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**RESEARCH ARTICLE**

# URBAN HEAT ISLAND CHARACTERISTICS UNDER DIFFERENT LAND USE LAND COVERS IN DHAKA, BANGLADESH

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**ABSTRACT**

Urban heat island (UHI) is a phenomenon of higher atmospheric and surface temperatures occurring in urban areas than in the surrounding rural areas due to urbanization. Rapid urbanization leads to increase in impermeable surfaces in the form of pavements and roads that may reduce natural vegetation cover and increase the surface temperature. Characterization of UHI is an important issue due to its harmful effects on human health and environment. The study was carried out to observe urban heat island (UHI) phenomenon under different land use land covers (built-up area, vegetated area, water body and bare soil) and its effect on human comfort in capital city Dhaka and its suburban area (Savar), Bangladesh. The last 30 years (1987-2016) temperature and relative humidity were collected from Bangladesh Meteorological Department (BMD) to investigate the presence of heat island phenomenon in the study areas. Air temperature and relative humidity under different land use land covers were measured using Thermo-hygro data logger from July to September, 2017 (10 July, 8 August and 8 September) in order to find out the thermal behavior of different land use land covers (built-up area, bare soil, vegetated area and water body). During the period of 1987-2016, annual average temperature increased by 0.024 °C / year in Dhaka, 0.0199 °C/year in Savar. In comparison with the rate of temperature increase with its suburban area, the rate of increase in Dhaka was higher, indicating the existence of urban heat island in this city throughout the study period (1987-2016). In Dhaka, the highest (3.5 °C) urban heat island intensity (UHII) was in 1999 and the lowest (0.6 °C) was in 2011. The built-up area exhibited the highest UHI effect in comparison with bare soil, vegetated area and water body. Highest UHII of Dhaka was 3.3 °C in built-up area and lowest was 0.2 °C in vegetated area. Thermo hygrometric index (THI) ranged from 26.2 °C to 32.6 for Dhaka city and 25.7 °C to 31.8 ° C for Savar sub-urban area indicating the more comfortable condition in Savar. From this study, it is found that land use land cover changes (from vegetated to impervious layer) in urban areas increased urban heat island phenomena compared to its surrounding sub-urban area.



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## INTRODUCTION

An urban heat island (UHI) is an urban area or metropolitan area, where air and surface temperatures are considerably warmer than its surrounding rural areas due to human activities that include changes to biophysical environments and ecosystems, biodiversity, and natural resources. It is characterized by increasing sensible heat flux due to a large expanse of non-evaporating impervious materials such as buildings, paved roads, and parking lots covering a majority of urban areas (Voogt and Oke, 2003; Trenberth, 2004). Replacement of natural vegetation coverage with impervious surfaces due to rapid urbanization is considered as one of the most significant factors to generate UHI (Kalnay and Cai, 2003; Chen *et al.,* 2006).

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Land cover represents the actual or physical presence of grass, trees, impervious surfaces, bare ground, water bodies, etc. on the land surface (Fry *et al.*, 2011). Modification of land covers to meet up the growing demands of excessive populations in urban areas influence the micro-climate such as temperature of a city (Rosenzweig *et al.,* 2008). Natural surfaces like vegetation and open ground (park, playground) utilize some of absorb solar radiation as latent heat flux and release water vapors through evapo-transpiration process and keep the surrounding area cooler than the developed hard surfaces (Rizwan, 2008). Impervious land surfaces re-radiate the absorbed solar energy in the form of thermal infrared heat resulting in hotter environment (Patz *et al.,* 2005). Now a day's UHI has received the attention of researchers in all over the world, mainly due to its harmful effects on human health and environment (Kovats and Hajat, 2008). An effect of the UHI is increasing mortality rate when a heat wave increases exponentially with the maximum temperature.

Increased temperatures cause heat stroke, heat exhaustion, heat syncope, and heat cramps which lead to permanent damage of organ systems (Kovats and Hajat, 2008). The problem is prominent in the growing cities and metropolises. Dhaka, the capital city of Bangladesh is one of the fastest developing cities in the world with a significant growth rate since 1981 (BBS, 1997; BBS, 2003). In this city, it is continued to increase population, motor vehicles, high rise building particularly in the last two decades which has created tremendous pressure on urban land, utility services, and other amenities of urban life. A substantial growth of built-up areas (urban development) cause rapid transformation of landscape from natural cover types to impervious surface. The rapid growing population in conjunction with very immediate developing urbanization has led to unplanned and uncontrolled expansion of Dhaka city resulted in the gradual loss of open and green spaces and water bodies in the city. Built-up area made up by concrete, asphalt etc. increased by 88.78% in the past 20 years (from 1989 to 2009) (Bari and Efroymson, 2009). Built-up areas have significantly different thermal bulk properties than that of vegetation and soil, resulting in a change in the energy balance of the urban area, leading to higher temperatures than surrounding rural areas. With the extension of urban area day by day, the impervious surface is also increasing which exacerbates UHI effect (Fuad and Mourshed, 2012).

