heat stress (Luis Inostroza, 2016).

5.1 SENSITIVITY:

Sensitivity is a relative concept and is often used in various contexts by authors (Gallopin, 2006). For instance, (Adger, 2010) defines sensitivity as "the extent to which a human or natural system can absorb impacts without suffering long-term harm or other significant state change". IPCC (2001) defines sensitivity as "the degree to which a system is affected, adversely or beneficially by climate-related stimuli." (Tomovic, 1963) Also defines sensitivity as the per unit change in the system caused by any disturbance. Moreover, (L.Luers, 2005) described it in context as the degree to which the system would respond to external disturbances and also its ability to resist the change. Also, the system's ability to return to pre-conditions.

5.1.1 INDICATORS FOR SENSITIVITY:

Dependency Ratio:

One of the important indicators of age structure is the dependency ratio which is defined as "the ratio of persons of non-working age to persons of working age." It is generally desirable to have a low dependency ratio as it indicates that a proportionate number of adults belonging to the working-age group are supporting the elderly and young population (C. Simon, 2012) That is not always the case, it depends on numerous other factors that influence the dependency ratio. It is one of the important indicators for measuring sensitivity and also for vulnerability assessment of heat waves. The dependency ratio tells us about the number or percentage of infants, children, and elderly persons which would be classified as a vulnerable population as compared to young persons because of restricted mobility and strength.

Female to Male Ratio:

This also shows the percentage of vulnerable populations and their dependency on the independent population. Due to our cultural barrier, this ratio would be relatively larger. The greater value would indicate a significant portion of the population (females) are more vulnerable to climate change impacts due to their limited mobility and physical strength.

The number of the elderly population employed:

This indicator was chosen to measure the sensitivity of the study area. The data analysis would reveal that what percentage of the elderly population is working and are exposed to heat. Generally, it can be assumed that informal settlements would relatively have higher values of elderly employed persons as compared to formal settlements due to financial constraints.

Household living on the top floors of the building:

Research showed that buildings are more exposed to solar radiation based on floor levels and are generally more susceptible to overheating in summers (Aoul, 2017). Thus, households living on top floors of buildings would be more susceptible to heat wave impacts. These indicators will tell us about the population living on top floors and their percentage adding to the vulnerable population. Table 5.1 below shows all the indicators used in assessing the sensitivity:

Table 5.1 Indicators of Sensitivity

	INDICATORS FOR SENSITIVITY	UNIT OF MEASUREMENT	TRANSFORMED VALUES/ WEIGHTS	EXPLANATION
1	Dependency ratio (dependents to total household size)	<=.0 .1 – 1 1.1 – 2 2.1 – 3 3.1 +	0.2 0.4 0.6 0.8 1	Infants, children, and the elderly will be more vulnerable than young persons and adults, because of limited mobility and dependency
2	Female/male ratio	<=.30 .31 - 1.98 1.99 - 3.65 3.66 – 5.33 5.34+	0.2 0.4 0.6 0.8 1	Males will be less vulnerable than females due to their mobility and physical strength
3	Household with recurring illnesses	Yes no	1 0	It shows that the household is more vulnerable
4	Household living on top floors of the building	Yes no	1 0	Household living on top floors will be more exposed to heat thus vulnerable.
5	Household who visited a doctor for heat-related symptoms e.g. fainting, vomiting, dehydration, stroke. Heat stress and exhaustion	Yes No	1 0	More vulnerable
6	Number of household elderly members employed	Yes No	1 0	More vulnerable due to unstable source of income and are exposed to heat.

5. 2 EXPOSURE:

The other predominant element of vulnerability is exposure which means "the degree, extent, and duration in which the system is in contact with or subject to perturbation" (Adger W. , 2006).

Whereas, (IPCC, 2014) defines exposure as ''The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.''

5.2.1 INDICATORS FOR EXPOSURE:

Infrastructural Indicators:

Infrastructural Indicators to measure exposure include housing type, building heights, building age, building construction material, and household with indoor or outdoor kitchen. All these indicators were assessed separately for formal and informal settlements to measure up the vulnerability of each household. Housing (detached, semi-detached, or row houses) with no alleys or front or rear spaces are more vulnerable to a heat wave. Also, the building height (number of stories) affects vulnerability i.e. single-story housing units are more vulnerable as compared to multi-story housing units. Similarly, housing built of mud is often cooler than those made up of other materials (bricked houses) (Mustafa.B, 2016).

Household working Environment Indicators:

Household working environment Indicators include household work location, working environment and location, and the number of members exposed to the sun daily. Occupational heat exposure puts at risk not only the health of worker but it also impairs the working capacity and performance of a worker. However, in developing countries, the risk of excessive heat exposure is significantly high. Workers are at greater risk due to densely populated large informal work sectors affecting occupational health (Rebekah A I Lucas, 2014).

Travel Time to market:

Travel time to market means the longer the distance from the residence to market, the higher will be the vulnerability because of the heat exposure.

