Spatial Variability of Urban Heat Island of Sargodha City in Pakistan

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Abstract: Sargodha is one of the most important cities of Pakistan. Located in the center of Pakistan, it is the hub of the Pakistan Air Force. Rapid urbanization in the city has caused it to expand it farther from its center. Sargodha is 11th most populated metropolitan city in Pakistan. Currently, it has 0.7 million population and covers an area of 52 km2. The objective of this study was to measure the spatial variability of urban heat island (UHI) in different areas of the city in comparison with the temperature of the urban center. The meteorological data was measured by installing digital weather stations at four sites, 3 within the city by considering the areas as urban highly dense, urban less dense and urban periphery and one at rural site almost 10 km away from the city center. The result highlighted that difference in temperature between urban densely built area and rural site was highest. The difference in temperature increased as one moved away from the city center where urban areas were found warmer than the sites comparatively away from the city center. It was observed that the UHI intensity is not same in different areas of the city. The highest intensity of UHI is observed on Sunday where it was measured 5.7 °C.

Keywords: Urbanization, urban heat island, land-use change effect, Sargodha.

1. INTRODUCTION

The construction materials used in buildings and infrastructure of urban areas are different from those used in rural areas. Mostly the urban areas have paved surfaces all around and they spread over larger areas. The characteristics of albedo and emissivity of urban material are not the same which we see in non-urban areas. Urban materials mostly trap and absorb short-wave solar radiations, due to low reflectness values. Anthropogenic activities generate heat and cause air pollution in urban areas that contribute to increase temperature in urban areas by re-emitting long wave radiations in the atmosphere [1]. The cities have larger areal extent than rural areas, so provide more place for heat storage. Rate of evaporation is less in urban areas as compared to rural areas, because urban material is watertight [2, 3].

As the result of modifications in atmospheric environment, the development of the phenomenon of urban heat island (UHI) is quite common in urban areas. The UHI is one of the best-known forms of anthropogenic climate modification at a local scale which was first documented in London by Luke Howard in 1833. Various studies highlight the presence of UHI in many cities of the world [4-6], where both the atmosphere and the lithosphere in cities (urban areas) have higher temperatures compared to their surrounding non-urbanized, rural areas [7]. The magnitude of urban heat island is significantly associated with the changes in surface areas but not well related to the population size of the area; therefore measurement of UHI according to population-based adjustment technique is rough estimation of heat island in any urban area [8].

Urban heat island (UHI) causes a modification of the local climate at mesoscale of atmospheric motion. These local climatic modifications enhance the use of energy consumption for cooling purposes in urban areas. Similarly temperature increase on a local scale can cause serious health problems for local inhabitants. The atmospheric modifications at the local scale affect energy balances and surface radiation that play a greater role in decreasing coolness in urban areas relative to its rural surroundings [9]. Indeed, vehicle exhaust emissions, industrial activity and increasing use of air conditioning are contributing to heat generation and this will increase in the future [10].

As the result of urbanization, the natural ecosystem is altered by human induced activities with the conversion of natural vegetated surfaces into buildings and impervious surfaces, with the enhancement of roughness elements during the development process of cities [11]. The urban areas have the characteristics of having different surface structures such as densely

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ISSN: 1814-8085 / E-ISSN: 1927-5129/15

built-up areas, sparsely built-up areas, suburbs of the cities and surrounding rural areas. The radiation balance is modified according to the surface structure due to materials' characteristics of albedo and emissivity. The objective of this work is to study the impact of spatial variability of the urban surfaces on development of UHI of Sargodha city of Pakistan. The city is a fully planned having different blocks with wide roads and open spaces. During calm and clear night the UHI is higher as compare to nearby rural areas because high buildings and densely populated areas of the city pose an obstacle to the natural circulation of air. Moreover, the dense areas have the capacity of the absorption of solar radiation during day times and re-radiation it during night. Part 2 of this study describes the study area and part 3 expounds the data and methodology used in this work. In part 4, results of the study are given.

