Temporal and Spatial Variability of Urban Heat Island and Residential Energy Consumption

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Temporal and Spatial Variability of Urban Heat Island and Residential Energy Consumption

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CERTIFICATE

This is to certify that this thesis entitled: **""Temporal And Spatial Variability of Urban Heat Island And Residential Energy Consumption".** submitted by Misbah Sahar is accepted in its present form by the Department of Environmental Economics, Pakistan Institute of Development Economics (PIDE), Islamabad as satisfying the requirements for partial fulfillment of the degree in **Master of Philosophy in Environmental Economics**.

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Dedication

Every challenging work needs self-effort as well as guidance of elders specially those who are very close to our heart.

My humble effort I dedicate to my sweet and loving

Father & Mother

Whose affection, love and encouragement make me able to get such success and honor.

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Misbah Sahar

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Abstract

People move from underdeveloped areas to the developed areas such as cities and towns which results in urbanization. This leads to the use of land for commercial purposes, provision of social and economic opportunities, transport and residential buildings. These activities led to the discovery of microclimatic changes due to human interventions Therefore, Cities experiences warmer temperature as compare to their surroundings forming a heat trap over cities which is known as Urban Heat Island. Rawalpindi city is fourth major city of Pakistan with an estimated population of 3.19 million. This piece of work emphasizes on the attributes of urban heat island (UHI) in Rawalpindi city, Pakistan. The study uses data of monthly air temperature from three different weather observatories which are located in Rawalpindi and its surrounding areas. One in urban site, second in sub urban site and third in reference rural site. The air temperature data from 2001-2015 is used to study the intensity of urban heat island in Rawalpindi city .The outcome demonstrate the presence of urban heat island in Rawalpindi city, when the urban station is compare to rural station but it shows negative urban heat island effect when urban area is compared to sub urban area. The mean yearly air temperature in Rawalpindi city is 0.47°C higher than rural area i.e. NARC and 0.78°C lower than sub urban area i.e. Dhamial from 2001-2015. . The annual total urban CDD value is up to 21.08 percent higher than the rural CDD value and 30.56 percent lower than sub urban value in fifteen years. The role of higher temperature in variation of residential electrical consumption is analyzed by using Cooling Degree Days (CDD) as quantitative index. Panel regression analysis is used to predict the effect of temperature alteration on residential electrical consumption. The residential electrical consumption is 16.6 times higher in sub urban area and 183 times in reference rural area as compare to urban area.

Key words: Urban heat island, Cooling Degree Days, residential energy consumption, suburban area and Rawalpindi

CHAPTER 1

INTRODUCTION

People move to cities and town because they view living in rural areas as hardship and lack of opportunity for better future. Therefore, as the people move from underdeveloped (rural) areas to the developed areas (cities and towns), the immediate result is urbanization. This leads to the use of land for commercial purposes, provision of social and economic opportunities, transport and residential buildings. Global trends show that more people are living in urban areas as compare to rural areas. The urban population of the world was 30 percent in 1950, while this proportion has increased to 54 per cent in 2014, and by 2050 the projection of urban population has risen up to 66 percent (UNDESA, 2014).

Pakistan is a low-middle income country with an estimated population of 195.4 million. In South Asia, it is among the countries with fastest urbanization trends and the share of populace of urban areas is growing at a significant rate. The decrease has been observed from 61.4 percent in 2014 to 60.8 percent in 2015 in the population of rural areas while the populace has risen up from 38.5 percent in 2014 to 39.2 percent in 2015 in urban areas of Pakistan (PES, 2015).People move to urban areas in search of good jobs and other facilities. Urbanization has its own pros and cons, as the cities grew so did their problems. Urbanization effect the environment by putting strain on natural resources including water, food, energy and land. When cities are built, changes are made to their existing natural environment, construction of roads; buildings and other types of infrastructure which replace the open land and vegetation thus converting the permeable and moist surfaces to impermeable and dry. The major land change driver is urbanization that leads to considerable, often fast, and near irreversible changes in systems of lands and their properties. This development results in changing the transfer and store of energy i.e., the energy balance of entire city. Rapid urbanization and industrialization led to the discovery of microclimatic changes due to human interventions. Temperature distribution in urban areas is very much effected because of urban radiation balance i.e. the amount of energy incident on an urban surface and the amount of energy leaving it. Solar radiation when reached the urban area is taken in and then transferred into the sensible heat. Majority of solar radiations strike roof and walls of the building and very small portion hits the land. The structure like roof, walls and ground then emits longer wavelength radiations into the sky. The amount of this radiation is dependent on the sky view factor. Sky view factor is the ratio between the radiations received by planar system and from the radiation emitted by whole hemisphere radiating surroundings and can be calculated as the portion of sky visible from ground. As the sky dome seen by the buildings and walls is blocked by other infrastructure under the urban conditions. The long wave radiation exchange does not result in major losses. The thermal energy balance of a particular city is determined by the net balance between the solar radiation gains and losses by emitting longer wave radiation. The radiant heat loss in city is very slow so net balance of energy is more positive in city as compare to its rural surroundings.

Therefore, cities experience elevated temperature as compared to its rural area; this difference in temperature makes up distinct aspect of urban climate called as Urban Heat Island (UHI). Every city and town is affected by Heat Island and it is prominent climatic sign of artificial urban structure, established as a result of urbanization. Oke (1977) has described that the space over the surface of a city is divided into two parts. One is urban air canopy and second is boundary layer i.e 'the urban air dome' which extends over the city space. The space surrounded by buildings up to their roof is urban canopy layer. The climatic conditions in the canopy layer rely on the nature of nearest surroundings and particularly by the geometry of the area, type of material used in that area and their properties. The air dome layer is the part of the planetary boundary layer whose attributes are affected by the existence of an urban surface at its lower boundary. The boundary layer of an urban area is generally more uniform in its properties over the surface of an urban area. There is a distinction between atmospheric urban heat island and surface urban heat island. The difference of surface temperatures between the urban and rural area constitutes surface urban heat island and is usually measured by remote sensing techniques in existing studies including Weng et.al (2004), Yaun and Bauer (2007) and Peng et.al. (2011). On the other hand, the atmospheric urban heat island is the corresponding differences in air temperature of urban and rural region.

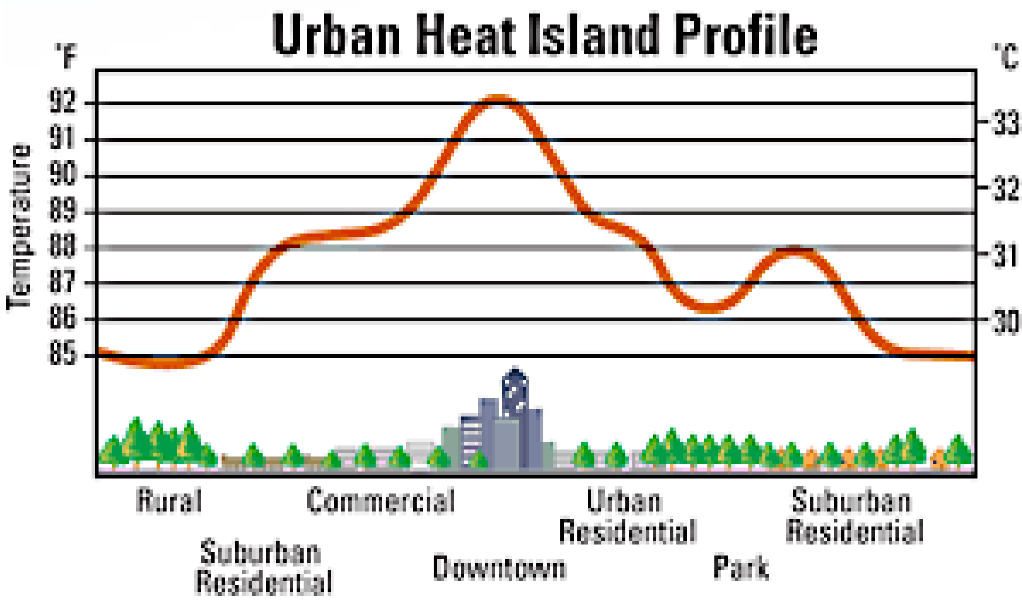
There are two types of atmospheric UHI, first is the Urban Boundary Layer (UBL) and the second is Urban Canopy Layer (UCL). The urban canopy layer-urban heat island is most important for thermal comfort since population of world live in the urban canopy layer. Among the two atmospheric types, the UCL-UHI is the most commonly observed in context of urban heat islands in existing literature including Santamouris et al. (2007), Arifwidodo and Chandrasiri (2015) and Rossi et.al. (2015).