Table 5.2 below shows the indicators for assessing exposure:

Table 5.2 Indicators of Exposure

	INDICATORS EXPOSURE	UNIT OF MEASUREMENT	WEIGHTS OR TRANSFORMED VALUES	EXPLANATION
1	Household size	<3 4-9 >9	0.33 .66 1	Larger the household size means more people are vulnerable in the neighborhood
2	Family type	Joint Nucleus Single	0.33 .66 1	The single-family type will be more isolated and has limited access to resources
3	Housing type	Detached (bungalow) Semi-detached(normal) Combined (row houses)	0.33 .66 1	Houses with no alleys or front or rear spaces will be more vulnerable
4	Building height (no. of stories)	Multiple Double single	0.33 .66 1	Households living in single-story houses will be more vulnerable.
5	Building age		.25 .5 .75 1	The old building will be more exposed to heat waves as compared to newer ones

6	Building construction material	Katcha (mud) Pacca (brick, cement)	.5 1	Relatively katcha houses are cooler than bricked houses
7	Household with deaths in last heat wave	Yes no	1 0	Means they are more exposed
8	Travel time to market (in hours)	Yes no	1 0	The longer the distance from the residence, the higher will be the vulnerability
9	House hold work location	Sun Mixed shade	1 .66 .33	Direct sun exposure means greater will be the vulnerability
10	Occupational environment	Indoor outdoor	1 .5	A household with Indoor workplace will be less vulnerable
11	Household members who are exposed to the sun on a daily basis	Yes No	1 0	vulnerable household
12	Household with Indoor or outdoor kitchen	Indoor outdoor	1 0	Indoor kitchens are relatively hot during summers
13	Working hours	Daytime night-time	1 0	Daytime means more exposure to the sun
14	Household with homes warmer than outside during summers	Yes No	1 0	Heat gets absorbed by the walls of the building making the dwelling hot as compared to outside.

5. 3 CAPACITY:

Understanding adaptive capacity is very crucial in assessing vulnerability, although it is a difficult task to perform due to the unavailability of specific data. In the context of climate change, (IPCC, 2001) defined capacity as the ability of a system to adjust climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences”.

5.3.1 INDICATORS FOR CAPACITY:

Critical infrastructure indicators:

Critical Infrastructure indicators include access to electricity and drinking water. During a heat wave, the demand and consumption for electricity and water significantly rise. The high electricity demand to use of air conditions triggers disproportionally power outages. Similarly, the excessive use of water due to heat wave puts on a significant threshold on the water table and it might result in water scarcity in the area. This research aims to measure the household access to these infrastructures to assess the vulnerability due to heat wave.

Infrastructural Indicators:

Infrastructural Indicators include the number of windows, adequate ventilation system, presence of veranda, balcony, front, and back courtyards, and use of insulation material in a housing unit. These all indicators account for the adaptive capacity of a dwelling. Their availability/presence lessens the vulnerability as well as it incapacitates a dwelling to withstand the impacts of a heat wave. To reduce the intense heat wave risks, insulation materials significantly play an effective way to reduce energy consumption (Sayanthan Ramakrishnan, 2016). Windows, veranda, balcony, and courtyards significantly help in ventilation thus lessening the heat.

Green Spaces Indicator:

Green spaces are known as the lungs of a city. They play a substantial role in mitigating the heat island effect in a city. In the context of climate change, with the increase in the intensity and frequency of heat waves, green spaces are considered essential as they can create a cooling effect that extends around the surroundings. Measurements of weather parameters (solar exposure humidity, wind speed, and temperature) were analyzed and it was found that the garden was comparatively cooler than the surrounding streets. Hence, the availability of green spaces is very important. Therefore, we have taken two indicators to assess their availability at home and in the workplace.

Life Insurance indicator:

Insurance plays a pivotal role in reinstating the business disrupted by disaster consequences. Although, heat wave does not directly impact your financial situation or business. Yet, it is life-threatening to human life. It is considered as a strength to withstand the impacts of any disaster. This indicator was used to assess to check the people's level of preparedness to cope with ay disaster.

Understanding the National warning system:

National Disaster management authority issues warnings when there is any risk of hazard to happen. Similarly, warnings are used whenever there is an onset of heat waves in the country. This indicator was used to assess the people's understanding level of warnings and what is the medium through which they receive these warnings (phone, radio, TV, Internet).

Table 5.3 below shows indicators for measuring the capacity that has been used to carry out the questionnaire survey in both formal and informal settlements selected as the study areas:

Table 5.3 Indicator for Capacity

	INDICATORS OF CAPACITY	UNIT OF MEASUREMENT	TRANSFORMED VALUES/ WEIGHT	EXPLANATION
1	Average monthly housing income	>120001 95001-120000 70001-95000 45001-70000 <= 45000	1 0.8 0.6 0.4 0.2	Lower-income results in higher vulnerability and takes more time for recovery
2	Occupation of the household head	Government service Trade and commerce Agriculture Daily wagers/ labours private	1 0.8 0.6 0.4 0.2	An unstable source of income means more vulnerable to the household or nature of work means at what level you are exposed to a heat wave
3	Household having access to drinking water	Yes No	1 0	It is considered a critical infrastructure that might fail under high demand. A household with access to drinking water are less vulnerable
4	Household having access to electricity	Yes No	1 0	A household with access to electricity will less vulnerable to a heat wave.
5	Household access to a nearest medical facility within 1km	Yes No	1 0	Access means the household is less vulnerable
6	Household having access to means of communication (TV, radio, internet, mobile)	Yes No	1 0	The greater the access, the more informed will be the household
7	Household access to means of transportation car, public transport, motorcycle	Yes No	1 0	Less would be the vulnerability
8	Number of windows in the house	<5 6-13	.25 .5	The number of windows indicates thorough