2. STUDY AREA

Figure **1** shows a map of Pakistan highlighting the position of the city of Sargodha and inset a satellite view of the urban area. The study focuses on the city of Sargodha which is located between 72°38"N and 72°43"N and between32°3" E and 32°7"E. The city is mainly located on flat surface at an altitude of 190 meters. In its surroundings, the fertile plains with citrus/orange trees are the main type of agriculture. Sargodha has arid type of climate with hot and cold characteristics of temperature where it reaches to 50°C in summer and may drop to freezing in winter. Sargodha is 11th most populated metropolitan city in Pakistan. Figure **2** highlights the demographic profile of the city since 1911 to 2013. Currently, Sargodha city has 0.7 million population and covers an area of 52 km^2 [12]. The rapid urbanization of the city has had several environmental consequences, mainly related to energy consumption, reducing vegetation cover within the cities and air pollution. Modification in land surface of the urban areas such as expansion of the city and expanding the paved surfaces, cause to develop UHI.

3. DATA AND METHODOLOGY

3.1. Data Type and Measuring Instrument

For this study, the observational data measured at an urban site and at a rural site were used to find the difference of temperature between the two sites ($\Delta T_{urban-rural}$). This method is widely used for the assessment of the UHI of cities [13]. A solar-powered

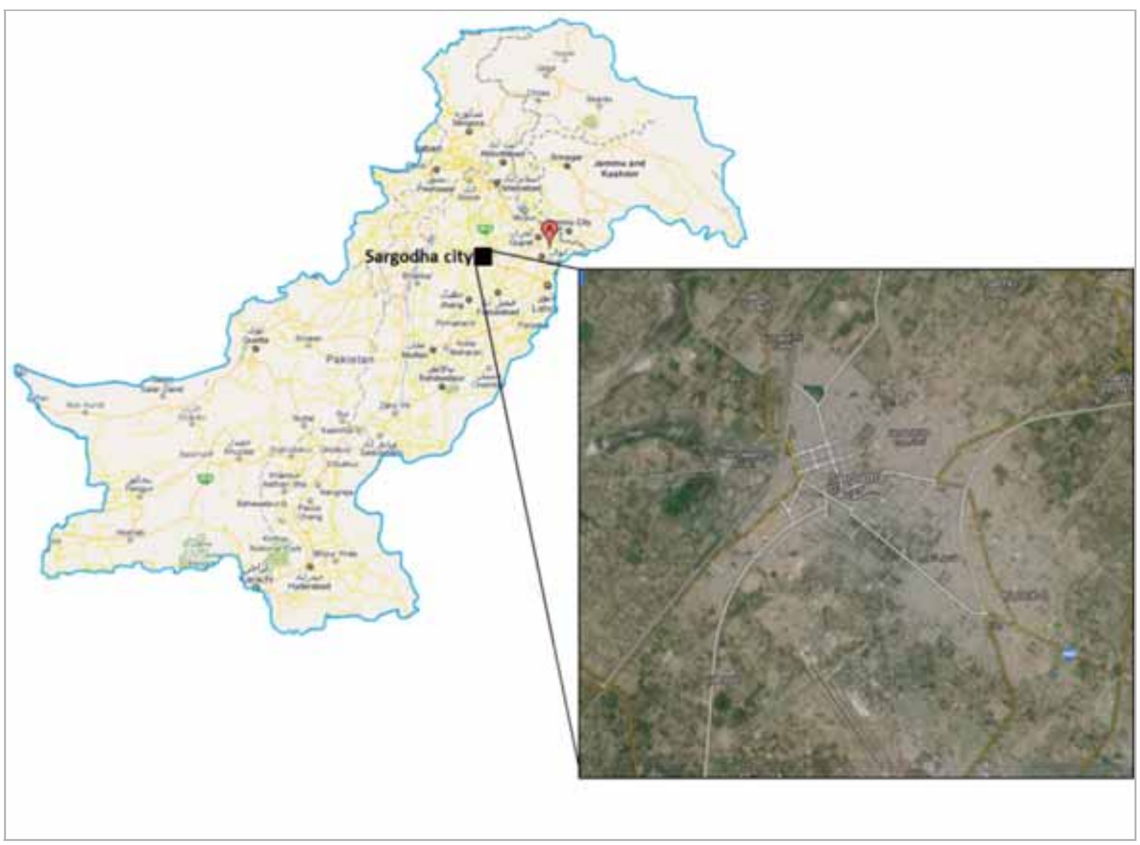

Figure 1: Location map of study area (Adapted from Google maps and redesigned in frame).

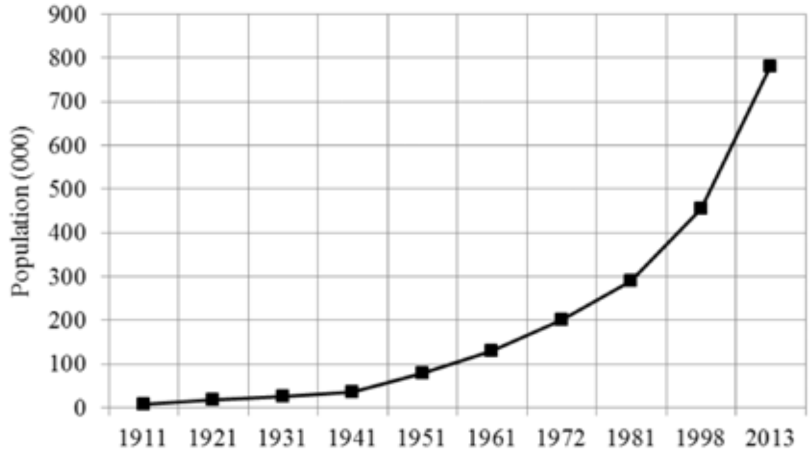

Figure 2: Urban population of Sargodha city from 1911 to 2013.

touch panel Weather Centre (WS-1080) with PC interface was used to measure the meteorological data. The weather station was powered by a solar panel along with a built-in radio transmitter. This digital weather station recorded, memorized and transferred the data *via* radio signal to a digital receiver (Figure **3**). This instrument is reliable source of data collection for this type of study. It has a long range and large capacity to measure the data with absolute accuracy ranging from -40.0 °C to + 65.0 °C for outdoor temperature and from 10% to 99% (1% resolution) for relative humidity.

3.2. Data Collection Sites

The data was collected for a period of three days starting from mid-day on 19^{th} of September to mid-day on the 22^{nd} September 2014 with resolution of 30 minutes from four sites having spatial variability of surface structure. The major sites of data collection were (i) a rural area located at *Jhal Chakian*, (ii) a densely built urban area (Block 9), (iii) a less dense urban built area (Canal Park) and (iv) an area at the urban periphery (*Muhafiz* Town) stations (Figure **4**). The urbanstation was considered as the reference