Expansion of unplanned urbanization and built structure cause adverse effect on the urban climate change such as abrupt temperature rise, erratic rainfall, degrading air quality resulting calamities like flood, water logging, health outbreak, and water scarcity (Tuli and Islam, 2014). Although it is likely that such rapid urbanization in Dhaka has a major impact on land cover changes and consequently on the urban micro-climate, little is known so far in this context. Few qualitative studies were found to assess the urban climate change in Dhaka city but not enough study has been performed yet to correlate urban heat island and land covers (Mayer *et al.,* 2003). Therefore, it is undoubtedly important to examine the correlation among urban development and increasing temperature in Dhaka city. As UHI is influenced by the unique character of each city (urbanization, population growth, vegetation covers), it is necessary to investigate UHI of Dhaka city under different land covers which will help to mitigate UHI for sustainable and comfortable environment. The specific objectives of this study were: to examine the heat island phenomenon in Dhaka city and to identify the contribution of different land covers in urban heat island formation.

## MATERIALS AND METHODS

**Study areas:** The study areas cover the Metropolitan area of Dhaka (DMP) and Savar (suburban area of Dhaka). Dhaka is the capital of Bangladesh, is one of the fastest growing mega-cities of the world (Ahmed, 2011). It lies between 23°42' and 23°54' N latitudes and 90°20' and 90°28'E longitudes (Banglapedia, 2014). Savar is an upazila of Dhaka district and it is located in between 23°44' and 24°02'N latitudes and in between 90°11' and 90°22' E longitudes.

**Site selection:** Four locations were selected to measure the air temperature and relative humidity from each of Dhaka city and Savar suburban area. The criteria for site selection in this study have been developed based on the typical land use pattern and characteristics of the cities. Various land use types were identified from the visual survey of the Web based GIS maps (Google Earth). The land use types that were selected to carry out the measurements were- 1) Built-up area, 2) Vegetated area, 3) Water body and 4) Bare soil.

**Data collection**

**Primary data collection:** Three hours interval (6.00 am, 9.00 am 12.00 pm, 3.00 pm, 6.00 pm and 9.00 pm, 12.00 am, 3. 00 am.) air temperature and relative humidity were measured using Thermo-hygro data logger (Model: PH -1000) on 10 July, 8 August and 8 September, 2017 over selected locations of Dhaka and Savar.

**Secondary data collection:** The 30 years (1987 to 2016) daily air temperature and relative humidity data were collected from Bangladesh Meteorological Department for Dhaka and from Department of Geography and Environment, Jahangirnagar University for Savar.

**Calculation of urban heat island (UHI):** UHI is the result of solar radiation absorbed by the atmosphere and the heat emitted by different surfaces (Minni *et al*., 2013). It is determined as the temperature deference between an urban and its surrounding rural area. In order to investigate UHI, yearly extreme maximum temperature/ maximum summer temperatures of urban and rural areas (the single hottest day in each year) are used (Jianguo *et al.,* 2009). In this study, past 30 years (1987–2016) of yearly maximum summer temperature (March to June) of Dhaka and Savar were used to observe the presence of UHI in Dhaka. Measured air temperature (July, August and September) under different land covers in Dhaka and Savar city were used to estimate UHI under different land covers.

**Calculation of urban heat island intensity (UHII):** The magnitude of an UHI or the degree of development of the UHI is known as UHII. This is the difference in temperature between urban and rural locations within a given time period (Fabrizi *et al.*, 2010). UHII is an important indicator of evaluating the severity of the urbanization of an area. According to Fabrizi *et al.* (2010),

$$UHII = \Delta T (u-r)$$

Where, $\Delta T$ = Temperature difference; u = Urban; r = Rural

**Calculation of thermohigrometric index (THI):** Thermohigrometric index (THI) or heat index is used as a measure of human comfort in urban and rural areas (Thom, 1959). The THI is used to determine the discomfort due to heat stress (Unger, 1999). Hourly air temperature and relative humidity for the months of July, August and September were used for the calculation of THI at each study location (Toy *et al.,* 2007):

$$THI=T- (0.55 - 0.0055RH) (T - 14.5)$$

Where, T is the air temperature (°C); RH is the relative humidity (%). The THI values were used for the evaluation of human thermal comfort.

