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Heat island phenomenon and thermal comfort under different land use patterns in urban and suburban areas of Mymensingh

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Abstract

The study was carried out to observe the formation of urban heat island (UHI) under different land use patterns (built-up area, vegetated area, water body and bare soil) in Mymensingh city. Temperature and relative humidity of 30 years (1987-2016) were collected from Bangladesh Meteorological Department. Air temperature and relative humidity were measured at three hours interval on 18 July, 10 August and 10 September, 2017 over selected locations of Mymensingh city and of its suburban rural area (Phulpur upazila) using Thermo-hygro data logger to investigate the heat island phenomena and heat stress condition. During the period of 1987-2016, annual average temperature increased by 0.0094 °C/year in Mymensingh city. In comparison with the rate of temperature increase in its suburban rural area, the rate of increase in Mymensingh city was higher indicating the existence of urban heat island in this city. In Mymensingh city, the highest (38.5 °C) temperature was found in built-up area in July and the lowest (27 °C) was found in water body in August. In Phulpur, temperature was also highest in July with the maximum of 35.8 °C and lowest in August (35 °C). Temperature was higher both in day and night in Mymensingh city compared to Phulpur rural area, signalling the urban warming phenomenon (UHI) in Mymensingh city. In Mymensingh, maximum urban heat island intensity (UHII) was 5.2 °C in July and minimum was 0.6 °C in September. UHII was higher at midnight and after that it gradually decreased. Thermo hygrometric index (THI) ranged from 28.8 °C to 32.1°C for Mymensingh city and 25.7 °C to 31.5 ° C for Phulpur rural area indicates the more comfortable condition in Phulpur rural area. The study revealed that increased imperviousness in urban area increased the urban heat island phenomena compare to its surrounding suburban rural area.

Introduction

Urban heat island (UHI) is the phenomenon of higher atmospheric and surface temperatures occurring in urban areas than in its surrounding rural areas. Land cover change (e.g., from vegetation, water body and bare soil to impervious cover such as pavement, roofs, asphalt) for infrastructure development and basic amenities (industries, vehicles etc.) in urban area is the main causes of changing air temperature because each land cover type possesses unique qualities in terms of radiation energy absorption. Materials (concrete and asphalt) commonly used in urban areas for roads, buildings which have significantly different thermal bulk properties (including heat capacity and thermal conductivity) and surface radiative properties (albedo and emissivity) than the surrounding rural areas. Dark surfaces in urban area (roads and buildings) absorb significantly more solar radiation, which causes a change in the energy budget of the urban area, often leading to higher temperatures than surrounding rural areas (Solecki *et al.,* 2005; Oke, 1982). Lack of evapotranspiration due to less vegetation in urban areas is another major reason for high temperature in urban area (Rahul *et al*., 2017). Urban heat island affects the microclimate such as temperature and eventually our health and wellbeing in different ways (Rizwan, 2008). Elevated temperatures from UHI, particularly during the summer, can affect a community's environment and quality of life. It increases energy demand for cooling in cities. Research shows that electricity demand for cooling increases 1.5–2.0% for every 0.6°C increase in air temperatures, starting from 20 to 25°C, suggesting that 5–10% of community-wide demand for electricity is used to compensate for the heat island effect (Akbari, 2005) which in turn leads to an increase in air pollutant and greenhouse gas emissions.

Mymensingh is one of the oldest and second densely populated cities in Bangladesh. The trend of urbanization is increasing here and land use pattern is changing in an unplanned manner. Since the urban area is extending day by day, the impervious surface is also increasing which creates or exacerbates UHI effect. As UHI is influenced by the unique character of each city (urbanization, population growth, vegetation covers), it

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is necessary to investigate UHI under different land covers which will help to mitigate UHI for sustainable and comfortable environment. Therefore, the present research work was conducted: to examine the presence of heat island phenomenon in Mymensingh city and to identify the contribution of different land covers for urban heat island formation.