		14-22 >23	.75 1	ventilation throughout the house
9	Adequate ventilation system in the house (exhaust fans)	Yes No	1 0	Availability of ventilation system less will be the vulnerability
10	Presence of veranda in the house	Yes No	1 0	Less direct exposure to the sun
11	Presence of projections to the windows (chajas	Yes No	1 0	Less direct exposure to the sun
12	Working condition of AC/ water cooler	Yes No	1 0	Enhance the ability of the household to cope up with heat wave
13	Presence of Front and back courtyard	Yes No	1 0	Less will be the vulnerability
14	Presence of balcony	Yes No	1 0	Enhance the capacity to cope up with heat wave
15	Automobiles with working AC	Yes No	1 0	Enhance the capacity to cope up with heat wave
16	Use of any insulation material/ measure for heat protection	Yes No	1 0	Promotes cooling effect inside the building by blocking the heat coming inside
17	Availability of green spaces in the neighborhood	Yes No	1 0	Large green spaces, lessen the impact of heat waves
18	Availability of first aid kit in the household	Yes No	1 0	Mitigation measure enhancing the ability to respond back
19	Ventilation system in the kitchen	Yes No	1 0	Better air circulation
20	House hold understanding of national warning system	Yes No	1 0	Enhance the preparedness measures and the ability to respond back
21	House hold head education level	Illiterate Primary to middle school	0 0.2	The higher the education, the less vulnerable would be the household

		High school College University	0.6 0.8 1	
22	House hold having health/life insurance	Yes No	1 0	Greater capacity for coping
23	Provision of AC at Indoor work place	Yes No	1 0	Less exposure to heat
24	Provision of drinking water at outdoor work place	Yes No	1 0	Lessen the effect of heat stress by continuous hydration
25	Household with In-home taps access	Yes No	1 0	Water plays a significant role in lessening the heat stress
26	Percentage of the household having access to green spaces at work	Yes No	1 0	Green spaces create a cooling effect, reducing heat

5. 4 VULNERABILITY FRAMEWORK

To understand the complex interaction of the environment and manmade activities in a holistic way, it usually requires a framework. In this study, features from existing frameworks were adapted as per the study objectives. It encloses diverse concepts and elements; exposure, sensitivity, and capacity. (Xueling Li, 2013). If a common approach already exists, then we need to begin with that framework otherwise there would be a need to formulate your framework (PATWARDHAN, 2005).

Exposure and sensitivity represent the predisposition and propensity of the system studied to be negatively affected by climate change whereas the capacity enables the system to withstand (Gallopin, 2006).

Therefore, “vulnerability can be expressed as the positive function of exposure and sensitivity, but a negative function of adaptive capacity.”

Vulnerability = f (Exposure, Sensitivity, Adaptive capacity)

= (Exposure, Sensitivity) / Adaptive capacity

V= (E x S) / C

5.4.1 Vulnerability Index:

By combining indicators of sensitivity, exposure, and adaptive capacity, an integrated index for the vulnerability of heat wave was created. The input indicators for the vulnerability model of the study include 6 indicators of sensitivity, 14 indicators of exposure, and 26 indicators of capacity.

5.4.2 Normalization Of data:

The foremost task is normalizing our data i.e. to assign weights between 1 to 0. By doing so, the differences in their input indicators are removed. After normalization, all the indicators range from 1 to 0. Weight assignment to indicators is significant in vulnerability assessment based on the individual contribution towards vulnerability. Using the respective weights, three indices for sensitivity (SI), exposure (EI), and capacity (CI) were made with values ranging from 0 to 1.

The sensitivity index is represented by:

$$\mathbf{S.I = \Sigma\ S / N}$$

Where,

S.I is the sensitivity Index

Σ S is the sum of all indicators of sensitivity

N is the total number of indicators of sensitivity

Exposure Index is represented by

$$\mathbf{E.I = \Sigma\ E/\ N}$$

Where,

E.I is the exposure Index

Σ E is the sum of all indicators of exposure

N is the total number of indicators of exposure

Capacity Index is represented by

$$\mathbf{C.I= \Sigma\ C\ /\ N}$$

Where,

C.I is the capacity Index

Σ C is the sum of all indicators of capacity

N is the total number of indicators of capacity

The tables below show the sensitivity index values, exposure index values, and capacity index values for Faisal Town (formal settlement) and Kotha Pindh (informal settlement):

5.4.3 Sensitivity Index:

The sensitivity index is the sum of indicators of sensitivity divided by the total number of indicators of sensitivity. Table 5.4 below shows that 45% of households in Faisal Town have moderate sensitivity whereas 48.5% of households in Kotha Pindh have moderate sensitivity. The analysis shows P-value .427 as the difference between the sensitivities of formal and informal settlements.

Table 5.4 Sensitivity Indices for Faisal Town and Kotha Pindh

Settlement Type	Classes	Very Low	Low	Moderate	High	Total	Descriptive Statistics	T-Test
Faisal Town	Range	<= .13	.14- .21	.22 - .29	>.30		Max .70	
	No. of HHs	14	86	90	10	200	Min .17	
							Mean	-.796
	%	7	43	45	5	100	0.62	P value= .427
Kotha Pindh	Range	<=.13	.14 -.20	.21 -.27	>.28		Max .71	
	No. of HHs	16	45	97	42	200	Min .49	
							Mean	
	%	8	22.5	48.5	21	100	0.63	

Source: field survey 2020

5.4.4 Capacity Index:

Capacity Index is the total of all values of indicators of capacity divided by the total number of indicators. Table 5.5 below shows the capacity index values for Faisal Town and Kotha Pindh. The data shows that 51% of households in Faisal Town have moderate capacity whereas 42.5% of households have high capacity. While 91.5 % of households in Kotha Pindh have low capacity. The analysis shows that Kotha Pindh lags Faisal Town in terms of capacity to cope with heat waves.