## RESULTS AND DISCUSSION

**Urban heat island (UHI) phenomenon:** The annual average temperature ranged from 25.4 to 27.3 °C from the year 1987 to

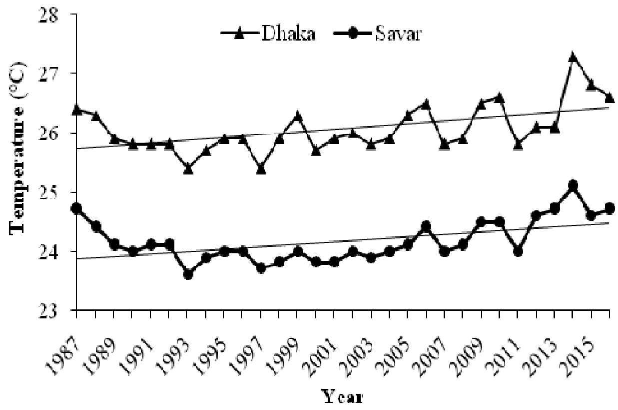


Figure 1. Annual average temperature of Dhaka and Savar

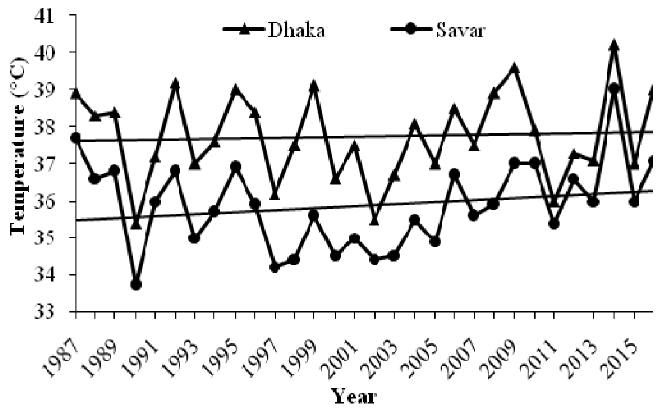


Figure 2. Annual variations in maximum summer (March to June) temperature

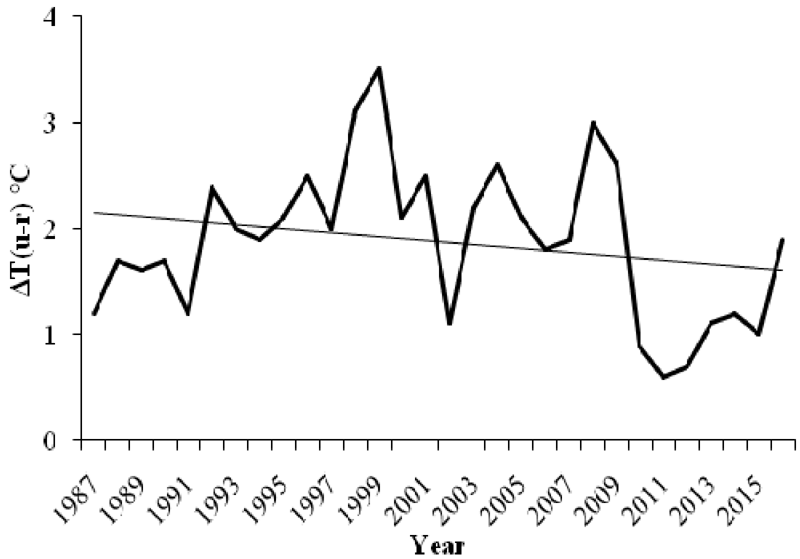


Figure 3. Annual variation in urban heat island intensity in Dhaka

2016 in Dhaka city and was highest (27.3 °C) in 2014 and lowest (25.4 °C) in 1993 (Figure 1). The trend line reveals the likelihood of increasing average temperature by 0.024°C/year during the period of 1987-2016. The causes of increases in the temperature may be many folds including urbanization, vegetation cover change, increased vehicle emission etc. Most of the leading public and private hospitals, school, college and universities and also most of the prestigious workplaces are situated in Dhaka city. This attracted rural people to migrate here. Rate of urbanization in Dhaka is showing an increasing trend 54.42, 61.48 and 77.36% in 1991, 2001 and 2011, respectively (BBS, 2012). Emission of $CO_2$ of Bangladesh has increased 0.2 to 0.4 MT/capita from 1995 to 2010 (World Bank, 2013). Dhaka city is experiencing this $CO_2$ emission more than other parts of country due to rapid urbanization (Karmakar and Shrestha, 2000). Also a significant portion of the $CO_2$ emission is occurring from motor vehicles which are also rapidly increasing in Dhaka city (Banglapedia, 2012). On the other hand, vegetation cover has been decreasing tremendously. According to Rahman *et al*. (2011), Dhaka lost 75.45 $Km^2$green cover during 1989 to 2010 period, which converted into different hard surfaces (brick and concrete pavements and plaza, pitched road, parking lots and buildings etc.). These hard surfaces are responsible for raising urban air temperature. In Savar, annual average temperature showed a positive trend between the periods of 1987-2016.

The average maximum temperature is likely to increase following a trend of 0.0199 °C/year (Figure 1). It is seen from this figure that average temperature stayed almost constant from the period of 1989-2006. But it increased gradually after 2007 with the exception of 2011. Now a day's many industries are established in this city which plays a vital role to rise temperature by increasing hard surfaces and $CO_2$ emission. Many rural people are migrated into this area due to industrialization which increases domestic demand. As a result huge open and vegetated spaces converted to hard and concrete surfaces and these concrete surfaces retain more heat than land surface. According to Rahman and Mallick (2010), Savar was a large jungle and a few families were living here which is being changed and now, there are 300 different industries (e. g., chemical, leather, dying, textile, garments, iron, pharmaceuticals, food processing etc.) in Savar city (Rahman and Mallick, 2010). The alarming reduction of vegetation coverage in Savar occurred from the period of 1989-2010 due to industrialization. Savar lost 27.68 $Km^2$ of green cover during 1989 to 2002 and it was 26.39 $Km^2$ from 2002 to 2010 (Rahman *et al.,* 2011). Bodrud-doza *et al.* (2016) stated that the north-western part of Dhalai beel and surroundings of DEPZ areas of Savar are under high emission of $CO_2$ which cause temperature rise of those areas. The average temperature of Savar city is increased during the period of 1987-2016 but not as rapid as Dhaka city.