Materials and Methods

Study areas

Mymensingh city is located in between 24°38' and 24°54' north latitudes and in between 90°11' and 90°30' east longitudes. Its total area is 91.135 square km and population is about 471,858. It is bounded by Nakla and Phulpur upazilas on the north, Trishal and Fulbaria upazilas on the south, Ishwarganj and Gauripur upazilas on the east, Muktagacha and Jamalpur sadar upazilas on the west. The climate of Mymensingh city is moderate. The temperature falls below 15 °C in winter which is spread over December and January. The highest temperature is felt during April–May period, when the temperature may be as high as 40 °C. High humidity causes heavy sweating during this period. (Banglapedia, 2015). Phulpur Upazila is located in between 24°44' and 25°02' north latitudes and in between 90°13' and 90°33' east longitudes. It is bounded by Haluaghat upazila on the north, Mymensingh sadar upazila on the south, Gauripur and Purbadhala upazilas on the east, Nakla upazila on the west. Phulpur is 39.4 km away from Mymensingh city (Banglapedia, 2015).

Site selection

Five locations were selected to measure the air temperature and relative humidity. The criteria for site selection in this study have been developed based on the typical land use pattern and characteristics of the city. 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- built up area, vegetated area, water bodies, bare soil like playground and rural areas with farmlands. *Bridge Mor,* Mymensingh sadar was selected as a built up area. This built-up area is characterized with dense population, intense transportation and commercial activity. Zainul Abedin Park was selected as vegetative area, Brahmaputra River (Beside Bangladesh Agricultural University Campus) was selected as water body and *Railway Eidgah Math* was selected as bare soil. Village Ghumgun at Phulpur upazilla was selected as rural area. Ghumgun is a completely rural area and built environment not exists there and hence this area is not categorized on the basis of land covers.

Data collection

Thermo-hygro data logger (Model: PH -1000) was used to measure air temperature and relative humidity. 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 on 18 July, 10 August and 10 September, 2017 over selected locations of Mymensingh and Phulpur. Data logger was kept at 1m above the ground in the selected locations for the measurement of instantaneous air temperature and relative humidity. The 30 years (1987 to 2016) daily air temperature and relative humidity data were collected from Bangladesh Meteorological Department (BMD).

Calculation of urban heat island (UHI)

UHI is determined as the temperature difference between an urban and its surrounding rural area. UHI is most noticeable during the summer and winter. In order to capture urban heat island of cities, yearly extreme maximum temperature or maximum summer temperatures of urban and rural areas (the single hottest day in each year) are used (Jianguo *et al.,* 2009). As UHI is characterized by increased temperature, past 30 years (1987–2016) yearly maximum summer temperature (March to June) was used to observe the presence of UHI in Mymensingh city. Measured air temperature on 18 July, 10 August and 10 September in different land usage was 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 UHI intensity. UHII is an important indicator for evaluating the severity of the urbanization of an area. This is the differences in temperature between urban and rural locations within a given time period (Fabrizi *et al.*, 2010).

Therefore, UHII = Δ T (u-r)
Where, Δ T = Temperature difference; u = Urban and r = Rural

UHII in Mymensingh city was calculated by subtracting the temperature of Mymensingh city and rural area of Phulpur.

Calculation of thermal heat index under different land covers

The thermal heat index or thermo hygrometric index (THI) is a measure of how hot it feels when relative humidity is added to actual air temperature. From this, a comfort level is calculated providing categories on how heat conditions might adversely affect someone.

Heat Index or thermo hygrometric index (THI) at each land cover was determined according to the following equation (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 (%).

Results and Discussion

Annual average air temperature and relative humidity trend of Mymensingh city

The yearly average air temperature of Mymensingh city showed an upward trend between the periods of 1987-

2016 (Fig. 1a). The average temperature was lower (24.5 ºC) in 1997 and that was higher (25.6°C) in 2014. It is seen that average air temperature increased gradually with some fluctuations from 1989 with the exception of 1997 when temperature dropped significantly. The average maximum temperature is likely to increase following a trend of 0.0094 °C/year. The increasing trend actually started during the 1989s which incidentally coincides with the beginning of the urbanization. Since 1980s, urbanization has started to expand in the Mymensingh city area (Banglapedia, 2015).