On a clear, calm night, cities with one million or more people can have annual mean air temperature 1 to 3°C warmer when compare to its nearby rural area and this difference in temperature can be as much as 12°C. Heat islands are produced even in smaller cities and town however the effect often decreases with the decrease in city size (UNDESA, 2014). UHI has diurnal and seasonal variations as well. The increased temperature in urban area as compared to rural area has several effects on community and local environment. These effects are positive such as the plant growing season has become longer, demand of heating has been reduced in cold season and so. But mostly UHI has negative effects including increased energy consumption, increased production of greenhouse gases and pollutants, impaired quality of water and threatens human health and thermal comfort. The warming due to urban heat islands in cities and towns changes the local climate of the area but their impacts are found locally and decrease with the increase in distance from the source.

Global warming is the most concerned issue of this century, temperature is rising, occurrence of heat waves is more frequent and more severe and the pattern of weather is changing. World is trying to lower the impacts of global warming. .Global warming is caused by increased solar intensity and by emission of greenhouse gases which are produced primarily by burning of fossil fuels. The impact of global warming is not regionally and locally confined. However, the combination of Heat island and global warming further exacerbate the consequences and urban areas bear the additional burden of the harsher heat events. Some studies provide evidences that local climate is contributing to global warming. Huang, & Lu (2015) showed that during the period of 1957–2013, average warming rates of average air temperature of megalopolises, huge cities, large cities, medium size cities, and small cities are 0.282 ± 0.042, 0.483, 0.314 ± 0.030, 0.225 ± 0.044 and 0.179 ± 0.046 °C per decade respectively. The average warming rate of average air temperature is 0.124 ± 0.074 °C per decade due to urbanization. There is a large spatial variability on the effect of UHI on climate change.

In the coming decades, sustainable urban planners face two most important challenges. First is the effect of climate change in urban area and the need for adaptation plans to lessen the penalties of climate change, and second is urbanization and the necessity of managing a range of conflicting spatial demands. In near future, citizens' thermal comfort and livability of urban areas are expected to become serious problems in many urban areas of the world. Local climate may change significantly within cities due to the construction of numerous artificial surfaces like buildings at the cost of open ground, vegetation and open water that makes distinctive local climates by changing temperature, radiation, patterns of wind and moisture etc. Community designs including different factors such as physical outline, workplaces, accessibility to goods, schools and services; and the designs and materials used in construction of building and other infrastructure have an effect on energy consumption of the area and vehicle use, and ultimately on emission of greenhouse gases. By addressing these issues through proper planning, use of smart growth principles, measures to reduce urban heat island and other initiatives, governments at local and regional scale can promote economic development while protecting their open spaces and important natural habitats, protecting water quality and air quality, and supporting to mitigate climate change. . Recent advances have been taken place to use the knowledge of urban climate in urban planning to achieve sustainable development. For the productive and sustainable making of adaptation plans and for the improvement in thermal environment of urban areas, there arises a need for the better knowledge of the temporal and spatial variability in the local climate of the area. The temporal and spatial variability of climate is important to access the variation in intra urban environment as the temperature and other climatic factors are not same throughout the city. Dense built up areas have higher temperature and lower wind velocities as compare to low built up areas i.e. urban or rural areas. Present study analyzed this temporal and spatial variation of climate in Rawalpindi city as compare to its surroundings.

Fig 1.1: Urban Heat Island Profile



Source: EPA 2008

The above mentioned figure of urban heat island gives a comprehensive view of air temperature of an urban area (EPA 2008). The air temperature of rural areas is much lower than downtown temperature due to natural vegetation. There is more water in rural surface and beside this, the large amount of solar radiation is used in the process of photosynthesis. More solar radiation has been used to evaporate water which cools the air through latent heat absorption. The downtown experiences high temperature due to increased commercial activities, dense infrastructure and green house gases which traps solar radiation.

1.1.Objective of study:

- To investigate the temporal and spatial variability in urban heat Island of Rawalpindi city with its nearby surrounding.
- To analyze the impact of urban heat island on residential electricity consumption in Rawalpindi city.

1.2. Research Question

- What is the magnitude of urban heat island variability in Rawalpindi city?
- To what extent household electrical consumption is dependent on temperature variation in city and its suburbs?

1.3. Problem statement:

There has been increasing temperature trend around the globe and people are trying to mitigate and adapt to this changing conditions of temperature. In addition to this climate change, cities are prone to Heat Island Effects which further worsen the situation. Cities experience warmer temperature as their local climate is altered by commercialization and industrialization. The expected increase in the population and visitors in cities increases the growth and change in urban form and this increase in development of urban area will tend to increase the temperature of that area. Therefore the urban heat islands increase the demand for electricity and peak demand which usually results in severe energy shortfalls especially in a country like Pakistan during summer months.

1.4. Significance of study

The global trend shows that UHI has significant impact on cooling demand and significant average global energy penalty is produced by per unit of the surface of city i.e. 2.4 kWh/m2 Santamouris (2014). With every 0.6°C increase in summertime temperature, peak urban electric demand increases 1.5-2% and over the last several decades' gradual increase in downtown temperatures results in 5-10 % increase in community-based demand for electricity to offset the heat island effect (UNDESA, 2014). The resulting increase in demand for cooling can put burden on household's budget and there is a need to assess this issue, especially when the country like

Pakistan, is facing energy shortfalls. Many studies regarding urban heat island have been done in Pakistan but none relates it to electricity (Sajjad, Batool, Qadri, & Shirazi, 2015; Sajjad et al., 2015 and Mehmood, Atif Butt, Mahmood, & Ali, 2017).

The present study examines the relationship between UHI intensity and residential electricity consumption. The outcomes of the study give important insight of adaptation measures which help in designing cities focusing at mitigating the impact of the UHI on thermal comfort in urban areas.

CHAPTER 2

LITERATURE REVIEW

Urban Heat Island has emerged as a challenge for the developed and less developed nations around the globe. The cities experience warmer temperature as compare to their rural surroundings. The city structure traps the heat due to the change in natural environment, properties of material used in construction, geometry of urban area and other related factors. Several studies have been done across the globe to analyze the impacts of this emerging challenge on different sectors of human development.