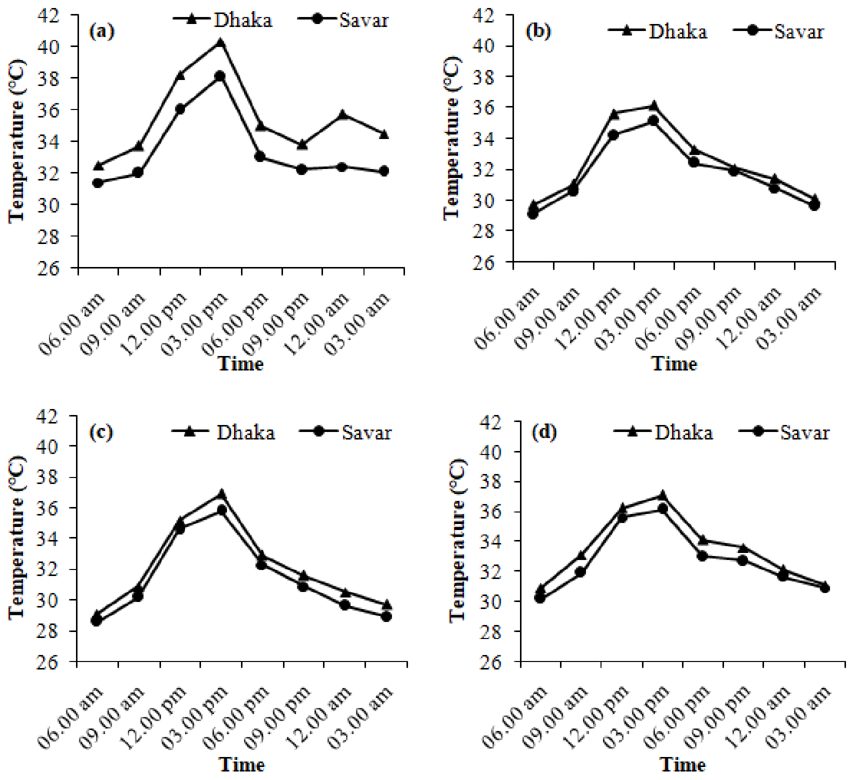


**Figure 4. Urban heat island effect for the month of July: a) Built-up area, b) Vegetated area, c) Water body and d) Bare soil**

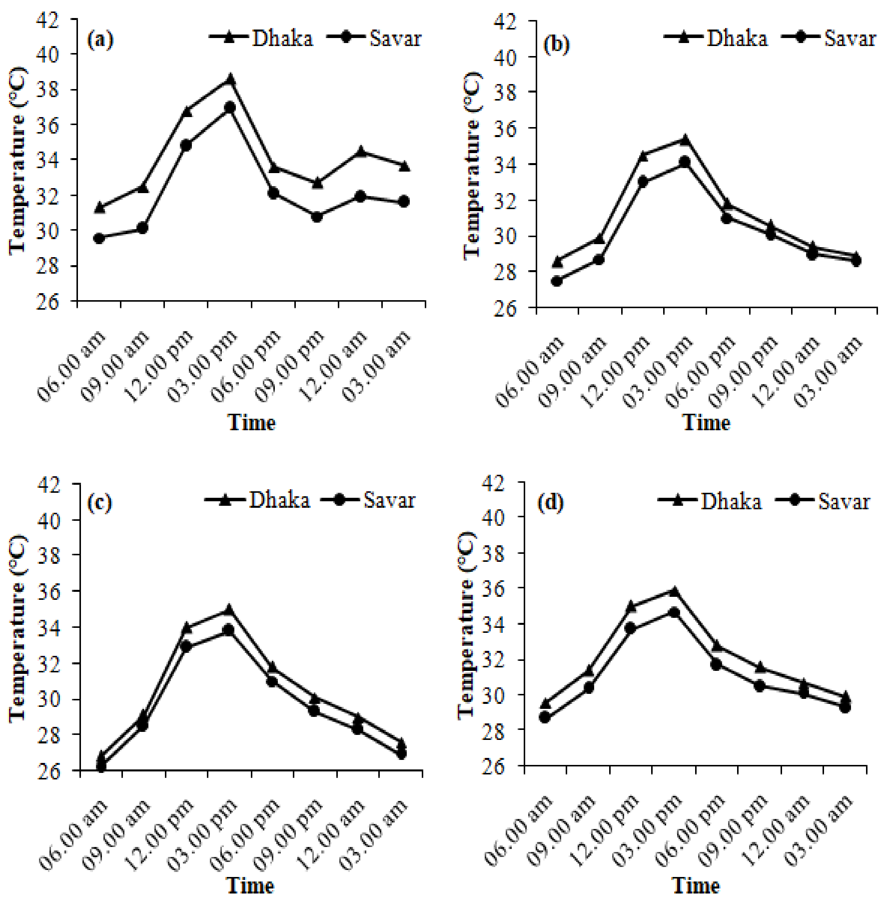


**Figure 5. Urban heat island effect for the month of August: a) Built-up area, b) Vegetated area, c) Water body and d) Bare soil**