Annual average relative humidity of Mymensingh city (1987-2016) is presented in Fig. 1b. The highest average relative humidity was 83% in 1994 and the lowest was 71% in 2016. It showed the decreasing trend and it decreased 0.2331%/year over the last 30 years (1987-2016). The causes of increased temperature may be many folds including urbanization, vegetation cover change, increased vehicle emission etc. It is observed that in Mymensingh city, a major part of the agricultural land has converted to residential zones. According to Urban Development Directorate (UDD), 35% of the total land is occupied by residential areas whereas agricultural land covers only 13% in 2014. The concentration of commercial zone is more along the central bazaar zone and the percentages increase to 2% of land. Different administrative land-uses are observed throughout the town. Patches of commercial developments are observed along the main street. In addition, over the last few years, the traffic jam is getting severe at different intersections especially at the *Bridge Mor*, Ganginarpar, Charpara intersections as the number of easy bikes ballooned in an uncontrolled way. Severe traffic jam is observed at the intersection all over the day except the early morning. It causes serious air pollution and thus worsens the overall environmental condition.

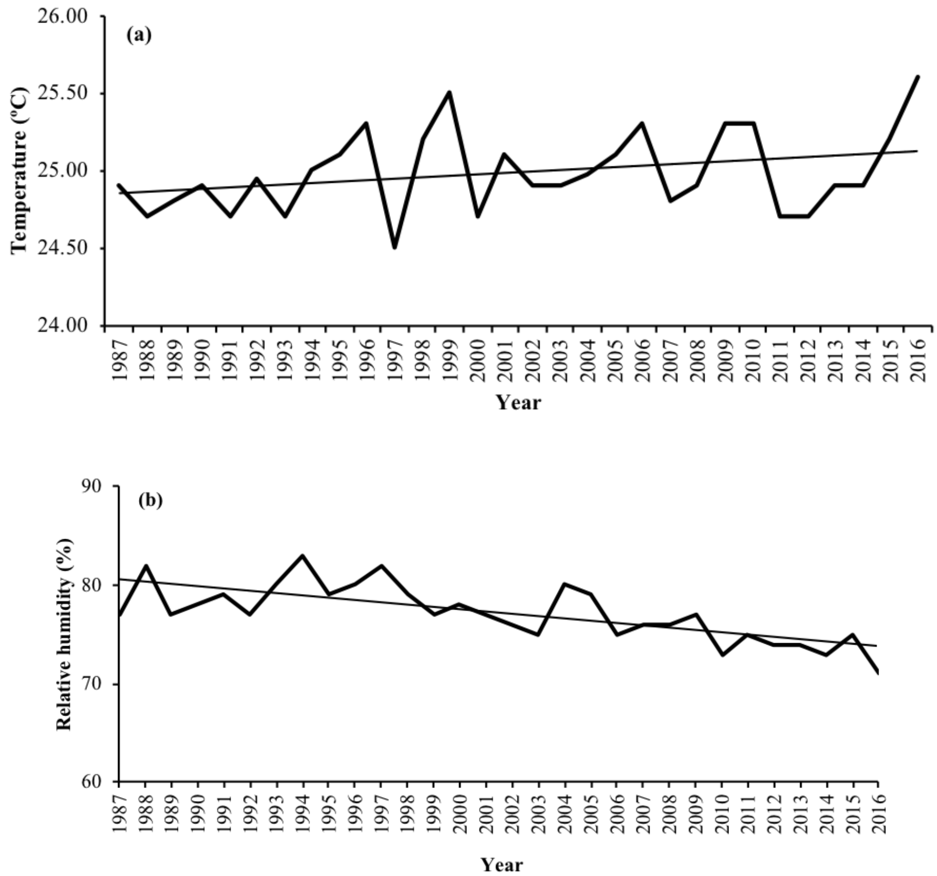

Fig. 1. Annual average (a) Air temperature and (b) Relative humidity trend of Mymensingh city

Diurnal variation in air temperature and relative humidity under different land covers in Mymensingh city