2.1. Impact of urban heat island on health

In recent years, the effect of Urban Heat Island on health has become a significant issue. In urban regions, the number of hot days and heat waves is increasing substantially. UHI is directly responsible for exacerbating the thermal situation. Therefore, the adverse health effects and heat related mortality from exposure to extreme thermal conditions are seen and it has been identified that people living in city center are more vulnerable as compare to rural areas (Tan et al. 2010; Tomlinson et al. 2011). High air pollution levels, reduced nighttime cooling and increase in daytime temperatures are related with urban heat islands which can affect health of human beings by causing discomfort problems, exhaustion and heat cramps, heat related mortality and non fatal heat strokes. The heat islands have the tendency to affect health and wellbeing of residents of urban area by worsening the impact of heat waves. Adults, children and those with bad health conditions are most vulnerable from such events. In United states, each year on average thousand people die because of extreme heat. (Changnon et al., 1996). Frequent heat events, or rapid and extreme temperature increases are very hazardous and can results in high rates of mortality. The Centers for Disease Control and Prevention (2006) gave an approximate calculation that from 1979–2003, more than 8,000 premature deaths occur due to extreme heat exposure in the United States. This number is more than the combined number of deaths resulting from tornadoes, hurricanes, earthquakes and floods.

2.2. Impact of urban heat island on thermal comfort of people

The issue of thermal Comfort has been addressed by many researchers as the hot days are increasing people are more exposed to uncomfortable indoor and outdoor temperatures. Therefore, mitigation strategies for improving thermal comfort have been evaluated. The study showed that cooling loads can be reduced from 18 to 93% and in air conditioned buildings peak cooling demand can be reduced from 11–27% by increasing the solar reflectance of roof. The indoor thermal comfort environment was advanced by reducing the hours of discomfort from 9 to 100 % by using solar reflectance. The maximum temperature can be reduced by 0.2– 3.78 degree centigrade depending on the climate in the city (Syneffa et al. 2007). Another study has been done by Van Hove et al. (2015) and he analyzed that a huge number of discomfort hours physiological equivalent temperature (PET > 23 °C) were shown in the urban areas in comparison with rural area (which is taken as reference area) due to the fact that velocities of wind in urban areas are much lower in Rotterdam agglomeration. PET is described as the air temperature in a particular indoor situation at which the heat budget of human body is balanced with same core and skin temperature as under the outdoor conditions to be calculated. It is used to evaluate the change in human well being due to change in thermal environment.

2.3. Impact of urban heat island on water quality

Urban temperature has also profound impact on water quality. Temperatures of rooftop and other concrete surface can heat water runoff. James (2002) has described that pavements having 38ºC temperature can increase temperature of initial rainwater from 21ºC to 35 ºC. This heated storm water usually turns out to be runoff which goes into storm sewers and increases the temperature of water in rivers, streams, lakes, and ponds. Water temperature has an effect on all characteristics of aquatic life, particularly the reproduction and metabolism of majority of species living in water. Dramatic changes occur in temperature due to warm water runoff can be mostly stressful and even fatal to aquatic life.

2.4. Impact of urban heat island on air pollution

The demand for electrical energy increases in summer due to urban heat islands. Companies which are supplying electricity usually rely on power plants running on fossil fuel to fulfill much of the demand, which results in increase in air pollutants and increase in emission of greenhouse gases. Sulphur dioxide, carbon monoxides, nitrogen oxides, mercury and particulate matter are the primary pollutants from power plants. These pollutants contribute in many problems related to air quality such as acid rain, ground level ozone formation (smog) and fine particulate matter. Increase in the emissions of greenhouse gases is contributed by increased use of fossil fuels by power generating plants which lead to global climate change (UNDESA, 2014).

2.5. Ecological footprints of urban heat island

There are numerous studies which have estimated the ecological footprints of Urban Heat Island. Santamouris et al. (2007) estimated the ecological footprints over Athens, and concluded that real footprints due to heat island are 1.5-2 times the metropolis's area. Similar study was carried out by Rossi et.al. (2016) which calculate real carbon footprints in UHI affected area and the result showed that UHI of 3.3C has been found in Rome city as compared to rural surroundings. UHI scenario increased the carbon footprint of LED lamps up to 800 tons of CO_2 per year as compared to rural surroundings. It has also been concluded as UHI increased by 1°C would result in 240 tons of CO_2 per year and 1C decreased in UHI will lead to 230800 tons of CO_2 per year decrease in GHGs

2.6. Impact of urban heat island on energy consumption

Another important aspect is the impact of urban heat island on the energy consumption. The present study mainly focuses on electrical consumption. The increased temperature in urban areas leads to high demand in cooling load and peak electricity demand in summers.

The enormous impact of summer heat island on the demand for cooling energy, peak cooling demand for cooling energy and the performance of cooling equipment have been studied. Hirrano et al. (2012) calculated the effect of UHI on energy consumption by taking the temporal and spatial distribution of energy consumption and air temperatures by using Colorado state university mesoscale model for both cases (with UHI and no UHI) and showed the increase in commercial energy consumption and the decrease in residential energy consumption. The total energy consumption decreases due to UHI may be due to fact that energy demand for space and water heating decreases more than energy demand for cooling purposes in Tokyo, Japan. Kaloustian and Daib (2015) highlighted that artificial surfaces in urban areas have strong impact on air temperature and the difference is 6 $^{\circ}$C when it is compared to vegetated surrounding in summer season. In vegetative areas, the cooling energy demand is 80 watt per meter square and in urban setting it is around 350 watt per meter square in Beirut. Yi-Ling et al. (2014) reported that there is peak electricity load in summer months due to cooling demand and low peak of electricity demand is observed in winter. The spatial distribution of cooling degree Days (CDD) and Heating Degree Days (HDD) is reflecting effects of urbanization in Shangai i.e. the city core experiences greater number of Cooling Degree Days in summer and smaller number of Heating Degree Days in winter due to increase temperature in Shangai city. Arifwidodo and Chandrasiri (2015) investigated that maximum UHII in dense urban areas ranges from 8-10 $^{\circ}$C. Energy consumption is high in the areas where there is high UHI in Bangkok, Thailand. Another study of Radhi and Sharples (2013) has calculated that air temperature of urban site has increased in the range of 1-5 $^{\circ}$C as compared to rural site. This difference leads to variation in electricity demand of 13 kilo watt-hour per meter square in hot arid regions. Kapsosomenakis et al. (2013) investigate the forty years of increase in ambient temperature in Greece and concluded that the heating load of buildings decreases upto approximately 1.0 kilo watt-hour per meter square per decade whereas the cooling load increases nearly 5.0 kilo watt-hour per meter square per decade over the span of 40 years. Santamouris (2014) has analyzed the impact studies from the globe regarding urban heating and revealed that urban heat island has significant effect on cooling demand and this has been increased up to almost 13%. This study also showed that the average global energy penalty per unit of city surface is 2.4 kilo watt-hour per meter square while the average Global Energy penalty (additional amount of energy needed to compensate urban heat island) per unit of surface and degree of UHI intensity is close to 0.74 kilo watt-hour per meter square per Kelvin. The average global energy penalty per person is approx. 237 kilo watt-hour per person and the global energy penalty per person and per degree of the UHI intensity is close to 70 kilo watt-hour per person per kelvin. These results are giving insight about the global impacts of urban heat island. Kolokotroni et al. (2006) studied the effect of urban heat island on the demand for cooling in summer season and night ventilation strategies in London and concluded that throughout an extreme hot week, an optimized office in urban setting would increase its cooling demand by 27% and in rural area, the cooling demand would be increased by 14% in London. Akbari et al. (2001) has concluded that the additional increase of temperature in urban areas due to the UHI results in boosting the demand of energy for cooling purpose. In cities, the increase of 1 °C in temperature will tend to increase the demand for electricity by 2–4 percent in cities. As a result, about 5–10% electricity demand of the urban areas is spent to cool buildings just to balance for 0.5–3.0 °C increased in temperature of urban area.