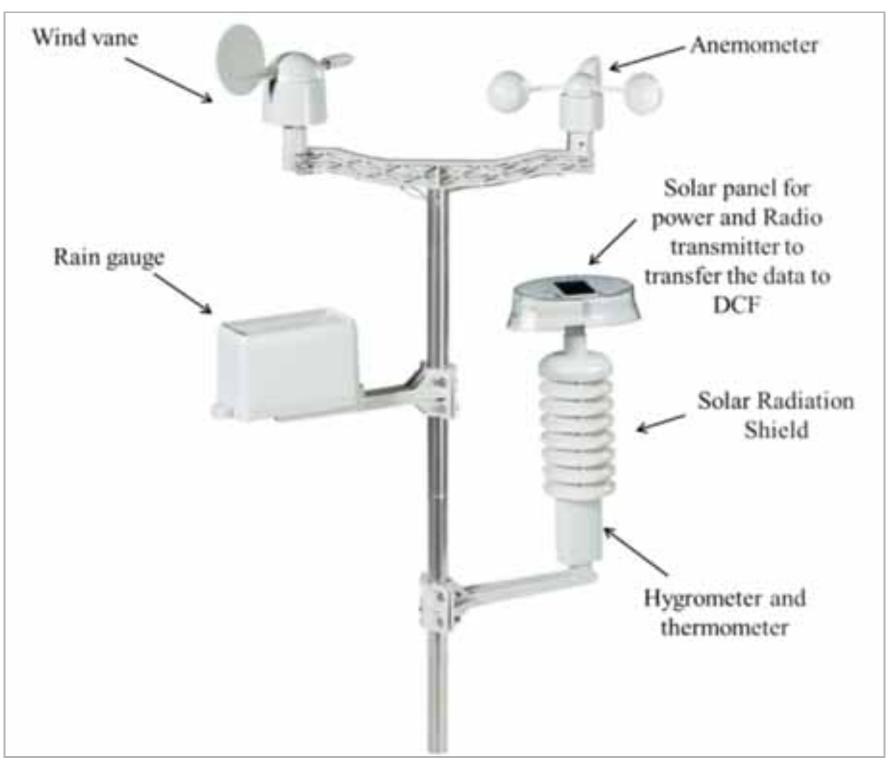

Figure 3: WS-1080 - Solar powered radio weather station used for data measurement.

Figure 4: Data collection sites in and around Sargodha city.

station. The distance between urban (dense) and rural station is 7.1 km. The distance between urban (dense) and urban (less dense) is 4.7 km and the distance between urban (dense) and urban periphery is 6.5 km.

3.3. Data Analysis

The data were analyzed by using linear regression, first by comparing the actual measured values observed at rural and urban (dense, less dense and urban periphery) stations and then by taking the difference of each from the reference series (urban-dense).

4. RESULTS

Figure **5** shows the overall variability of temperature at four different sites located within Sargodha city and in its surroundings. The data with resolution of 30 minutes show that the variability of temperature among different stations is higher during night times and minimum during day times. All the days and nights have same pattern of changing temperature and range of temperature among the different stations during the study period. The variability of temperature among the stations is not homogeneous. It varies as the distance from the center of the city increases (distance between the stations is given in section 3.2).

Figure **6** shows the temperature observed at urban (dense) and the rural station. Figure **7** highlights the temperature observed at urban (dense) and urban (less dense) and Figure **8** shows the perature observed at urban (dense) and urban periphery. The above given figures show that as the distance from urban densely built-up area increases toward less dense built area or toward urban periphery, the temperature decreases faster and constantly.

Figure **9** shows the spatial variability of urban heat island at urban densely built-up area, less dense built-up area and urban periphery in comparison of rural stations. The difference in temperature to see the UHI at different urban sites is measured by subtracting rural temperature from the temperature at each of the other three observational sites. Figure **9** also highlights that the maximum intensity of UHI is in the densely built-up urban areas. Through analysis and comparison of different data sets of the observed data, it was seen that the UHI decreases as the distance between urban area and nearby rural areas increases. It highlights that UHI is mainly because of the presence of urban structural effect on local climate.

Table **1** describes the highest and lowest temperature observed at different observational sites.