Diurnal variation in air temperature under different land covers during measurement periods (July, August and September) is presented in Fig. 2. The highest temperature was found in built-up area and it was 38.5 °C for July, 38.1 °C for August and 37.9 °C for September. The lowest was found in water body and values were 27.5 °C for July, 27.2 °C for August and 27 °C for September (Fig. 2). Temperature in built-up area was progressively increased from morning and reached at the peak value at midday, after that it started to decrease and a few hours later it increased again, remained high throughout the night hours until predawn hours when levels begin to fall. On the other hand, temperature in other three land covers (vegetated area, water body and bare soil) was high during the day and after sunset it dropped significantly and gradually decreased. It might be happened due to different absorption and re- radiation rate of incoming solar radiation by different land covers. Built surfaces trap incoming solar radiation during the day and then re-radiate it at night as heat. But vegetation and water body exhibit very little thermal response during night time. According to Young (2012), solar energy reaches the earth as short-wave radiation during the day, part of this solar energy is absorbed by the earth's surface and building envelopes. Heat energy absorbed by building during day is released as long wave radiation to the atmosphere at night in built-up area. Hung *et al.* (2006) studied the urban heat island effects in Asian mega cities. They reported that for the tropical city of Bangkok, the diurnal variation in surface temperature was largest in dense built-up area, followed by water body, open spaces and lowest was found in perennial orchard.

Relative humidity was the highest in vegetative area, while built-up area had the lowest relative humidity for all of the three months (Fig. 3). RH was maximum in September and minimum in July for all of the land cover. The maximum value of RH in vegetative area was 91 % in September and the minimum RH in built-up area was 52 % in July. From the Fig. 3, it is found that for all land covers, highest RH value was at morning and the lowest value was at noon. It is also found that RH in built-up area decreased gradually from morning and that was lowest at 03:00 pm, after that it started to increase and after 09:00 pm it again started to decrease. On the other hand, RH of other three land covers (vegetated, water body and bare soil) decreased gradually from morning and that was lowest at 03:00 pm, after that it gradually increased. Incoming solar radiation remains higher at noon which decreases the moisture content of atmosphere in built environment. Vegetation and water body contain huge moisture especially at morning and night, thus during this two times (morning and night), RH was higher than noon in vegetated, water body and bare soil.

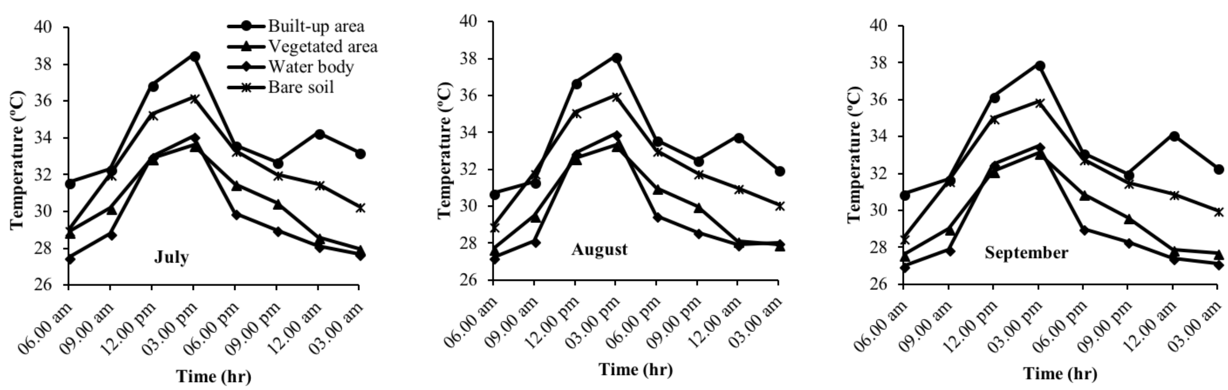

Fig. 2. Diurnal variation in air temperature under different land covers of Mymensingh city