2.7. Urban Cool Island UCI

In temperate zones, cities often show an urban heat island while in contrast the cities of semiarid and arid areas may have the possibility to show urban cool islands (UCI). However, very few investigations to the urban cool island were made.

Frey et.al. (2005) investigated surface temperature, albedo (the part of sun's energy reflected by the Earth back into space. It evaluates the reflectivity of the surface of earth), emissivity (the capacity of a surface to release radiant energy when compared to black body at same temperature and with the same area) and net radiation in different urban and sub urban/rural classes in an arid area by using ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) technique and concluded that urban areas has lower albedo and higher net radiation leading to lower temperature as compare to rural areas. The investigation showed distinct daily cooling island of Dhubai and Abu Dhabi. Rasul et. al. (2015) investigated the spatial variation of Land Surface Temperature (LST) and the surface urban cold island intensity in cities of semi-arid climates using Landsat 8 satellite imaging. The results indicated that densely built up areas, for example, central areas of the city, water bodies and green area have lower Land Surface Temperature (LST) and act as cool islands when compared to non urbanized area around the city. Urban Cool Island Intensity is between 3.5 to 4.6 °C compared to a 10 km buffer zone around the city of Ebril in Iraq. Another study Shigeta et. al. (2009) revealed urban Cool Island in the daytime, the air temperature of urban central area is 1 to 2 C lower than rural surroundings in City Okayama. The intensity of heat island is small in the daytime while it is significant in the night time i.e.3 to 4 C higher than rural area which shows temporal change in Heat island Intensity. The urban cool island is significant at day time while it is small in night time and it again shows the temporal change in urban cool island intensity in the city of Japan These lands were gradually cleared of the agricultural fields; road & street networks were built over these with housing plots and other infrastructure for utilities.

2.8. Summary of literature

The literature concluded that urban heat island is the obvious phenomena in cities and it has greater impact on cities with warmer climates of tropical and sub tropical regions. The main drivers of urban heat island are the land use changes, transportation and urban growth. The temperature is found to be higher when compared to their rural vegetative surroundings. The largest urban heat island occurs at night, four to five hours after sunset and it is more pronounce in winter season. Due to urban heat island effect climate changes locally which have direct impact on health, energy, water and thermal comfort of effected community. The risk of heat related illness and mortality tends to increase in the area with high urban heat island effect. It also effect the thermal comfort of people hence reduces their productivity. The energy penalty has increased over the past years with increasing development in urban areas. The people need to use more energy in cities as compare to rural areas to compensate the increase in temperature in urban areas. Densely populated cities have larger urban heat island with greater cooling degree days (CDD) in summers and lesser heating degree days (HDD) in winters. There is a high demand of cooling in summers as compared to rural areas. Though the literature includes some of the main potential channels through which the urban heat island effect have an impact on the society, but the present study focuses on the impact of urban heat island on household electricity consumption based on existing literature for Rawalpindi city of Pakistan. Ironically, there is a strong evidence of urban cool island i.e. the city is cooler than its nearby surroundings. Most of these occur in arid and semi arid environments.

CHAPTER 3

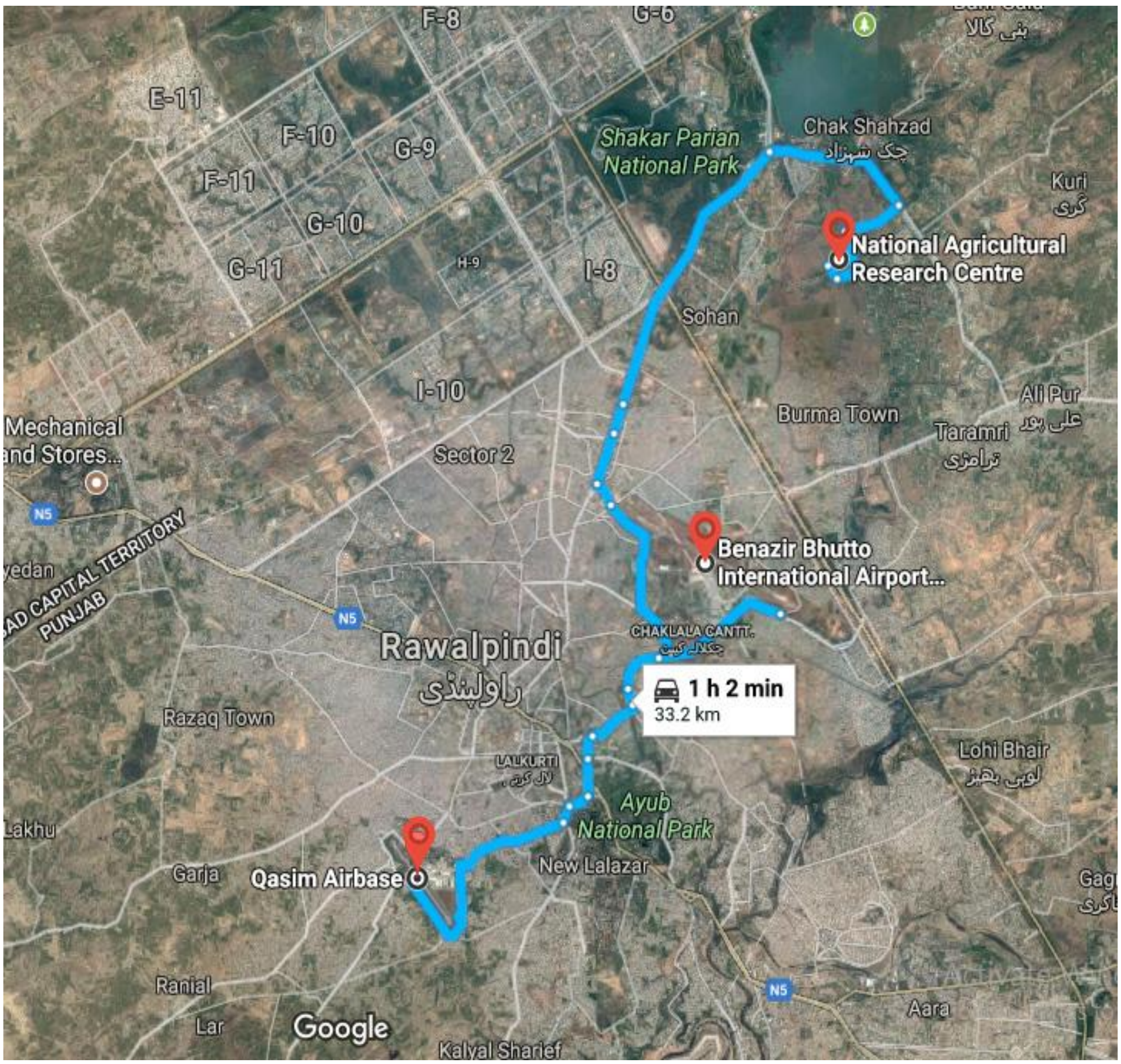
DATA AND METHODOLOGY

3.1. Study area:

Rawalpindi is a city in Punjab Pakistan. According to 1998 census, it is the fourth largest city in Pakistan by population with 212,429 numbers of households. It has 1.41 million population with average annual growth rate i.e 3.43 and in 2014, its estimated population is 3.19 million (Pakistan Bureau of Statistics). It is located in Potohar plateau and the climate is subtropical where summer is long and very hot and winter is short and mild. The city of Rawalpindi has significant rate of urbanization i.e. 3.43 according to 1998 population census.("POPULATION SIZE AND GROWTH OF MAJOR CITIES," n.d.). People migrate from small cities and towns to the third largest metropolitan area of the country in search of jobs and other economic activities. Rawalpindi has GPS coordinates of 33° 37' 33.8052" N and 73° 4' 17.1912" E**.** Its elevation is 506 meters high which is equal to 1,660 feet.