Table 5.5 Capacity Indices for Faisal Town and Kotha Pindh

Settlement Type	Classes	Very Low	Low	Moderate	High	Total	Descriptive Statistics	T-test
Faisal Town	Range	<= .64	.65 - .74	.75– .84	>.85		Min .64	39.294 P value = 0.000
	No. of HHs	1	18	99	82	200	Max .96	
	%	.5	9	49.5	41	100	Mean 0.82	
Kotha Pindh	Range	<=.41	.42 -.56	.57 -.71	>.72		Min .40	
	No. of HHs	1	110	85	4	200	Max .85	
	%	0.5	55	42.5	2	100	Mean 0.51	

5.4.5 Exposure Index:

Exposure Index is the sum of all values of indicators of exposure divided by the total number of -indicators. Table 5.6 below shows the exposure index values for Faisal Town and Kotha Pindh. The data shows that 38.5 % of households in Faisal Town are highly exposed whereas in Kotha Pindh 51.5% of households are highly exposed to heat waves. The analysis shows that Kotha Pindh is widely exposed as compared to Faisal Town. To measure the exact difference between the two settlements, the T-test gives the p-value of 0.043 which shows the actual difference that exists among the two settlements.

Table 5.6 Exposure Indices for Faisal Town and Kotha Pindh

Settlement Type	Classes	Very Low	Low	Moderate	High	Total	Descriptive Statistics	T-test
Faisal Town	Range	<= .50	.51- .57	.58– .64	>.65			
	No. of HHs	1	31	91	77	200	Max .71 Min .51	
	%	.5	15.5	45.5	38.5	100	Mean 0.82	-2.041 P value = 0.043
Kotha Pindh	Range	<=.50	.51 - .57	.58 -.64	>.65			
	No. of HHs	1	17	79	103	200	Max .71 Min .49	
	%	.5	8.5	39.5	51.5	100	Mean 0.51	

5.5 DESCRIPTION OF INDICES OF EXPOSURE, SENSITIVITY, AND CAPACITY:

Vulnerability Index:

Vulnerability Index is the sum of indices of sensitivity, exposure divided by capacity. Vulnerability Index is represented as:

$$\mathbf{V.I = \Sigma\ S.I + \Sigma E.I\ /\ \Sigma\ C.I}$$

Where,

V.I is the vulnerability Index

Σ S is the summation of the sensitivity index

Σ E is the summation of the exposure index

Σ C is the summation of the capacity index

Table 5.7 below shows the vulnerability indices for Faisal Town and Kotha Pindh. The data indicates that the vulnerability index for Faisal Town is comparatively low to that of Kotha Pindh. In Faisal Town, 56.5% of the respondents have low vulnerability whereas Kotha Pindh's respondents have 53.5% have moderate vulnerability as well as 36.5% with highly vulnerable. The T-test shows that a significant difference with p-value 0.000 exists between Faisal Town and Kotha Pindh.

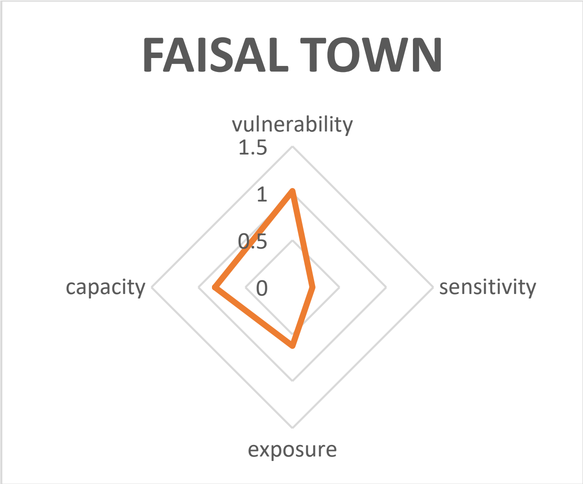
Table 5.7 Vulnerability Indices for Faisal Town and Kotha Pindh

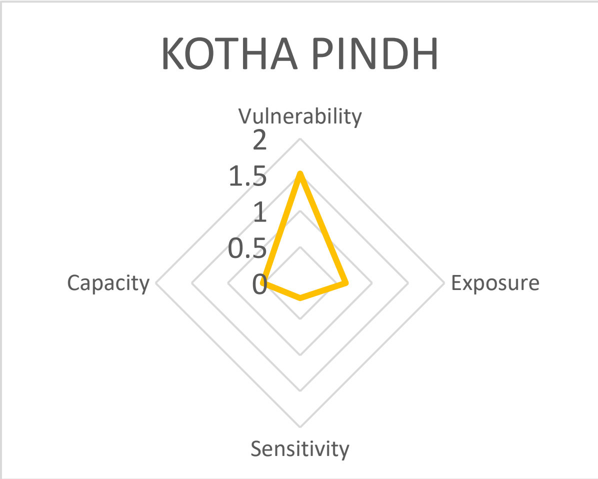
Settlement Type	**Classes**	**Very Low**	**Low**	**Moderate**	**High**	**Total**	**Descriptive Statistics**	**T-Test**
Faisal Town	Range No. of HHs %	<= .78 1 0.5	.79- 1.03 113 56.5	1.04– 1.28 77 38.5	>1.29 9 4.5	 200 100	Max 1.48 Min .78 Max 1.02	-31.475 P-value =0.000
Kotha Pindh	Range No. of HHs %	<=1.06 1 0.5	1.07–1.31 19 9.5	1.32 -1.56 107 53.5	>1.57 73 36.5	 200 100	Max 1.93 Min 1.06 Mean 1.5	

Source: Field Survey 2020

5.6 GRAPHICAL PRESENTATION OF VULNERABILITY INDICES:

The graph below shows the graphical explanation between the vulnerabilities of Faisal Town and Kotha Pindh. The graph indicates that in Faisal Town vulnerability is comparatively low as compared to Kotha Pindh where vulnerability is relatively high for heat waves. Plotted on individual axes the dimensions of vulnerability Sensitivity, capacity and exposure, and vulnerability. It shows that how a higher value of capacity lowered the vulnerability in Faisal Town and its lower value resulted in increased vulnerability in Kotha Pindh.