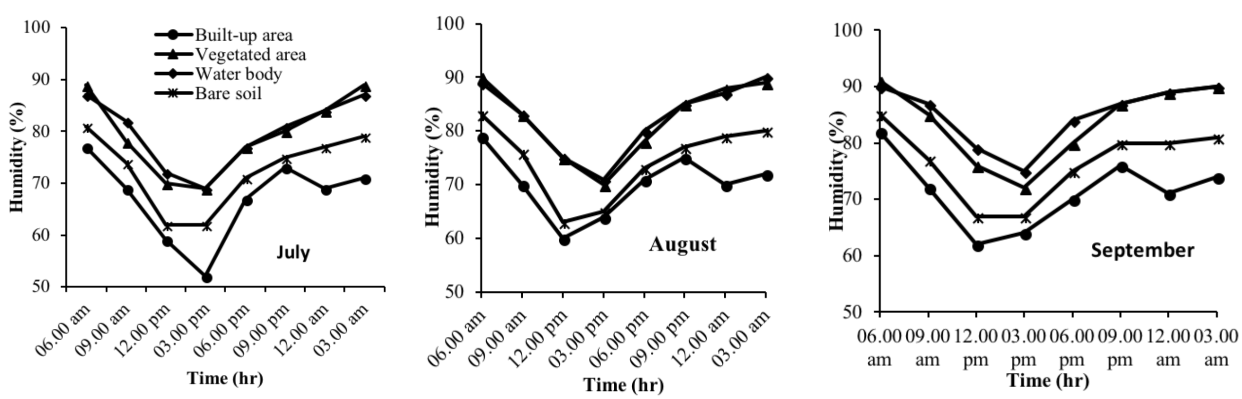

Fig. 3. Diurnal variation in relative humidity under different land covers of Mymensingh city

Diurnal variation in air temperature and relative humidity of Phulpur

Fig. 4a represents the three hours interval of air temperature in the three consecutive months (July, August and September) for Phulpur rural area. Air temperatures were high in July (maximum 35.8 °C) and low in August (maximum 35°C). Temperature was lowest at morning, it gradually increased with time, peaked at 03:00 pm and after that it gradually decreased for all of the month. Temperature of Phulpur rural area was quite low compared to the values of Mymensingh city. This is because there are many trees, rare built surface, and low density of population in this village. Land with green cover tends to lose heat quicker via evapotranspiration.

Heat dissipates through the evaporation of the water vapor and cools the surrounding environment. According to Young (2012), leaves and branches of trees and vegetation shade the areas below them by reducing the amount of solar radiation that is transmitted through their canopy. Shading greatly reduces the temperatures of underneath tree and vegetation cover. Diurnal variation in relative humidity (RH) of Phulpur rural area for three consecutive months (July, August and September) is presented in Figure 4b. Among three months, RH was maximum in August and minimum in July. For July, maximum RH was 87% and minimum RH was 63%. In August maximum RH was 93% and minimum RH was 69% and in September maximum RH was 90% and minimum RH was 65%. All of the maximum and minimum RH values were found at early morning and noon, respectively.

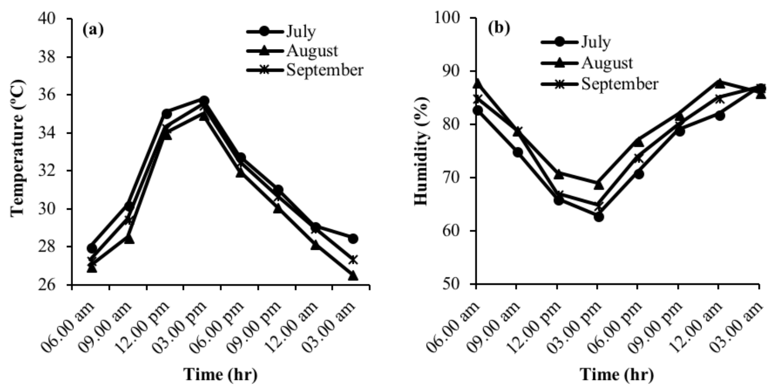

Fig. 4. Diurnal variation in (a) air temperature and (b) relative humidity of Phulpur rural area

Urban heat island effect in Mymensingh

Three days air temperature data of Mymensingh city (urban area) and Phulpur (rural area) for the month of July, August and September are presented in Fig. 5. Temperature was higher both in day and night in Mymensingh compared to Phulpur indicating the warming phenomenon (UHI) in Mymensingh city. Phulpur experienced extensive heat conditions during the day, but cooled off at night for all of the three months. It might be happened because rural landscapes have low impervious surface cover. Vegetation and plants through evapotranspiration create cooler surrounding environments. The difference in thermal properties and canyon geometry of urban and rural areas may result in a difference in the heat releasing process contributing to the urban heat island effect. According to Quattrochi *et al.* (2000), heat islands develop in areas that contain a high percentage of non-reflective (such as stone, concrete and asphalt), water-resistant surfaces and a low percentage of vegetated and moisture trapping surfaces. Young (2012) studied urban heat island (UHI) effect in the Puget Sound region and reported that there is an observed urban heat island when comparing the downtown area to the light residential areas of the city. Trees and vegetation are able to moderate urban heat island conditions through shading, evapotranspiration and wind shielding process.