To check the spatial and temporal variability of Urban Heat Island, three stations have been selected. One is Rawalpindi airport (urban station) having 33°36'35.39" N 73°05'34.20" E co ordinates. This area is being surrounded by dense and compact infrastructure. Second station is Qasim air base at Dhamial camp (sub urban) station having 33°33'22.19" N 73°01'60.00" E co ordinates. The Qasim air base was established outside the city with distance of 10 km from city centre but now it is mostly covered by urban population due to urban sprawl. Third station is NARC (National Agriculture Research Centre) Islamabad having co ordinates 33°40'17.56" N 73°07'55.28" E. NARC is located at Chak Shahzaad and consist of large green landscape. NARC is considered as the reference rural station. The distance between the Rawalpindi airport and Qasim air base is approximately 10 km. The distance between airport and NARC is approximately 8 km. The city of Rawalpindi has experienced massive growth in terms of its geographical size & population in recent years. The reason for selecting these particular three locations in Rawalpindi city is that the metrological observatories were available at these three locations in Rawalpindi city which can give reliable data.

Fig 3.1: Map showing the distance between the three selected station



3.2. Data collection

For investigating urban heat island, the meteorological data of air temperature for a time series (2001-2015) for urban station, sub urban station and the reference rural in the city of Rawlpindi was collected by taking data from Benazir Bhuto International Airport Rawalpindi, Qasim Aviation Base and National Agriculture research centre respectively. The reason to select these three stations is that the meteorological observatories are located here. The air temperature data is taken on monthly basis due to unavailability of data at hourly basis on suburban station. This data is used to find out the possible trends in local climate in intra urban environment and also to examine the magnitude of urban heat island effect of Rawalpindi city with its nearby surroundings. To analyze the effect of urban heat island on electricity consumption of residential sector, data of residential electrical consumption for the year 2014 has been taken from Water and Development Authority (WAPDA) for all of the three stations i.e. Rawalpindi airport (urban), Qasim air base (sub urban) and NARC (rural) station.

3.3. Methodology

Kolokotroni et.al. (2006) has defined urban heat island intensity UHII as the temperature difference between the urban and rural/ sub urban (reference) stations.

To calculate urban heat island intensity (UHII) is estimated through following equation

$$UHII = Tu - Tr \qquad \text{(Eq. 3.1)}$$

where **Tu** is the mean value of air temperature of urban area and **Tr** is the mean value of air temperature of reference area.

With the help of the above mention equation, the study analyzed the urban heat island intensity at urban station by comparing it with sub urban station and also by the reference rural station. This gave clear insight about the spatial variability in temperature in intra urban environment.

It is anticipated that the urban heat island effect would have an impact on the consumption of electricity. In particular, this is obtained through the estimation of Cooling Degree Days and Heating Degree Days commonly known as CDD and HDD respectively. Degree days are basically an easier illustration of outside air temperature data. They are used mainly in the energy sector for calculations which shows the effect of outside air temperature on energy consumption of the building. A Degree Day is define relative base temperature.

Heating Degree Days or HDD is used to access that how much in degree and for how long in days, the outside air temperature was lower relative to a specified base temperature. HDD are used for calculations which measures the amount of energy consumption required for heating buildings.

Cooling Degree Days or CDD is used to access that how much in degree and for how long in days, the outside air temperature was higher relative to a specified base temperature. CDD are used for calculations which measures the amount of energy consumption required for cooling buildings.

One degree above the particular base temperature is one cooling degree day. One of the best things about cooling degree days is that it can be added up. By adding the daily cooling degree days of whole month, you can get cooling degree days for whole month.

For the purpose of this study, Only Cooling Degree Days for the summer months are estimated to analyze its relationship with residential electrical consumption. The summer months in Pakistan starts from May, June July, August and September. From the available air temperature data, cooling degree days are calculated for three selected stations from the time period of 2001-

2015, the long term data of air temperature will give important insights about the trend of Cooling Degree Days over these years.

For estimating Cooling Degree Days, the study follows the definition given by Yuan and Qian (2004) as given below

$$CDDr = (Tm - Tb)m \qquad \text{(Eq. 3.2)}$$

where CDD are monthly cooling degree days for area r, Tm is monthly average temperature of area and Tb is base temperature of the area, m is number of days in month. The base temperature is set at 26 C (the standard set by Water and Power Development Authority WAPDA) in summers.

The Degree Day method has been used in literature to express the non linear relationship between temperature and demand of electricity (Arifwidodo and Chandrasiri 2015; Radhi and Sharples 2013).

Following above mention studies cooling degree day method is used to assess the relationship between temperature and cooling electricity consumption. For assessing the relationship between CDD and household electricity panel random effect estimator has been used. The panel data is useful with observations that span both time and individuals in a cross-section, more information is available, giving more efficient estimates. The use of panel data allows empirical tests of a wide range of hypotheses. With panel data we can control for unobserved or unmeasurable sources of individual heterogeneity that vary across individuals but do not vary over time and omitted variable bias. The random effects approach attempts to model the individual effects as drawings from a probability distribution instead of removing them. Each individual effect is modeled as a random drawing from a probability distribution with mean 0 and with constant variance. We are assuming that the composite disturbance term u has a value for a particular individual at a specific time which is made up of two components. To estimate the relationship between air temperature and residential electrical consumption, electrical consumption of residential sector has been regressed on monthly cooling degree days and dummies for different classes of consumers which are made on units of electricity consumption per month.

The main panel regression equation is

$$EC_{it} = \beta_0 + \beta_{1i}CDD + \beta_{2i}D1 + \beta_{3i}\, D2 + \beta_{4i}\, D3 + \beta_{5i}\, D4 + \mu_{it} \qquad (3)$$

EC it: residential energy consumption of household in kwh of ith station

Where

- ‘i’ represent the stations: urban, sub urban and rural.
- “t” represents time. It is taken on monthly basis. Time include five months starting from May 2014 to September 2014.

CDD : Cooling degee day of ith station and is independent variable

$\mu_{it:}$ It represents the error term.

D1 is dummy for class of consumers using electricity 50-250 units per month

D2 is dummy for class of consumers using electricity 251-500 units per month.

D3 is dummy for class of consumers using electricity 501-1000 units per month.

D4 is dummy for class of consumers using electricity 1001-1500 units per month.

Data of residential electrical consumption for the year 2014 has been taken from Water and Development Authority (WAPDA) for all of the three stations i.e. Rawalpindi airport (urban), Qasim air base (sub urban) and NARC (rural) station. Data of Cooling Degree Days of summer months of year 2014 has been taken from the urban, sub urban and rural station for analysis.

To estimate the residential energy consumption of selected sector with respect to cooling degree days of that particular station eq. 3 has been used. To control the income and population effect of household, the study builds classes of electricity consumption**.**

Table 3.1: Variables and data sources:

Variable Name	Definition	Source	Unit
Residential electrical consumption	Electric energy consumption is the actual energy demand made on existing electricity supply.	Water And Power Development authority WAPDA	kWh
Temperature	Air temperature is a measure of how hot or cold the air is.	Pakistan Meteorological Department Qasim Aviation Base National Agriculture Research Centre.	Degree centigr-ade.