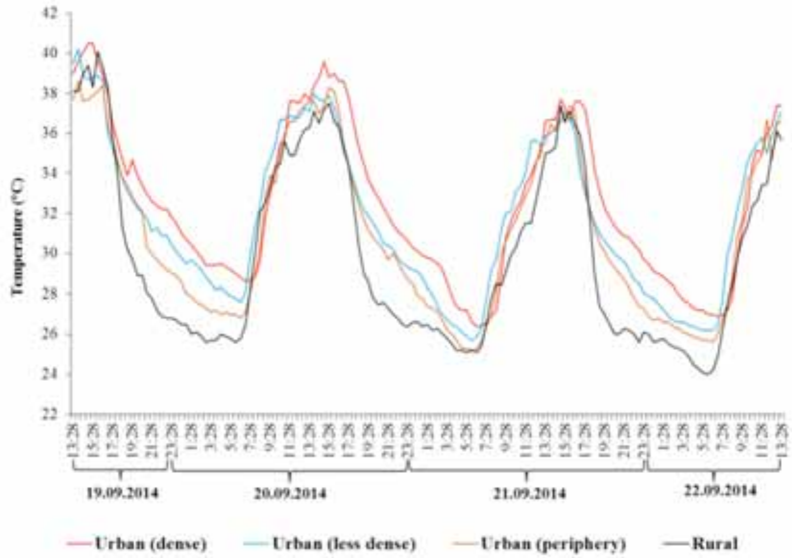

Figure 5: Spatial and temporal variability of temperature in and around Sargodha city.

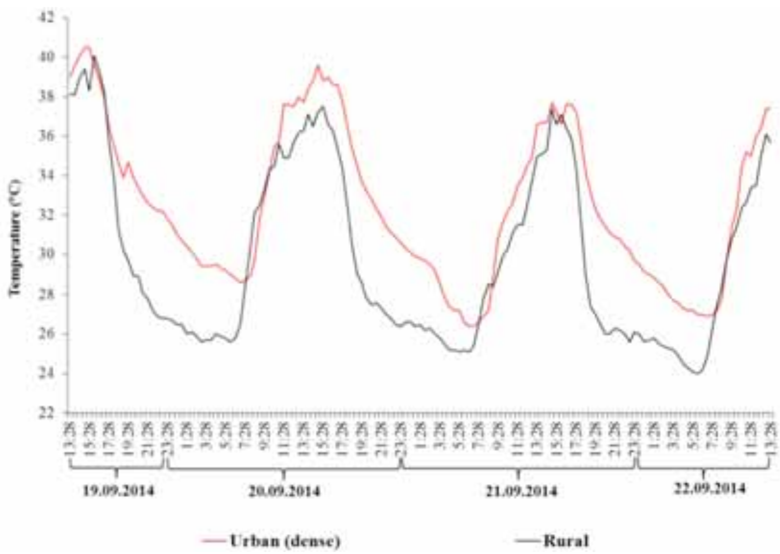

Figure 6: Spatial and temporal variability of temperature of densely built urban area and rural site.

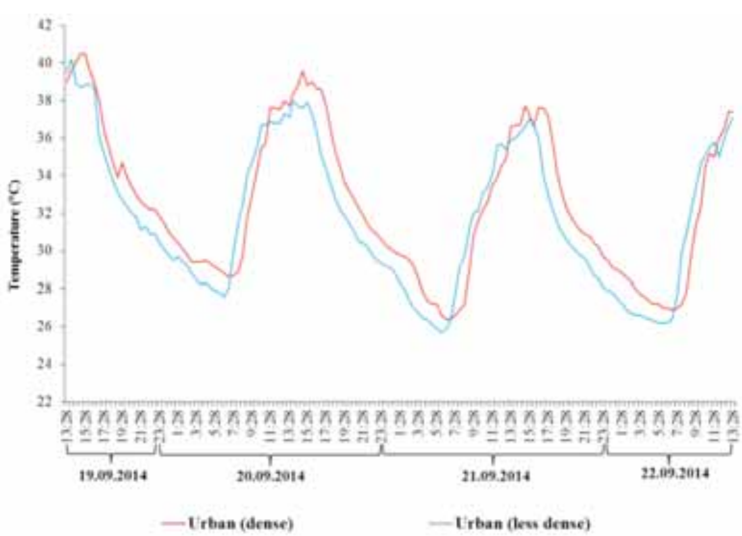

Figure 7: Spatial and temporal variability of temperature of densely built urban area and less dense urban area.