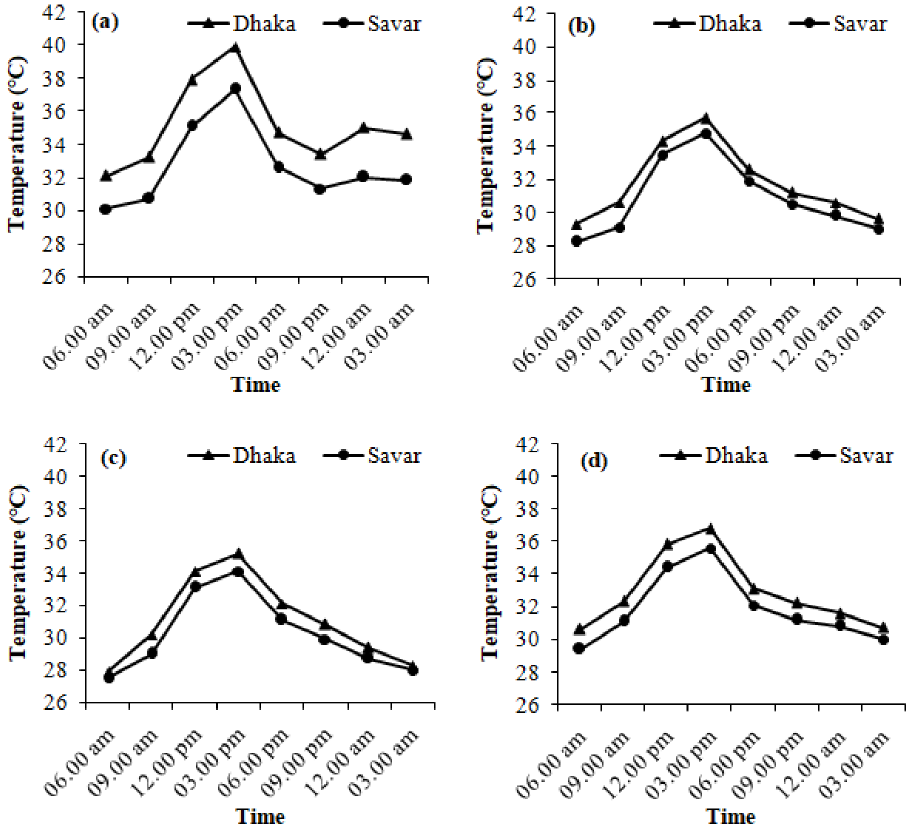


**Figure 6. Urban heat island effect for the month of September: a) Built-up area, b) Vegetated area, c) Water body and d) Bare soil**

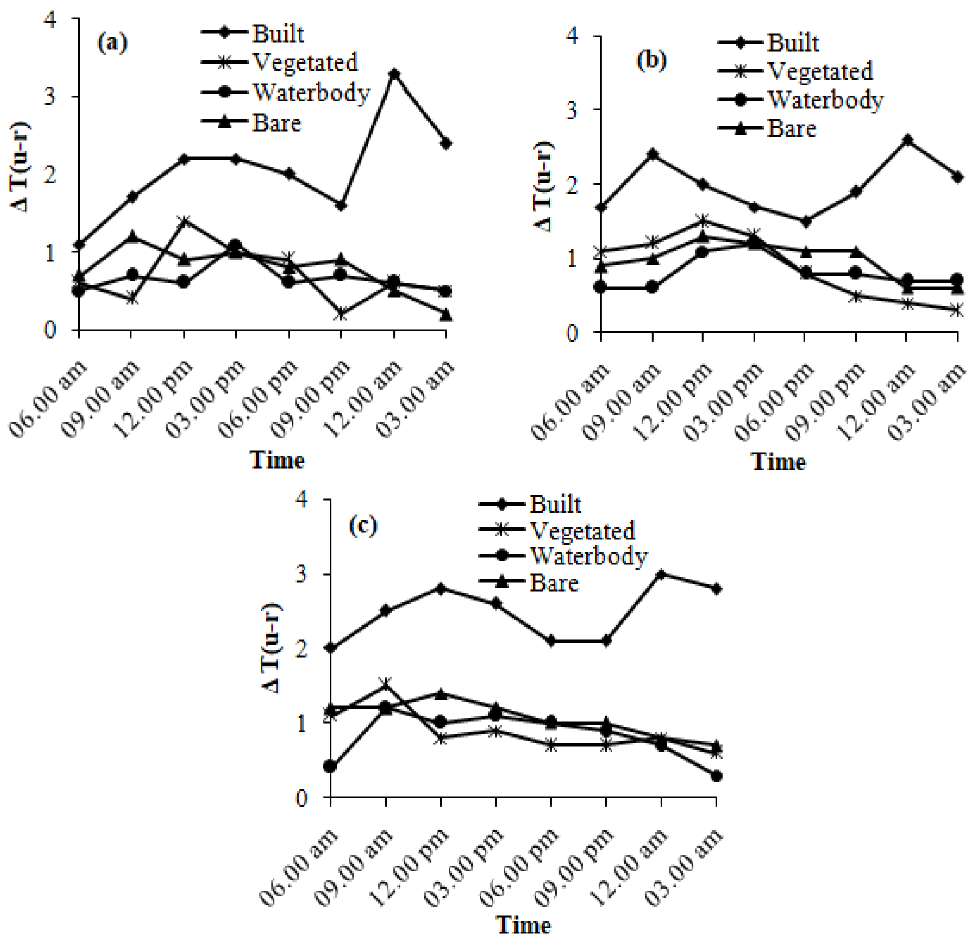


**Figure 7. Urban heat island intensity under different land covers for the month of: a) July, b) August and c) September**