CHAPTER 4

RESULT AND DISCUSSION

4.1. Descriptive statistics

To calculate the mean daily air temperature value, the average of mean value of daily minimum and the mean value of daily maximum is taken:

$T_{mean} = 0.5(T_{max} + T_{min})$

Table 4.1: Air temperature trends of Rawalpindi urban station

time	Annual mean temperature	Annual minimum temperature	Annual maximum temperature
2001	22.4	15.2	29.5
2002	22.4	15.4	29.4
2003	21.2	14.5	28.5
2004	21.6	14.3	29.6
2005	20.5	13.4	28.3
2006	22.1	15.3	29.5
2007	21.1	13.7	29.2
2008	21.15	14.4	27.9
2009	21.5	14.1	29.5
2010	22.5	15.9	30.2
2011	22.0	15.8	28.9
2012	21.4	14.6	28.8
2013	21.5	15.0	28.7
2014	20.9	13.7	28.4
2015	21.7	15.9	28.3

The average annual mean temperature of Rawalpindi urban station from 2001-2015 is 21.6 ^{o}C with standard deviation of 0.60. The average annual mean minimum temperature is 14.8 ^{o}C from

2001-2015 with standard deviation of 0.8 ^{o}C. Average annual mean maximum temperature is 29 C with standard deviation 0.6 ^{o}C.

Table 4.2: Air temperature trends of Rawalpindi sub urban station

time	Annual mean temperature	Annual minimum temperature	Annual maximum temperature
2001	22.92	15.69	30.15
2002	22.81	15.76	29.86
2003	22.81	15.23	28.72
2004	22.70	15.93	29.47
2005	21.62	15.00	28.23
2006	22.75	16.35	29.15
2007	21.82	15.23	28.41
2008	21.79	14.58	29.00
2009	22.08	15.03	29.14
2010	22.83	15.75	29.91
2011	22.48	16.09	28.87
2012	22.30	15.86	28.74
2013	22.35	16.12	28.58
2014	22.45	16.13	28.76
2015	21.94	16.18	27.71

The average annual mean temperature from 2001-2015 is 22.38 ^{o}C with standard deviation of 0.43 ^{o}C. The average annual mean minimum temperature is 15.66 ^{o}C with standard deviation of 0.52 ^{o}C. The average annual mean maximum temperature is 28.98 ^{o}C with standard deviation of 0.66 ^{o}C. The temperature in sub urban area is high because the land has been cleared off for infrastructure development and there is sparse vegetation which results in increase in temperature.

Table 4.3: Air temperature trends of Rawalpindi Reference rural station

time	Annual mean temperature	Annual minimum temperature	Annual maximum temperature
2001	21.72	13.83	29.61
2002	21.70	13.83	29.58
2003	20.8	13.89	27.71
2004	21.06	13.79	28.33
2005	20.25	12.91	27.59
2006	21.47	14.40	28.54
2007	21.08	13.54	28.62
2008	20.97	13.94	28.00
2009	21.29	13.68	28.91
2010	21.81	14.23	29.39
2011	21.31	14.06	28.56
2012	21.20	14.12	28.28
2013	21.03	14.19	27.86
2014	20.29	13.57	27.01
2015	20.93	14.19	26.18

The average mean minimum air temperature from the period of 2001-2015 is 13.88 ^{o}C with standard deviation of 0.36 ^{o}C. The average annual mean maximum temperature for the observed time period is 28.38 ^{o}C with standard deviation of 0.76 ^{o}C. Average value of mean air temperature over the period of fifteen years is 21.13 ^{o}C with standard deviation of 0.46 ^{o}C.

The mean annual air temperature in Rawalpindi city is higher by 0.47°C higher than rural area and 0.78°C lower than sub urban area from 2001-2015. Over all sub urban station shows higher mean air temperature and mean minimum air temperature than urban station due to clearing of agricultural fields for construction purpose which results in barren land having high temperature. But the value of mean maximum air temperature was higher in urban station as compare to sub urban station. The reference rural station show less mean air temperature, mean maximum and mean minimum temperature than urban station over the observed time period.

4.2. Calculation of Cooling degree Days for summer months

Data of mean monthly air temperature for all summer months of period 2001-2015 has been used for calculating cooling degree days for the three selected stations. These are calculated on monthly basis and measured as the difference of mean monthly temperature and the particular base temperature i.e. 26 ^{o}C and then multiplied the difference with number of days in a month. Below are the statistics of Cooling Degree Days of all the three stations.

Table 4.4: Cooling Degree Days for Rawalpindi Airport (urban station)

time	MAY CDD1	JUN CDD1	JUL CDD1	AUG CDD1	SEP CDD1
2001	158.7	124.5	81.2	102.4	43.7
2002	143.4	177.1	177.7	75.8	-18.2
2003	56.0	131.8	94.4	73.6	3.4
2004	66.8	78.7	109.9	48.0	25.3
2005	20.8	130.5	69.7	80.4	41.1
2006	157.0	102.2	102.6	62.8	7.4
2007	79.9	100.5	73.1	60.6	3
2008	88.0	59.9	90.6	-90.2	9
2009	50.4	98.5	169.1	97.2	19.9
2010	106.1	121.6	138.1	80.6	23.5
2011	142.1	158.4	100.5	95.1	34.7
2012	61.4	139.3	202.2	96.9	-6.8
2013	96.5	146.1	112.8	56.0	6.3
2014	10.9	139.5	126.0	68.7	1.5
2015	73.7	109.0	103.5	102.8	34.1

The urban station provides the higher number of degree days in the month of June and the lower number of Cooling Degree Days are observed in the month of September. The Cooling degree days shows larger temporal fluctuations within a month. The negative values show that mean air temperature of the month is lower than the base temperature of 26 C.

Table 4.5: Cooling Degree Days for Dhamial (sub urban station)

time	MAY CDD 2	JUN CDD2	JUL CDD 2	AUG CDD2	SEP CDD2
2001	170.5	138	94.55	109.5	54.25
2002	167.4	168	179.8	87	-18.6
2003	167.4	168	179.8	87	-18.6
2004	85.25	124.5	141.05	75	82.15
2005	12.4	196.5	110.05	91.5	65.1
2006	170.5	144	105.4	76.5	37.2
2007	93	154.5	96.1	94.5	27.9
2008	114.7	96	85.25	76.5	12.4
2009	71.3	136.5	142.6	108	71.3
2010	80.6	151.5	151.9	82.5	54.25
2011	164.3	187.5	105.4	103.5	66.65
2012	91.45	235.5	203.05	109.5	18.6
2013	100.75	181.5	128.65	73.5	55.8
2014	34.1	195	147.25	108	57.35
2015	54.25	129	100.75	103.5	26.35

The sub urban station provides higher number of Cooling Degree Days in the month of June and the lowest number of Degree Days is observed in the month of September. Only two negative values in the month of September has been observed from 2001-2015 which explains that temperature in sub urban area remains higher than base temperature.

Table 4.6: Cooling Degree Days for NARC (Reference rural station)

time	MAY CDD 3	JUN CDD3	JUL CDD 3	AUG CDD3	SEP CDD3
2001	128.65	105	75.95	85.5	6
2002	105.4	144	176.7	67.5	-40.5
2003	-3.1	135	91.45	57	4.5
2004	32.55	73.5	102.3	40.5	31.5
2005	-27.9	115.5	69.75	55.5	30
2006	120.9	99	83.7	49.5	6
2007	32.55	73.5	102.3	40.5	31.5
2008	46.5	72	65.1	58.5	-13.5
2009	43.4	109.5	144.15	81	39
2010	65.1	94.5	106.95	57	6
2011	100.75	138	69.75	75	28.5
2012	38.75	174	238.7	63	-7.5
2013	48.05	130.5	93	37.5	18
2014	-23.25	115.17	105.4	67.65	-1.05
2015	4.495	81	76.88	65.25	-2.55

The same trend has been observed here that the number of Cooling Degree Days is higher in June and the lower number of Degree Days is observed in September. The lower number of cooling degree days in reference rural station shows that green cover and less infrastructure development lower the air temperature of the area.