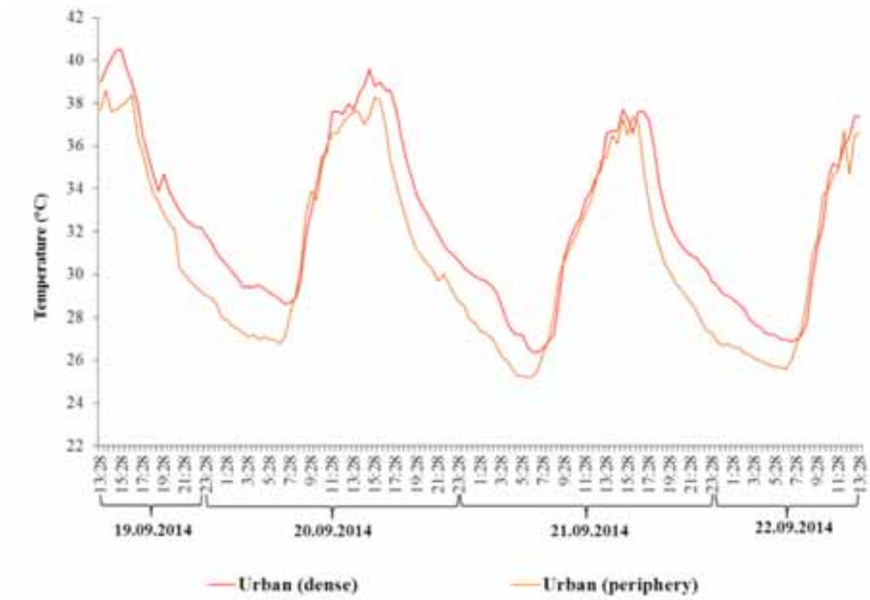

Figure 8: Spatial and temporal variability of temperature of densely built urban area and urban periphery.

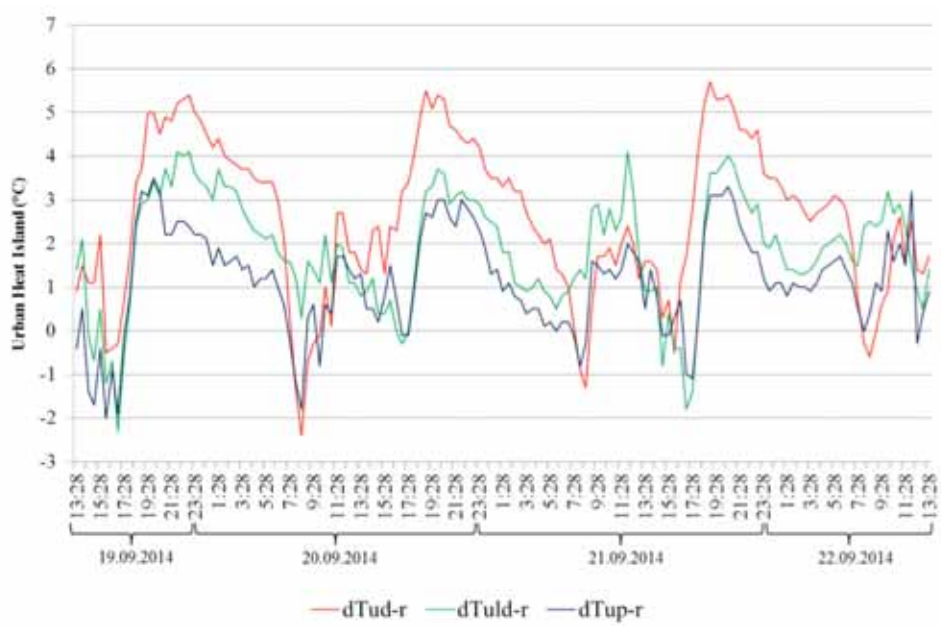

Figure 9: Urban heat island for densely built urban area, less dense urban area and urban periphery.