Urban heat island intensity (UHII) in Mymensingh

Fig. 6 represents UHII of Mymensingh for the month of July, August and September. In July, maximum UHII was 5.2 °C and minimum was 0.8 °C. In August, maximum UHII was 5.6°C and minimum was 1.6 °C. In September, maximum UHII was 5.1 °C and minimum was 0.6 °C. All of these maximum UHII were found during night and minimum UHII were found in day time. From the result, it is found that UHII was progressively decreased from morning and at evening it was the lowest. After sunset it started to increase, at midnight it was highest and was remained high through the night until predawn hours. This is because during the morning, the urban surface is getting warm.

On the other hand, natural rural surface remain cool during the morning. Besides this, artificial surface in urban area absorbs more solar radiation than natural surface in rural area and re-radiates it at night. During the night natural rural surface gradually becomes cool and thus enhances the temperature differences between urban and rural areas. Asimakopoulos *et al.* (2001) studied energy and climate in the urban built environment and reported that the heat that is absorbed during the day by the buildings, roads and other constructions in an urban area is reemitted after sunset, creating high temperature differences between urban and rural areas at night. Wong and Yu (2005) studied urban heat island in a tropical city and reported that a maximum (4°C) UHII was found between the well planted green areas and the most built-up region of central business district in Singapore.

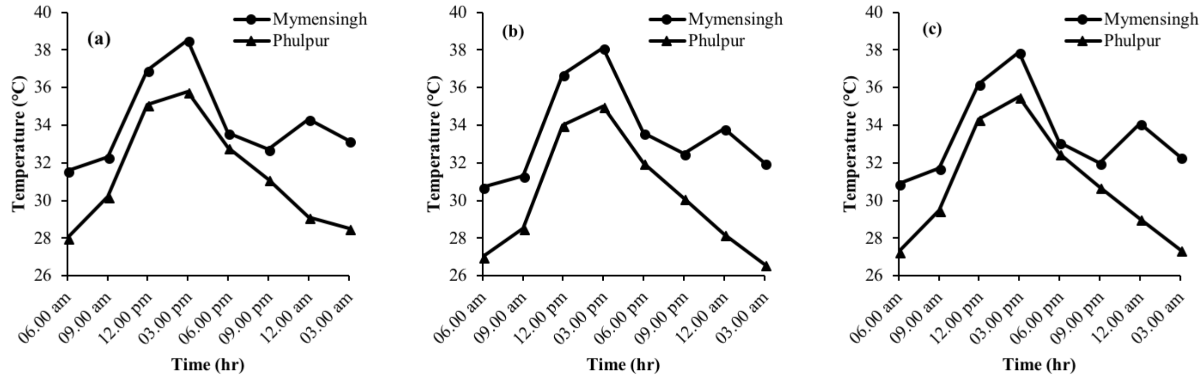

Fig. 5. Urban heat island effect in Mymensingh for the month of (a) July, (b) August and (c) September