The negative values are taken as zero. The annual total urban CDD value from 2001-2015 is up to 21.08 percent higher than the rural CDD value and 30.56 percent lower than sub urban value from 2001-2015. The higher CDD in urban station refers to higher temperature due to barren land with sparse vegetation. The lower number of CDD in rural station refers to lower temperature as compare to urban and sub urban station due to large vegetative cover which cools the air.

Table 4.7: Monthly mean number of Cooling Degree Days for the base 26 °C

station	May	June	July	August	September
Base 26 C					
Rawalpindi airport(urban)	84.66	121.16	116.74	67.38	15.2
Dhamial Air Base (sub urban)	105.19	160.40	131.44	92.40	39.47
NARC(reference rural)	47.52	110.68	106.81	60.06	9.06

Monthly mean number of Cooling Degree Days shows that the month of June has higher temperature and lower temperature has been observed in the month of September from 2001 to 2015.

Table 4.8: Percentage increase in mean number of Cooling Degree Days for base 26 °C

Months	Urban- Sub urban	Urban-Rural
May	24.25%	78.03%
June	39.24%	9.47%
July	12.59%	84.33%
August	37.13%	12.19%
September	159.67%	67.77%

Monthly data of summer months from period 2001-2015 has been observed and the monthly mean number of cooling degree days is observed for the base temperature i.e. 26 C. Among the three stations, a higher number of days with higher temperature were found in June at the sub urban station located in Dhamial, peripheral part of Rawalpindi city in the south. By using a percentage increase formula, in the month of May 24.25% more Cooling degree days were recorded in sub urban station when compare to urban station. 39.24% more days were recorded than urban station in the month of June. 12.59% more days were recorded in the month of July, 37.13% were more in the month of August and 159.67 % in the month of September. The monthly mean number of cooling degree days of urban station were compared with the reference rural station and 78% more days were recorded in the month of May. In the month of June 9.47% more days were recorded, in July 84.33% more days were recorded, in August 12.19% more days were recorded and in September 67.77% more days were recorded in urban station when compare to reference rural station. The difference between the sub urban and urban station can be attributable to the fact that sub urban area i.e. Dhamial station has barren land which lies vacant for development of housing schemes and other infrastructure from past several years. The agriculture fields have been cleared off and the land is made compact for construction purpose. There is very little moisture in the land with sparse vegetation and the compaction of soil for construction purpose make it further worse especially when the area is semi arid and the moisture depends only on the rain. Also the difference between urban and reference rural station can be attributed to the fact that rural area has large vegetative cover and the solar radiation when incident on the plants, the process of evapotranspiration occurs which cools the air. Beside this, there is little infrastructure and low heat is absorbed as compare to urban structure.

4.3. Urban heat island intensity

Urban heat island intensity is the mean temperature difference between urban and sub urban /reference rural station. It can be diurnal, daily, monthly or annually. Present study will focus on the annual Urban Heat Island and the data from 2001-2015 has been used to show the trend of urban Heat island.

Table 4.9: Urban heat island intensity (urban and sub urban area)

time	Rwp.urban	Dhamial sub urban	UHII
2001	22.4	22.92	-0.55
2002	22.4	22.81	-0.41
2003	21.2	22.81	-1.58
2004	21.6	22.70	-1.13
2005	20.5	21.62	-1.07
2006	22.1	22.75	-0.70
2007	21.1	21.82	-0.73
2008	21.05	21.79	-0.74
2009	21.5	22.08	-0.62
2010	22.5	22.83	-0.31
2011	22.0	22.48	-0.46
2012	21.4	22.30	-0.93
2013	21.5	22.35	-0.82
2014	20.9	22.45	-1.59
2015	21.7	21.94	-0.21

All the values of air temperature are in Degree centigrade and urban heat Island Intensity has been obtained as the difference between the annual mean air temperature of urban station and sub urban station. The negative values show that the mean air temperature at sub urban station is higher as compare to mean air temperature of urban station. The Highest value was -1.59 which occur in 2014. This difference in temperature is due to land clearing activities for the construction of housing schemes. The vacant land shows higher temperature as compare to covered land in semiarid and arid conditions. This analysis is supported by study done by Shah and Ghauri (2015) consist of mapping the surface urban heat island by using Land sat TM images and concluded that the surface urban heat island (SUHI) of Lahore or a city of similar growth pattern does not appear as a single structure in the city centre or even with the densely populated older quarters of the city. The SUHI of Lahore seems to be warmest at its boundaries due to the development of newer housing colonies and the boundaries of the SUHI roll outwards as the city expands. Sand/ vacant land turns out to be warmest of LULC (Land Use Land Change) types in city of Lahore.

Table 4.10: Urban heat island intensity (urban and reference rural area)

time	Rwp.(urban)	NARC(rural)	UHII
2001	22.4	21.72	0.65
2002	22.4	21.70	0.70
2003	21.2	20.80	0.43
2004	21.6	21.06	0.51
2005	20.5	20.25	0.30
2006	22.1	21.47	0.58
2007	21.1	21.08	0.01
2008	21.05	20.97	0.08
2009	21.5	21.29	0.17
2010	22.5	21.81	0.71
2011	22.0	21.31	0.71
2012	21.4	21.20	0.17
2013	21.5	21.03	0.50
2014	20.9	20.29	0.61
2015	21.7	20.93	0.80

All the values of air temperature are in Degree centigrade and urban heat Island Intensity has been obtained as the difference between the annual mean air temperature of urban station and reference rural station. The positive values show that the mean value of air temperature at urban station is higher as compare to mean value of air temperature at rural station. When the solar radiation hits the ground, the energy is then utilized in evapotranspiration which lower the air temperature. Hence the vegetation of rural station lowers the air temperature by increasing moisture.

The temporal and spatial variability has been observed in Urban Heat Island Intensity across three stations. When the urban and sub urban stations have been compared, high temperature was observed in sub urban station as compare to urban station. Sub urban station has barren land which lies vacant for development of residential schemes and other infrastructure from past several years. The green fields have been cleared off and the land is made compact for construction purpose. There is very little moisture in the land with sparse vegetation and the compaction of soil for construction purpose make it further worse especially when the area is semi arid. The urban centre seems to be cool as compare to sub urban area. When urban station is compared to reference rural station, the urban heat island intensity is positive that mean the urban station is warmer than rural station. The difference is made due to the presence of green cover in rural station.

Panel regression is developed to check the sensitivity of residential electricity consumption (EC)for a particular station with respect to change in Cooling Degree Days (CDD) during cooling season which include May, June, July, August and September and it also includes dummy for different classes of consumers depending on units of electricity consumption per month as discussed in chapter three.