CHAPTER 6:

ADAPTIVE AND COPING STRATEGY FOR HEAT WAVE RISK REDUCTION

6.1 INTRODUCTION:

The degree and extent of communities and individuals to heat waves is a function of multiple factors such as age, socio-economic factors, pre-existing illness and medication, awareness of the risks, level of exertion, and quality of housing and the environment (Queensland University of Technology, 2010). Heat-related mortality or illnesses will increase substantially in the future concluded by nearly all researchers projecting heat-health impacts (Jr, 2015).

The climate change adaptation regarding heat waves includes:

1. Physiological adaptation
2. Technological adaptation
3. Behavioral adaptation

Acclimatization refers to physiological adaptation (IPCC, 2014). Whereas Societal or human adaptive capacity is defined as the "ability to adjust potential damage, to take advantage of opportunities, or to respond to consequences." (Jr, 2015). IPCC defines adaptive capacity as the following types as anticipatory and autonomous capacities which are infrastructure, technological and behavioral adaptations. These three adaptations are collectively made up of both individual and collective adaptive measures adopted by a community (Deschenes, 2014). Behavioral adaptation is defined as "a set of actions that households (individuals), communities, and populations can take to adjust to change". It involves changing the structure of activity and geographic mobility. (IPCC, 2014).

Individuals and different groups within a community reflect a diverse range of adaptive capacities which are mainly based on physical or socio-economic conditions (Fussel, 2010).

One of the objectives of the study is to identify the indigenous knowledge and adaptive measures that households adopt in Kotha Pindh and Faisal Town to reduce heat stress impacts.

6.2 ADAPTIVE STRATEGIES:

The following are the adaptive strategies that both settlements adopt during heat stress:

6.2.1 Strategies for Protection from Heat Exposure at Home:

1. Use of Air conditioners (AC):

The use of air conditioning is a very common and effective practice in reducing air temperature and thermal strain (Parsons, 2009). To combat heat wave, most of the households use AC to normalize the indoor temperatures. The data analysis showed that 89% of the households in Faisal town use AC at home whereas households in Kotha Pindh do not have AC due to low income.

2. Avoid outdoor activities during daytime:

The best practice is to stay indoors to avoid sun exposure during heat waves. Plan your activity in the morning or evening to avoid high temperatures. 39% of households in Faisal Town adopt the measure of staying inside whereas 15% of respondents in Kotha Pindh adopt this measure.

3. Windows covered with vegetation cover:

Urban vegetation plays a remarkable role in reducing the impacts of heat waves especially to buildings which decreases the solar heat gain by shading (Laurent Malys, 2016). Trees act as natural insulations for buildings. 27% of the respondents in Faisal Town have trees shading their household whereas respondents of Kotha Pindh did not have trees in their household for shading purposes.

4. **Wear light clothes:**

During heat stress, it is advisable to wear lightweight, light-colored, and loose-fitting clothing. Dark-colored clothing tends to absorb heat when exposed to the sun which may lead to sunburn that can affect the body's ability to cool off (WHO, 2006). 83.5% of respondents in Faisal Town adopt this measure. Similarly, in Kotha Pindh, 93.5% of respondents adopt this strategy to cope with the heat.

5. **Hang wet sheets on the windows:**

It is a local adaptive strategy adopted by residents in Kotha Pindh by hanging wet sheets on the windows. It helps in creating the cooling effect inside the rooms. 57% of respondents adopt this measure during summers.

6.2.2 Strategies for Protection from Heat Exposure at Work:

1. **Wear a cap or covering head:**

98% of respondents in Kotha Pindh wear a cap or cover head when exposed to the sun during heat wave whereas 29% of the respondents adopt this measure in Faisal Town.

2. **Use umbrella:**

The use of an umbrella is another strategy to cope up with intense heat exposure during day time. 17% of respondents in Faisal Town use umbrella whereas only 5.5% of respondents in Kotha Pindh use an umbrella.

3. **Walking or standing under shade:**

17% of respondents in Faisal Town walk or stand under shade during heat wave whereas 39% of respondents in Kotha Pindh use trees for shading purposes during walking.

4. **Stay hydrated:**

The human body responds to heat stress in form of heat strain which involves increased heart rate, palpitation, excessive sweating which can lead to illness and death in vulnerable people when their body temperature is higher than the normal level i.e. 98F. Excessive sweating can lead to dehydration and increased body temperature can lead to heatstroke and death (Parsons, 2009). 98% of respondents from Faisal Town and Kotha Pindh drink water to cool off heat stress.