The highest temperature is observed at urban station (densely built-up), where it measured 40.5°C on 19 September 2014. The lowest temperature is observed at rural station, where it was 24°C on 22 September 2014. Table **2** shows the intensity of UHI during studied period. It is observed that the highest UHI is measured on Sunday that is a fully working day in the city. On this day, many people from nearby rural areas come to the city for shopping and for other activities. So it is the busiest day of the city. Because of the day with affluent economic activities on Sunday, the city has the highest UHI on this day (5.7°C).

5. CONCLUSION AND DISCUSSION

This study was focused on the measurement of UHI with spatial variability of land surface. The latest method to collect the meteorological data was used in which the WS-1080 meteorological observatory was used. The data was collected from different sites within the city and around the city. Four important sites were selected based on different types of land-use. The important site was the densely built-up urban area which was considered as the reference series to compare the data with other data series collected from

Table 1: Highest and Lowest Temperatures Measured at Densely Built Urban Area, Less Dense Urban Area, Urban Periphery and Rural Sites During Selected Dates and Time

Day, date and time of the week	Urban dense (ud)		Urban less dense (uld)		Urban periphery (up)		Rural (r)	
	Highest Temperature	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature	Lowest Temperature
Friday (19.09.2014) From 13:28 to 23:58	40.5	31.5	40.2	30.1	38.6	28.9	40.1	26.7
Saturday (20.09.2014) From 00:28 to 23:58	39.6	28.6	38.0	27.6	38.3	26.8	37.5	25.6
Sunday (21.09.2014) From 00:28 to 23:58	37.7	26.4	37.0	25.7	37.4	25.2	37.4	25.1
Monday (22.09.2014) From 00:28 to 13:28	37.4	26.9	37.1	26.2	36.7	25.6	36.1	24.0

Table 2: UHI During Different Days of Observational Period

Day, date and time of the week	UHI ($dT_{Urban-Rural}$) Unit: ˚C
Friday (19.09.2014 – From 13:28 to 23:58	5.4
Saturday (20.09.2014) – From 00:28 to 23:58	5.5
Sunday (21.09.2014) - From 00:28 to 23:58	5.7
Maximum intensity during studied period	5.7
Minimum intensity during studied period	-2.4

three other sites (rural, urban less dense and urban periphery).

The data were collected every 30 minutes over a period of three days. The data was analyzed using statistical techniques and the results were presented in form of tables and graphs. The study brought out the findings that in urban areas especially in case study area, a UHI is present. The temperature difference moving from rural area toward city center decreases rapidly. The maximum UHI intensity in case of Sargodha city was observed to be 5.7°C that is a significantly higher temperature within city than in the surrounding rural areas. The findings of this study are in agreement with other regional studies [4, 5].

The town councils' role to reduce UHI or mitigate its effect is not effective. Adopting the mitigation strategies to overcome this issue will not only reduce the energy consumption, it will also help to develop the sustainable cities in Pakistan. The step toward the use of solar energy can be better solution as the city is located in arid type climate zone.

ACKNOWLEDGEMENT

Second author greatly acknowledges Dr. Sajjad Hussain Sajjad for supervision of this research work. All the authors highly acknowledge Prof. Dr. Akram Choudry, Vice Chancellor, University of Sargodha, for the sanction of required funding to purchase the weather stations that were used to collect the data used in this research. First and second author shall like to thank Prof. Dr. Khalid Mahmood, Chairman, Department of Earth Sciences for his kindness and support during data collection period and completion of this work.

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Received on 28-01-2015 Accepted on 18-03-2015 Published on 26-03-2015

http://dx.doi.org/10.6000/1927-5129.2015.11.40