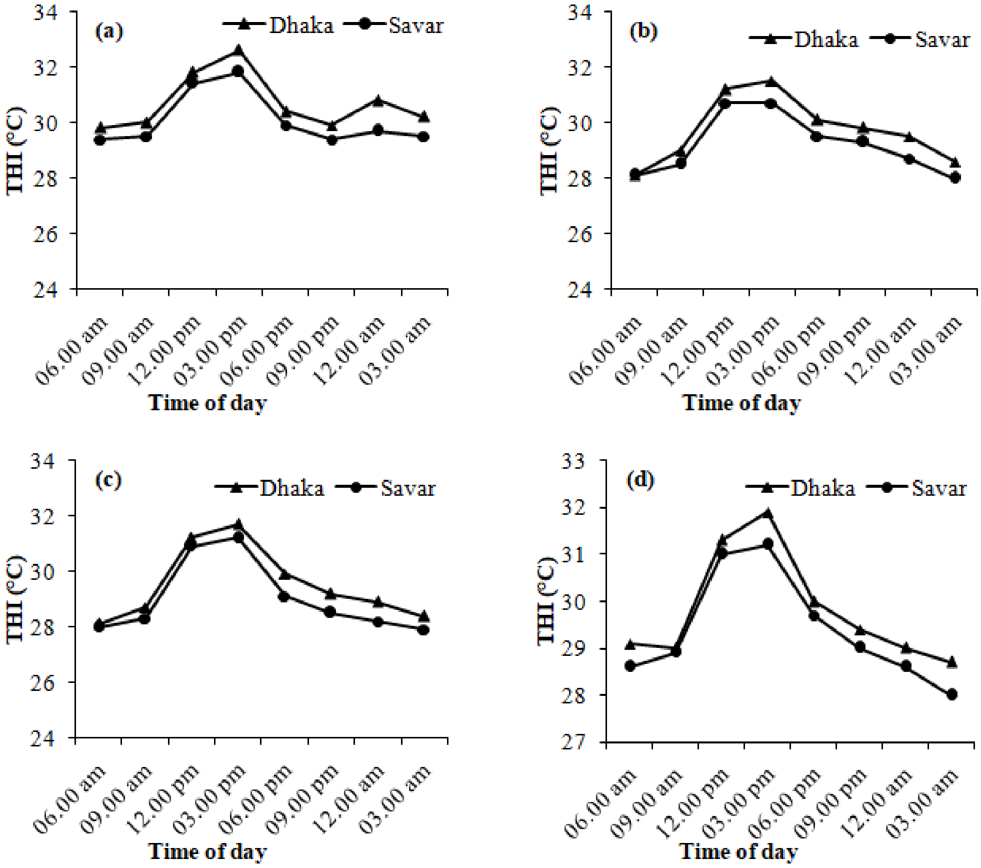


**Figure 8. Thermal heat index (THI) for the month of July: (a) Built-up area, (b) Vegetated area, (c) Water body and (d) Bare soil**