Table 6.1 below shows the distribution of the adaptive strategies adopted by Faisal Town and Kotha Pindh settlements:

Table 6.1 Adaptive Strategies Adopted in Faisal Town and Kotha Pindh

STRATEGY	Faisal Town	Kotha Pindh
	Percentage (%)	**Percentage (%)**
Use of Air conditioners (AC)	89	1.5
Avoid outdoor activities during daytime	39	15
Windows covered with vegetation cover	27	0
Wear light clothes	83.5	93
Hang wet sheets on the window	0	57
Wear a cap or covering head	29	98
Walking or standing under the shade	17	39
Stay hydrated	98	98
Use of Umbrella	17	5.5

Source: Field survey 2020

This shows that despite the varying frequencies, the adaptive strategies for coping with heat waves, are the same in both Faisal Town and Kotha Pindh.

6.2.3 Strategies for Coping with Heat Wave:

These are some of the strategy's respondents suggested for coping with heat waves:

1. Promote walkability and public transport:

Urban heat islands happen when the cities' natural terrain is replaced with dense concentrations of concrete buildings and pavements that absorb and retain heat. It results in high energy costs (e.g., for air conditioning), increase in air pollution with compromised quality of life (Environment Protection Agency, 2020). Due to the increased built-up area, the temperature has already risen remarkably and the trend continues to spike up in the future. This requires concern to lower the pace of rising temperatures due to manmade activities. In doing so, the respondents of Faisal town suggested the measure of promoting walkability and the use of public transport to cope with the heat wave. Walkability tends to lessen the level of air pollution which significantly contributes to increasing annual mean temperature. Similarly, using public transport tends to protect from direct heat exposure for households that do not have their car especially in Kotha Pindh where only 0.5 % of households have their car as compared to Faisal Town.

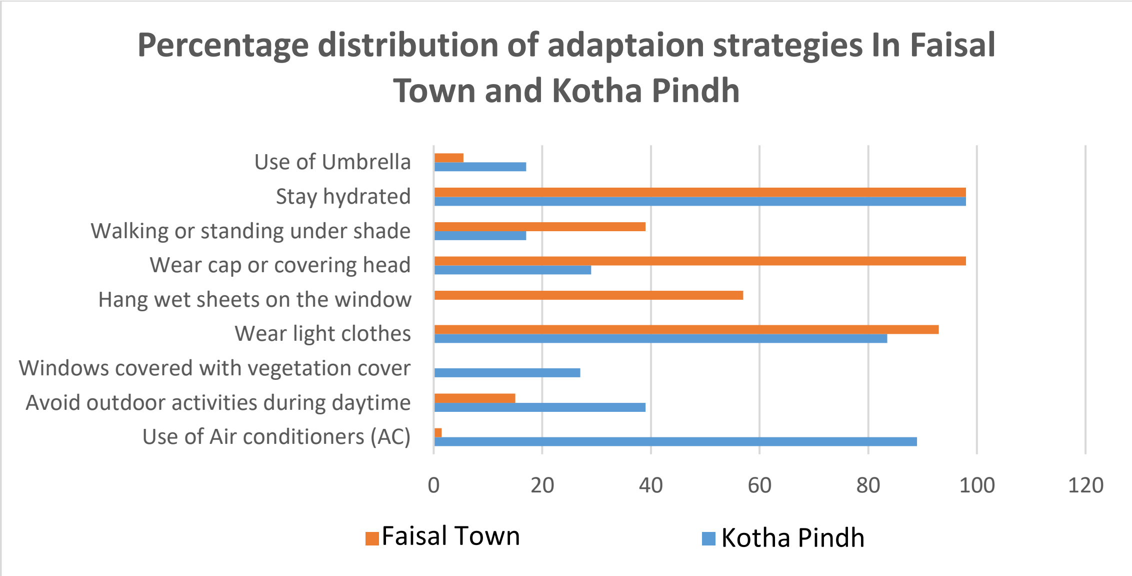
2. Promote rooftop gardening

Generally, green infrastructure can include urban tree canopy, green streets, green walls, and green roofs**.** They play an eminent role to reduce the heat stresses associated with urban heat island effects within the city (Fernando, 2018) **.** Green roofs have multiple benefits such as soil acts as the substrate and the vegetation provides an insulation effect. It also provides shade and evapotranspiration which creates the cooling effect for the building (Andrew M. Coutts and, 2013).

3. Tree planting and vegetation to add green spaces to the city:

In the urban environment, green spaces contribute profoundly to the mitigation of the urban heat island. With the expected increase in temperature and intensity and frequency of heat waves, green spaces contribute are assumed of higher importance for creating a cooling effect that extends to the surroundings of the city (Vaz, 2011). This phenomenon is called the urban green space cooling effect.

GRAPHICAL PRESENTATION OF ADAPTIVE STRATEGIES IN FAISAL TOWN AND KOTHA PINDH:



Source: Field survey 2020

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION:

The study aimed to assess the actual difference between the heat wave vulnerability in formal and informal settlements of the Lahore Metropolitan Area. In doing so, various indicators of components of vulnerability (sensitivity, exposure, and capacity) were derived to construct indices. The data analysis showed that informal settlement i.e. Kotha Pindh is more vulnerable to heat wave as compared to Faisal Town, which strengthened the hypothesis of the study. Keeping in view the socio-economic and infrastructural conditions, Kotha Pindh lags the Faisal Town, making it more exposed and sensitive to a heat wave. The increase in the land surface temperature in Lahore is the consequence of diminished vegetation cover and increased built-up area. (Nasar-u-Minallah, 2019). Moreover, (Mahmood, 2020) stated that during 1996 – 2016, a 9% decrease in green spaces resulted in a 6◦C increase in temperature around the built-up area and predicted that only a 3% decrease in green spaces would result in 2◦C increase in temperature by 2035. This fact draws a huge concern in addressing heat waves in the future. These slum areas are the potential hotspots for heat waves and entail a greater risk for its residents. These hotspots tend to have sparse access to infrastructure and services (Mani, 2018).