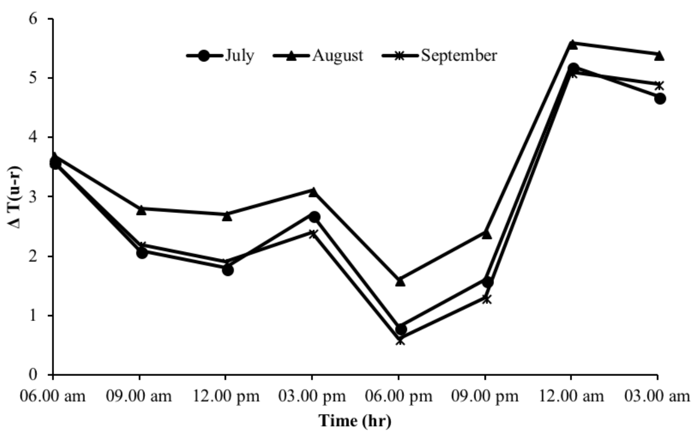

Fig. 6. Urban heat island intensity in Mymensingh

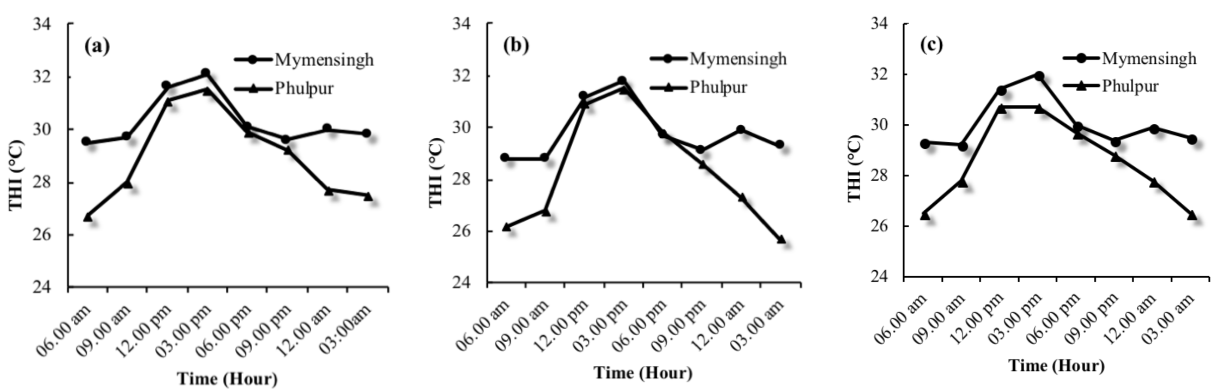

Fig. 7. Thermal heat index (THI) of Mymensingh and Phulpur for the month of (a) July, (b) August and (c) September

Heat stress condition (THI) in Mymensingh and Phulpur

The calculated THI values at Mymensingh and Phulpur for the month of July, August and September are presented in Fig. 7. From these figure, it is found that THI values for urban area were always higher compared to rural areas for all of the three months. In Mymensingh, very hot (+26.5 to +29.9°C) and torrid (≥+30°C) conditions were predominant throughout day and night for all of the months. The month of August recorded the lowest frequency of very hot and torrid conditions, while July recorded the highest frequency of very hot and torrid conditions both in Mymensingh and Phulpur. The majority of THI values both in Mymensingh and Phulpur were classified as torrid from12:00 pm to 06:00 pm. The situation was different at night and morning hours (9:00 pm-9:00 am), where a large percentage of the THI values were under the hot condition both in Mymensingh and Phulpur. About 4 h after sunset, the THI in Mymensingh increased, while in Phulpur it gradually decreased till early morning and comfortable category were detected for all of the months. Due to huge open spaces and vegetation, Phulpur cool down quickly after sunset. On the other hand, due to the thermal mass of the asphalt and concrete surface, much of the absorbed solar radiation stored in the material and released after sunset which improves thermal discomfort conditions at night. Ahmed *et al.* (2010) studied comparisons of urban and rural heat stress conditions in a hot humid tropical city. They stated that hot conditions were predominant at both sites, comfortable conditions were only experienced in the morning and evening at both sites, but the rural area has more pleasant. The higher frequencies of high temperatures in the city center suggest a significant heat stress and health risk in hot humid environment of that area.

Conclusion

The study of the heat island phenomenon indicated the changes of urban temperature (increasing) over the last three decades. In addition, study on the urban heat island formation under different land covers (built-up area, vegetated area, water body and bare soil) confirm their frightful contribution in UHI effect while built-up area exhibited the highest UHI effect. Replacing the natural vegetation with buildings and roads raises the summertime cooling demands of buildings which lead to higher emissions from power plants, as well as increase smog formation as a result of warmer temperatures. Planting of trees and use of high albedo urban surfaces could be the effective measures to reduce urban heat island effects by shading building surfaces, deflecting radiation from the sun, and releasing moisture into the atmosphere. Proper care in designing urban landscape, implementation of environmental laws and policies, regular monitoring and mass awareness should be ensured for a comfortable urban environment.

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