Table 4.11. Pane regression results of residential electricity consumption on Cooling Degree Days

Dhamial sub urban station

Dependent Variable: EC
Sample: 2010M05 2010M09
Periods included: 5
Cross-sections included: 500
Total panel (balanced) observations: 2500

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	31.82701	7.907074	4.025131	0.0001
CDD	0.076598	0.032370	2.366361	0.0180
DD1	105.6869	7.715709	13.69763	0.0000
DD2	292.1109	8.042404	36.32134	0.0000
DD3	589.1053	11.08093	53.16389	0.0000
DD4	1133.166	29.13265	38.89676	0.0000
R-squared	0.732331	Prob(F-statistic)		0.000000

Rawalpindi urban station

Dependent Variable: EC
Sample: 2010M05 2010M09
Periods included: 5
Cross-sections included: 500
Total panel (unbalanced) observations: 2499

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	550.5445	24.70772	22.28229	0.0000
RCDD	0.061966	0.110146	2.462576	0.0168
RD1	124.4491	25.21531	15.16734	0.0000
RD2	196.0941	25.95657	7.554702	0.0000
RD3	382.6191	29.78568	4.183859	0.0000
RD4	642.8069	42.06585	15.28097	0.0000
R-squared	0.354741	Prob(F-statistic)		0.000000

NARC reference rural station

Dependent Variable: EC
Sample: 2010M05 2010M09
Periods included: 5
Cross-sections included: 500
Total panel (unbalanced) observations: 2499

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	245.3232	16.47934	14.88671	0.0000
NCDD	0.170374	0.042031	4.053535	0.0001
ND1	75.01788	16.84202	-4.454208	0.0000
ND2	101.3525	16.62815	6.095238	0.0000
ND3	383.1788	17.25301	22.20939	0.0000
ND4	909.5389	27.05949	33.61257	0.0000
R-squared	0.705420	Prob(F-statistic)		0.000000

Residential electrical consumption has been regressed on monthly cooling degree days on all the three station. Results are given in table 4.11. In Dhamial station, one degree increase in Cooling Degree Day will increase overall residential electricity consumption by 0.07 units. In Dummy 1(DD1), in which the residential consumption ranges from 50-250 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 105 units. In Dummy 2 (DD2), in which the residential consumption ranges from 251-500 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 292 units. In Dummy 3 (ND3), in which the residential consumption ranges from 501-1000 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 589 units. . In Dummy 4 (ND4), in which the residential consumption ranges from 1001-1500 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 1133 units. All these coefficients are statistically significant. The coefficient values of DD1, DD2, DD3 and DD4 shows increasing trend. The reason may be in two dimensions. The increase in electricity consumption is may be due to income effect. The more affordable the consumer is, the variation in electricity consumption due to higher temperature is more pronounced. Secondly, the construction in sub urban area is more compact with less green cover and low wind velocity, so to cope with increasing temperature the residents are using more electricity.

In Rawalpindi station, one degree increase in Cooling Degree Day will increase overall residential electricity consumption by 0.06 units. In Dummy 1(RD1), in which the residential consumption ranges from 50-250 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 124 units. In Dummy 2 (RD2), in which the residential consumption ranges from 251-500 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 196 units. In Dummy 3 (RD3), in which the residential consumption ranges from 501-1000 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 382 units. . In Dummy 4 (RD4), in which the residential consumption ranges from 1001-1500 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 642 units. All these coefficients are statistically significant. The coefficient values of RD1, RD2, RD3 and RD4 shows increasing trend. The increase in electricity consumption is may be due to income effect. The more affordable the consumer is, the variation in electricity consumption due to higher temperature is more pronounced. The overall value of CDD is lower as compare to sub urban station which may be due to presence of green cover within the construction of infrastructure i.e. trees on the sides of road, in homes and parks etc. The roads are wide and there is less compact infrastructural development as compare to sub urban station.

In NARC station, one degree increase in Cooling Degree Day will increase overall residential electricity consumption by 0.17 units. In Dummy 1(ND1), in which the residential consumption ranges from 50-250 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 75 units. In Dummy 2 (ND2), in which the residential consumption ranges from 251-500 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 101 units. In Dummy 3 (ND3), in which the residential consumption ranges from 501-1000 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 383 units. . In Dummy 4 (ND4), in which the residential consumption ranges from 1001-1500 units of electricity, one degree increase in cooling degree day will increase electrical consumption by 909 units. All these coefficients are statistically significant. The coefficient values of DD1, DD2, DD3 and DD4 shows increasing trend. The increase in electricity consumption is may be due to income effect. The more affordable the consumer is, the variation in electricity consumption due to higher temperature is more pronounced. But the less variation in electricity consumption is observed as compare to other stations which may be due to less temperature as compare to other two stations. The reason is large green cover which lowers the temperature. The overall coefficient of CDD is higher which may be due to high income profile of the area as compare to urban and sub urban stations.

The existing literature (Arifwidodo and Chandrasiri 2015; Radhi and Sharples 2013 and Kapsosomenakis et al. 2013) shows that electricity consumption is high in urban areas due to high temperature as compare to sub urban area. The urban area in existing theory is compact structure with high economic activities and less green cover. The sub urban area in the existing theory is low density built up area with the green cover and rural area is having large green landscape than sub urban urban area and very low built up area. But in this study, the urban centre has more green cover than sub urban area which results in less temperature as compare to sub urban area. Sub urban area has come under the urban sprawl and the unplanned development in sub urban area leads to compact infrastructural development and least green cover which results in higher temperature. The economic activities in sub urban area are approximately equal to urban area. Thus, high temperature leads to high electricity consumption. The rural area in this study is though have large green cover and having less temperature but it is high income profile area as compare to urban and sub urban area which results in high electricity consumption.

Chapter 5

CONCLUSION

The study finds the impact of Urban Heat Island, proxied by increasing temperature on residential electricity demand in Rawalpindi city. It used annual air temperature of Rawalpindi (urban) area and Dhamial (sub urban) from 2001-2015 to estimate the urban heat island characteristics. The study further compares the Rawalpindi (urban area) to reference (rural area). The analysis suggests that Urban Heat Island exist, when urban area is compare to rural area and the intensity of Urban Heat Island ranges from 0.01-0.80 ^{o}C. The urban station when compared to sub urban station shows negative Urban Heat Island i.e. city is cooler than its suburb. This situation is supported by existing research done in arid and semi arid region. The range of negative urban heat island is between -0.21 to -1.59 ^{o}C which is quite high. The profile of Cooling Degree Days also shows that the higher number of Cooling Degree Days occurs in sub urban area followed by urban area and the least number of Cooling Degree Days are found in rural areas. The study also examines the relationship of urban heat island with residential electricity consumption and concluded that the area with higher temperature has more electrical consumption than area with lower temperature but the electrical consumption is higher in NARC, area with high income despite of lower temperature there. The residents of Dhamial station used 16.6 times more electricity and of NARC used 183.33 times more than Rawalpindi station. The temperature is high in Dhamial so to cope with higher temperature more energy used. The energy used in NARC is due to high income profile of that area as compare to other two areas.

5.1. Policies and recommendations

- The metrological observatories must be set at different location in cities and the data should be precisely recorded and saved so that difference in air temperature in intra urban environment can be easily identified.
- The analysis shows that area with less vegetative cover have higher temperature as compare to urban areas with green spaces between their structure so development of new residential schemes in the peripheral parts of city should incorporate the design which has large green area for example Dhamial with less vegetation have more temperature as compare to NARC which has large green area.
- The high temperature leads to high electrical consumption, mitigation strategies by combining the concept of urban heat island should be adopted in order to lower the temperature of cities. The warmer areas of city should have solar reflectance on their roof and paint their houses with light colors.

5.2. Limitation of study

- The present study uses the monthly data of air temperature to estimate cooling Degree days due to unavailability of air temperature at on hourly basis at three selective stations. Cooling Degree hours give more accurate estimates of change in Urban Heat Island diurnally.
- The Increase in residential electrical consumption is just attributable to increasing temperature, no other factors are included which may affect electrical consumption like increase in GDP growth rate, the socio-economic factors like household size, number of electrical appliances etc.

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