7.2 MECHANISMS TO DEAL WITH HEAT WAVES:

The data analysis shows that Kotha Pindh's residents are more exposed to heat waves as compared to Faisal Town's residents. The higher values of exposure indicators such as housing type, household size, family type, building type, building age, household work location, building construction material, and household with deaths during heat waves. The higher values of these indicators need to be reduced to lessen the exposure of Kotha Pindh's residents. Similarly, the sensitivity index shows higher that Kotha Pindh's residents are more sensitive to heat waves as compared to Faisal town's residents. The higher values of indicators of sensitivity such as dependent to independent ratio, number of elderly members employed in a household, and household with recurring illnesses show that a significant percentage of the population is at risk in Informal settlements. Several studies showed that women are more susceptible to heat risk than men due to their physiology. Similarly, aged people, people with cardiovascular issues, and other pulmonary illnesses show greater susceptibility (Creutzig, 2015). The data findings show that Faisal Town, being a formal settlement, have greater adaptive capacity to cope up with heat waves as compared to Kotha Pindh. Kotha Pindh's residents are vulnerable in terms of socio-economic and infrastructural conditions to heat waves. Indicators such as household income, education, access to critical infrastructures, and access/ availability of green spaces in neighborhood and workplace, play a significant role in enhancing the adaptive capacity to mitigate the effects of heat waves. The intensity and frequency of heat waves will affect households to different degrees. Understanding the housing living standards and characteristics of the vulnerable households will be beneficial for developing targeted policies in these areas. Analyzing the alternative adaptive strategies, existing literature review highlighted some of the ambitious mitigation actions, encompassing a wide spectrum of policies. Formulating policies/ mechanisms to mitigate heat wave would be broadly categorized into three levels:

POLICY MEASURES	**MECHANISMS**
Large scale urban reconfiguration Policy	Structural/institutional
Building scale policy	Technological
Behavioral change policy (Lemonsu, 2020)	Cultural/behavioral (Pullen, 2014)

7.2.1 STRUCTURAL/INSTITUTIONAL

Policies shall be formulated to ensure the equal distribution of amenities to the extent to which policy benefits are spread in a way that no group receives minimum or maximum benefit. Usually, Policymakers ensure to measure how fairly a service is equally distributed among various targeted groups keeping in view the demand of everyone as per the recipient group's needs. Commutative justice ensures the equitable distribution of services based on the level of their need (Creutzig, 2015). The first and foremost policy that the study recommends is the augmentation of green spaces in urban areas. It is considered one of the significant policies in mitigating heat waves effects. The study conducted in Paris showed that only 10% of the city was converted to green spaces and watered during heat wave had an optimal cooling effecting of the vegetation due to evapotranspiration (Lemonsu, 2020). As the data findings showed the minimum availability of green spaces in Kotha Pindh, this policy would significantly enhance their adaptive capacity and lessening their sensitivity to a heat wave. Similarly, trees and vegetation play an important role in heat reduction by shading the buildings, other surfaces, and pavements to prevent the absorption of heat and transmitting the heat to the surrounding air. This fact has been quantified by several studies (RESILIENCE STRATEGIES FOR EXTREME HEAT, 2017).

7.2.2 TECHNOLOGICAL:

The second adaptation action shall be about the building scale policymaking. It involves the effort for more stringent bylaws and building codes and regulation, for existing and new buildings to incorporate the insulation codes and standards. It will involve the use of reflective materials for walls and roofs which will reflect the heat away from the building' surfaces. Research showed that by improving building insulation has a profound impact on potential energy consumption by lessening the demand for using air conditioners (Lemonsu, 2020). Cool roofing products are made up of emissive and highly reflective materials that remain 50-60 degrees cooler than the other traditional materials during summers. These materials have high solar reflectance properties and transfer less than 35% to the building. These cool roofs reduce the indoor air temperatures and it also contributes to lower rates of heat-related illnesses and mortality, especially in top floors of buildings and households without air conditioners. (RESILIENCE STRATEGIES FOR EXTREME HEAT, 2017). Despite heat waves casting a huge impact on health and life safety, the role of buildings, remains unclear, relative to the other factors such as age and health of the affected persons. Buildings' ability to maintain a stable internal temperature will somehow lessen the imposing risks of heat waves. Therefore, thermal comfort should be given importance by selecting the energy-efficient materials and formulating the minimum standards for insulating materials used to regulate a building's internal temperature (Pullen, 2014). Some of the studies have recommended natural ventilation to minimize power consumption and also it will improve the indoor air quality (Hoy-Yen Chan, 2010). Whereas, studies showed that wall insulation is considered as the most effective intervention in reducing solar heat gain (Shao, 2012).

7.2.3 CULTURAL/ BEHAVIORAL:

The third Policy shall address the behavioral changes in mitigating heat waves by raising awareness under the vulnerable groups and enhance their preparedness measures. Attitude, awareness, behavior, and knowledge of building occupants on heat waves and adaption measures are crucial factors. The occupants' way of using the building and their willingness to adapt to heat wave risks, plays a significant role in mitigating heat waves. The other adaptive behaviors for coping with heat wave includes reducing outdoor activities and staying indoors, staying hydrated, changing floor coverings, and opening or closing of curtains or blinds. Before the onset of the heat wave, the city shall put forward its emergency plan to identify vulnerable groups with special attention on those who will be more vulnerable to heat stress such as adults, children and females, people with medical complications, low-income residents, and daily wagers which are more exposed to the sun. Listed below are some of the measures that can be completed before the onset of heat waves:

- National warning system, determining the medium for dissipation of the information about heat warnings, services available at rescue centers, warning alerts in different languages, and its outreach to the vulnerable population.
- Establishment of cooling centers in public buildings for people during waves with open public access during the onset of a heat wave.
- Develop a database of organizations and facilities that serve the vulnerable population during disasters (RESILIENCE STRATEGIES FOR EXTREME HEAT, 2017).