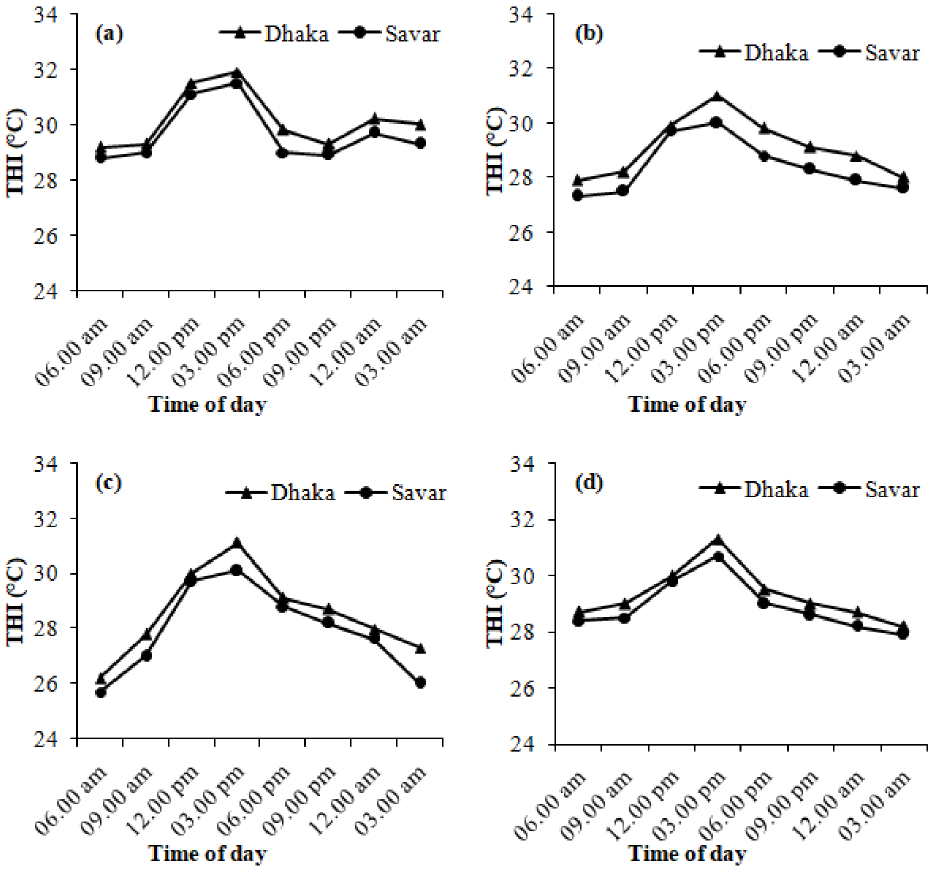


**Figure 9. Thermal heat index (THI) for the month of August: (a) Built-up area, (b) Vegetated area, (c) Water body and (d) Bare soil**

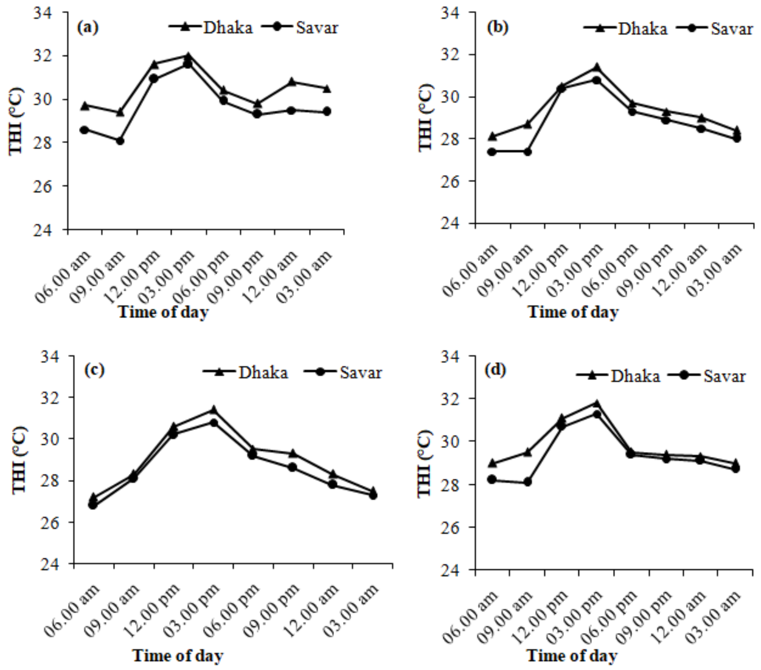


**Figure 10. Thermal heat index (THI) for the month of September: (a) Built-up area, (b) Vegetated area, (c) Water body and (d) Bare soil**

Annual maximum summer temperature for all the studied years is presented in Figure 2. From the figure, it is found that both Dhaka and Savar experienced a temperature increase in the last three decades. However, temperature in Dhaka was higher compared to Savar indicating the existence of heat island in Dhaka. UHI is primarily caused by the built environment in urban areas, in which natural areas are replaced with non-permeable and high temperature absorbing concrete and asphalt surface (Jones *et al.,* 1990). Built-up area increased by 88.78% and water body and vegetation declined gradually in the past 20 years (1989 to 2009) in Dhaka city (Ahmed *et al.,* 2013).

**Urban Heat Island intensity (UHII):** An annual variation in urban heat island intensity (UHII) during the period of 1987-2016 is shown in Figure 3. UHII increased from 1987 with some fluctuations in different years which reached its maximum (3.5 °C) in 1999. After that it gradually decreased (except 2008) and the lowest (0.6 °C) was in 2011.UHII showed a decreasing trend during the period of 1987-2016. Day by day the rate of temperature rise in Savar has increased due to industrialization and thus the differences in temperature between Dhaka and Savar is decreased. Kim and Baik (2005) studied spatial and temporal structure of the urban heat island in Seoul using weather station data and reported maximum air temperature based UHII was 3.4 °C. Bonan (2002) studied ecological climatology and stated that, the majority of cities were around 2 °C warmer than rural areas and commercial and high density residential areas were hotter by 5 to 7 °C.

**Urban heat island (UHI) effect under different land covers**

Diurnal variations in air temperature under different land covers of Dhaka and Savar for three consecutive months (July, August and September) are presented in Figure 4, 5 and 6. Both in day and night time, temperature were higher at Dhaka city compared to Savar sub-urban area for all of three days (Figure 4, 5 and 6) in all land covers. The built-up area exhibited the highest UHI effect when compared with bare soil, vegetation area and water body. Artificial surfaces like asphalt tend to warm more intensively during the day time than those of other land covers and acting as a reservoir of heat energy.

Temperature was lowest at morning (06:00 am), it gradually increased with time, peaked at 03:00 pm and after that it gradually decreased for all of the land covers except built-up area. Here, temperature decreased sharply from 03:00 pm and again it started to increase from 09:00 pm. It might be happened due to built surfaces trap incoming solar radiation during the day and then re-radiate it at night as heat. But vegetation and water body exhibited very little thermal response during night time. According to Farina (2012), cities (provide concrete surface) absorb radiation and re-radiate as heat; water body absorbs radiation in a dynamic fashion and vegetated area (provides dark surface) capture a significant fraction of the solar radiation by the plants and use to make food through photosynthesis and thus doesn't re-radiate as heat. Minni *et al*. (2013) studied urban heat island effect and imperviousness factor and found that vegetation helps in reducing the urban air temperatures by shading and evapotranspiration processes. Tree canopies reduced the amount of short wave radiation that reached the ground surface and block long wave radiation coming off from various surfaces.

**Urban heat island intensity (UHII) under different land covers:** UHII for the month of July, August and September under different land cover is presented in Figure 7. In July, maximum UHII was 3.3 °C in built area and minimum was 0.2 °C in vegetated and bare soil; in August, maximum (2.6°C) was found in built area and minimum was (0.3 °C) found in vegetated area and in September, maximum was 3 °C in built area and minimum was 0.4 °C in water body. UHII in built up area increased progressively at day time which decreased at evening and again increased at mid night hours until predawn hours when levels begin to fall for all of the months. Increasing building density, artificial surfaces in built up area retain huge solar radiation in day time and re - radiate at night as heat. On the other hand, UHII in vegetated area, water body and bare soil increased at day time which was decreased gradually at night. Vegetated area, water body and bare soil absorb solar radiation at day time but were not re–radiate as heat. Moreover, vegetation provides important shading effects as well as cooling through evaporation. UHII is influenced by climate region, local topography, industrial development of a city and land cover change (Stathopoulou *et al.,* 2007). According to Santana (2007) UHII is influenced by vegetation abundance. Minni *et al*. (2013) reported that the greater UHII was found between the city and surrounding rural areas at nights than during the day and especially in built-up areas. Giridharan *et al*. (2004) studied daytime urban heat island effect in high rise and high-density residential developments in Hong Kong. They reported that UHII was low as 0.4°C and as high as 1.5°C within and in between three housing estates in Hong Kong. Kim and Baik (2005) studied spatial and temporal structure of the urban heat island in Seoul using weather station data and reported maximum air temperature based UHII was 3.4°C. They also asserted that the UHIIs were high during night time or early morning and low in day time. Fabrizi *et al.* (2010) analyzed urban heat island in the city of Rome. They reported that UHII of about 3–4 °C is expected for built up areas during the night (around 21:00 UTC) and a negative or almost zero for vegetated area during the daytime (around 9:00 UTC).

**Heat stress condition of Dhaka and Savar:** The calculated THI values at Dhaka and Savar under different land covers for the months of July, August and September are presented in Figure 8, 9 and 10. For the month of July, THI ranged between 28.1 °C to 32.6°C for Dhaka and 27.9 °C to 31.8 ° C for Savar, that fell into the categories of very hot (+26.5 to +29.9°C) and torrid (≥+30°C) (Toy *et al.,* 2007). For the month of August, THI ranged between 26.2 °C to 31.9°C for Dhaka and 25.7 °C to 31.5 °C for Savar that fell into the categories of hot (+20.0 to +26.4°C), very hot and torrid (Toy *et al.,* 2007). For the month of September, THI ranged between 27.2 °C to 32°C for Dhaka and 26.3 °C to 31.6 °C for Savar that fell into the categories of hot, very hot and torrid (Figure 8, 9 and 10). From these figure, it is found that THI values for built-up area were always higher than other land cover for all of the three months.

It probably happened due to temperature of the built-up area (asphalt, concrete surface) is likely to be warmer (due to lower albedo) than other land covers and thus radiate heat which will worsen thermal comfort conditions during the day. However, due to the thermal mass of the asphalt, much of the absorbed solar radiation will be stored in the material and released after sunset which will improve thermal discomfort conditions at night. The THI values and frequencies of very hot and torrid conditions for Dhaka were consistently higher compared to Savar. Other three land covers (vegetation, water body and bare soil) both in Dhaka and Savar had the advantageous effects on the thermal conditions of human. According to Kamoutsis *et al.* (2013), the midnight THI in the inner densely built-up areas expresses the higher heat stress after a hot day. Yilmmaz *et al.* (2007) studied human thermal comfort over three different land surfaces during summer in the city of Erzurum, Turkey. They reported that thermal comfort values are always higher in ashphalt surface than grass and bare soil. Hot range is prevalent for most of the day time and mid night for asphalt surface; the most favorable surface is grass because the number of hot hours is less than others.

**Conclusion**

The study of the heat island phenomenon in Dhaka indicated the changes of urban temperature (increasing) over the last three decades. Urban heat island formation under different land covers (built-up area, vegetated area, water body and bare soil) confirms their frightful contribution in UHI effect while built-up area exhibited the highest UHI effect. It could be said that increase imperviousness in urban areas increases the urban heat island problem of the cities.

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