The study is a useful document for understanding the high exposure of slum communities to extreme weather due to global warming. The death toll in the coming due to global warming and related diseases will cost more to the Government as its resources are limited to handle a major disaster. Therefore, the author is recommending an action that is realistic and will transform these communities into economic opportunities in Pakistan. After de-urbanization, the slums in major cities of Pakistan should plant trees massively and convert these areas as "RESERVE FORESTS" for future generations of Pakistan.

7. 3 FUTURE RESEARCH DIRECTIONS:

Due to the unavailability of hazard data, the risk could not be calculated for these settlements. It would have helped us in identifying perceived heat waves risk prevailing in these settlements. Also, it would have helped in formulating risk reduction strategies. Similarly, a framework can be used to assess the vulnerability for the rest of the informal settlements in Lahore or Sindh province, as it is more at risk of heat waves and has already been through severe heat waves in the last decade.

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Annexure I

Questionnaire Sr. No: ______ Date: _______ Area: (Formal/Informal)

The purpose of this study is to make "Heatwave Vulnerability Assessment of Formal and Informal Settlements in Lahore Metropolitan." This study is being conducted at National University of Science and Technology (NUST) Islamabad. The information provides will be kept in the strictest confidentiality and

1. Age: _________________ 3. Average Household Income: ______________

2. Education: __________________ 4. Gender: Male ☐ Female ☐

5. Household size _______________

6. Number of males ___________________

7. Number of females __________________

8. Number of elderly people (<65) _________________

9. Number of elderly people (66 and above ________________

10. Number of children (specify ages) __________________________

11. Family type: a) joint b) Nucleus c) Single

12. Housing type

   a) Detached (bungalow) b) Semi- detached(normal) c) Combined (row houses)

13. Number of stories (building height): a) single b) double c) triple

14. Building age _____________

15. Building construction material: a) Pacca (brick, cement) b) Katcha (mud)

16. Household with deaths in last heat wave a) Yes b) No

17. House hold head education level ___________________

18. Occupation of household head

   a) Government service b) Trade and commerce c) Agriculture d) daily wagers e) unemployed

19. Household having access to drinking water a) Yes b) No

20. Household having access to electricity a) yes b) No

21. Household having access to

TV ______________ Radio ____________ Internet___________ mobile_________

22. Number of windows in the house __________

23. Household's location of kitchen ☐ Indoor ☐ Outdoor.

24. Household with homes warmer than outside during summers. a) Yes b) No

25. Household with In-home taps access. a) Yes b) No

26. Households in dilapidated residential area/ building. a) Yes b) No

27. Households living on the top floors of the building. a) Yes b) No

28. Adequate ventilation system in the house (exhaust fans). a) Yes b) No

29. Ventilation system in the kitchen. a) Yes b) No

30. Presence of veranda in the house. a) Yes b) No

31. Presence of projections to the windows (chajas). a) Yes b) No

32. Availability of AC/ air cooler. a) Yes b) No

33. Working condition of AC/ water cooler. a) Yes b) No

34. Presence of Front and back courtyard. a) Yes b) No

35. Presence of balcony. a) Yes b) No

36. Use of any insulation material/ measure for heat protection. a) Yes b) No

37. Availability of green spaces in the neighbourhood. a) Yes b) No

38. Automobiles with working AC. a) Yes b) No

39. Mode of transportation for going to work (multiple modes can be chosen)

Owned car ☐ Public transport ☐ Cycle/ Motorcycle ☐ No access to transport ☐

40. Household members who are exposed to sun on daily basis (in number) __________

41. Household work location. a) Sun b) shade c) mixed

42. Potential heat exposure occurred at a) home b) work c) Transit

43. Occupational environment: a) indoor b) outdoor

44. Specify Working hours: daytime or night time

45. Provision of AC at Indoor workplace. a) Yes b) No

46. Provision of drinking water at the outdoor workplace. a) Yes b) No

47. Household having access to green spaces at the workplace. a) Yes b) No

48. Travel time to market (in hours) ____________.

49. Household access to the nearest medical facility. a) Yes b) No

50. Distance to nearest medical facility (in hours) __________

51. Household having previous experience with heat wave. a) Yes b) No

52. Availability of first aid kit in the household. a) Yes b) No

53. Household an understanding of the national warning system. a) Yes b) No

54. Household knowing first aid. a) Yes b) No

55. Household having health/life insurance. a) Yes b) No

56. Household living with cardiovascular issues. a) Yes b) No

57. Number of household elderly members employed ______________

58. Household with heat-related symptoms. a) Yes b) No

59. Household members who previously experienced heat-related symptoms. a) Yes b) No

60. Household who had visited a doctor for heat-related illness. a) Yes b) No

61. Household worried about getting sick from heat wave. a) Yes b) No

62. How do you protect yourself from heat when working outside? Specify measures

63. How do you protect yourself from heat at home? Specify measures.

64. In your opinion, how can we cope with the heat wave?

65. If any other strategy is used write below and give your comments and suggestion: