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Summertime Urban Heat Island study for Guwahati City, India

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ABSTRACT

Summertime Urban Heat Island (UHI) effect in Guwahati, a small but rapidly growing city of India, is studied, by using half hourly temperature data measured at four fixed observation sites – two in the urban core and the others at the periphery, away from the city. The in situ measurements were conducted using stationary loggers from the months of May to October 2009 to study the temporal variation. Also, mobile measurements were carried out during the months of June, July and August 2013 to bring out the intra-city temperature variation. The results show existence of UHI above 2 °C. The highest magnitude of daytime Urban Heat Island Intensity (UHII) for the entire period of study was found to be 2.12 °C while highest nighttime UHII was 2.29 °C. Diurnal ranges of temperature (DTR) showed wide variation in each of months included in this study. Higher DTR were experienced in the month of May for all the stations – rural as well as the urban. As the summer progressed, the DTR showed declining trend through the months of June to August and started rising again in September showing the influence of monsoon in air temperature regime. Variation in the average monthly DTR within the season is low in urban stations compared to rural ones. The temperature difference, recorded in the mobile runs, between the urban pockets and the suburban areas, ranged from 1.23 to 0.78 °C.

1. Introduction

Urban Heat Island (UHI) is a phenomenon where surface and atmospheric modifications due to urbanization generally lead to modified thermal climate that is warmer than the surrounding non-urbanized areas (Voogt & Oke, 2003). The UHI effect has been extensively studied for several cities of the world like London (Kolokotrani & Giridharan, 2008), Osaka (Huanga, Taniguchib, Yamanoc, & Wangd, 2009), Johannesburg (Tyson, Toit, & Fuggle, 1972), Hongkong (Giridharan, Ganesan, & Lau, 2004), Nanjing (Huang, Li, Zhao, & Zhu, 2008; Zeng, Qiu, Gu, He, & Wang, 2009), Singapore (Jusuf, Wong, Hagen, Anggoro, & Hong, 2007; Wong et al., 2007), etc. Long-term temperature record have revealed that the influence of urbanization on thermal environment is not only confined to large cities but also have been detected in cities with population less than 10,000 (Karl, Diaz, & Kulka, 1988). India, being a growing economy, has undergone rapid urbanization in the last few decades. The phenomenon of UHI which is associated with urbanization has not drawn much attention of the scientific fraternity within the Indian subcontinent. Only a few studies have come up over a large span of time (Deosthali, 2000; Emmanuel, 2000, 2005; Sundersingh, 1990/91). Reduction in land area, in terms of total area available for residential purposes, coupled with projected doubling of the global urban population by 2030 and resultant increase in the levels of air pollution, call for greater attention to this field in order that effective strategies for managing microclimate in the cities can be devised. Studies in the field of UHI also become imperative due its effect on energy demand, human health and environmental conditions related to pollution dispersion (Crutzen, 2004; Harlan, Brazel, Prasad, Stefanov, & Larsen, 2006).

Guwahati (26°10′ N, 92°49′ E) is the largest city in the state of Assam, India. The urban area is around 262 km^2 and has a population of about 12 lakh (Census of India, 2011). It has a starfish like urban form with a core in the central areas and tentacles extending in the form of growth corridors towards south, east and west. River Brahmaputra intersects the Guwahati into two parts with southern part comprising the urbanized core and extensions, while the northern part representing the rural areas. The general climate of the city as well as the entire region is of warm humid type. Being the gateway to the entire northeastern region of the country, the city has undergone rapid urbanizational changes in the past decade. There has been considerable increase in the density of the population in the past and is projected to grow up to 21.74 lakh by 2025 (GMDA, 2009). Rapid population growth has pushed the expansion of the urban areas in the southern Guwahati into the suburban extents. Most of these expansions are unplanned. Replacement of natural vegetated areas with dry impervious surfaces, use of building materials having high heat capacity and low surface reflectivity and increased anthropogenic heat emission into the urban atmosphere are likely to modify the thermal regime of this city.

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So far no study analyzing the thermal environment of Guwahati city using actual ground data has been reported. Therefore, this study has been undertaken with the main objective of studying the UHI of Urban Canopy Layer (UCL) of Guwahati city.

2. Material and methods

Three methods are usually employed to measure UHII; urban–rural difference method, city traverse method or remote sensing (Goldreich, 1995). Though comparison between the urban and the rural climates is the most common approach towards analyzing UHI effect, researchers have also studied the phenomenon based on the comparative temperature measurements of vegetated and non-vegetated surfaces (Wong & Yu, 2005; Wong et al., 2007).

Most of the works in this field make use of either in-depth field measurements (Wong & Yu, 2005; Wong et al., 2007) or meso-scale measurements with the help of remote-sensing satellites (Chen, Zhao, Li, & Yin, 2006; Streutke, 2005). The results are generally expressed in terms of Urban Heat Island Intensity (UHII), which, in turn, has also established itself as an important indicator for evaluating the severity of the urbanization of an area (Memon, Lung, & Chunho, 2008).

In this study, the summertime UHI of Guwahati City is analyzed using half hourly temperature and humidity data measured at four fixed stations. HOBO Pro V2 Temperature and RH data loggers were used for the purpose. The data loggers have temperature measuring range of −40 to 70 °C with an accuracy of ±0.21 °C from 0 to 50 °C. The humidity measurement range is from 0 to 100% RH with accuracy of ±2.5% from 10% to 90% RH. This instrument is used because of its weatherproof housing for outdoor usage or condensing environments and highly accurate temperature and RH sensors.

The data loggers were stationed at the height of 1.5 m and covered with hollow wooden cuboids to avoid direct sunlight. The sites for data logger stations were selected in such a manner that they could give faithful representations of both urban and rural surroundings. Local knowledge of the area as well as the settlement pattern of the city based on satellite imagery was used for locating the observation sites. Bhangagarh and Ganeshguri areas are situated in highly urbanized G.S. Road corridor in the southern part of Guwahati. The G.S. Road corridor is an important commercial area with retail, wholesale and offices developed along the main road, and it is also a densely built residential area in the inner parts. North-Guwahati on the other hand represents rural areas of Guwahati with proximity to water body due to its location in the north bank of Brahmaputra. Basistha, with abundant vegetation and considerable distance from Brahmaputra represents rural area from another perspective. The temperature and humidity readings from Bhangagarh and Ganeshguri areas are averaged for having a true representation of an urban area (URB) while North-Guwahati (RUL1) and Basistha (RUL2) are selected for representing the rural surrounding with proximity and remoteness to a larger water body respectively (Figs. 1 and 2). In situ field measurements were conducted for 170 days from 1 May to 17 October 2009. The mobile measurements which were carried out, in the months of June, July and August to analyze the intra-urban air temperature variation, were conducted by mounting the temperature–humidity sensor over a vehicle and running the same at a constant speed. The experiments were conducted during nights between 1.00 and 3.30 AM.

3. Results and discussion

3.1. Urban Heat Island

Temperature differences were taken into account for finding the Urban Heat Island Intensity. Half hourly data recording between 6.00 h and 17.59 h was considered for daytime temperature and

Fig. 1. Google image showing the study area.

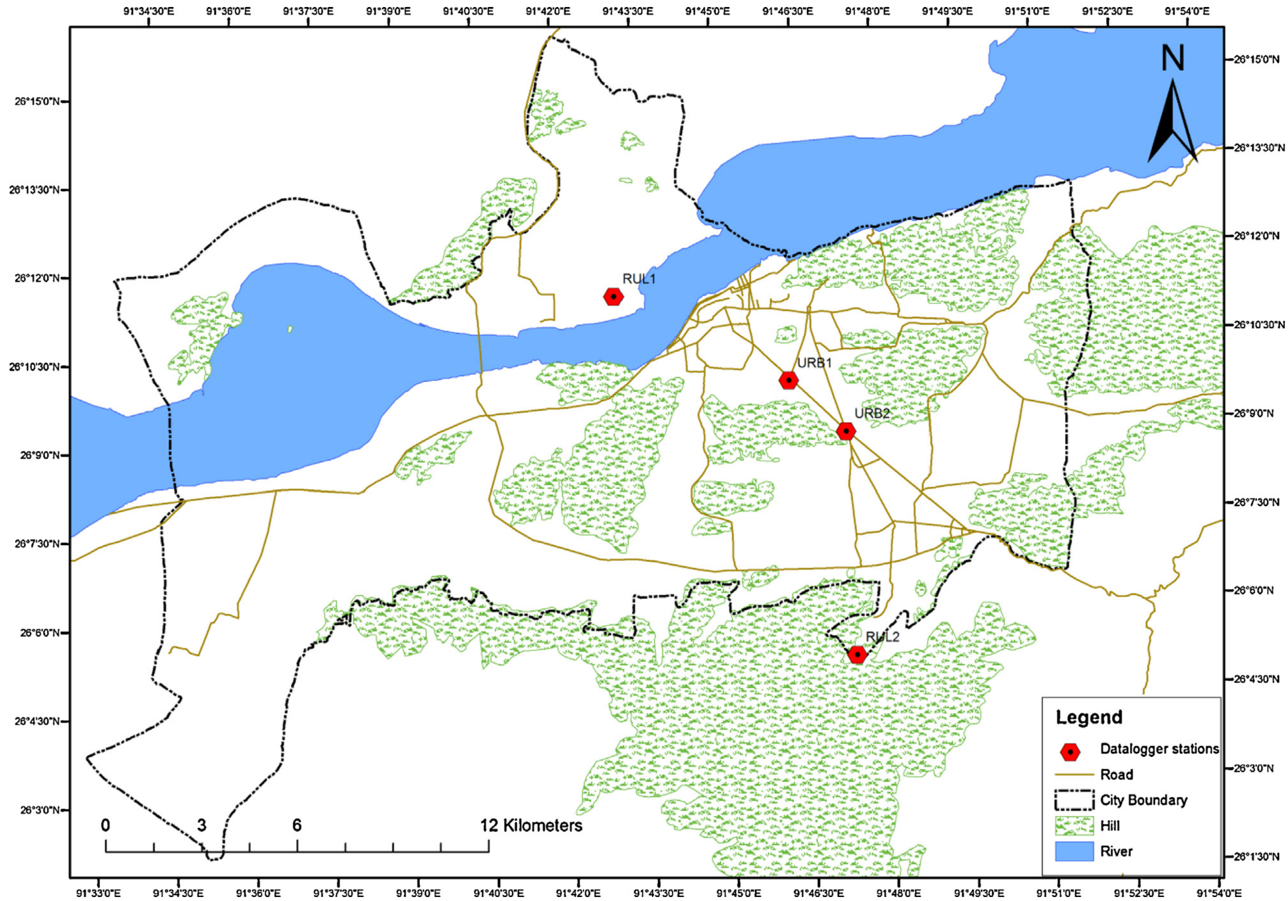

Fig. 2. Map showing data-logger stations.

humidity values while same between 18.00 h and 5.59 h was considered for nighttime.

The results show existence of UHII above 2 °C for daytime as well as nighttime. The highest magnitude of daytime Urban Heat Island Intensity (UHII) for the entire period of study was found to be 2.12 °C while highest nighttime UHII was 2.29 °C. It is found that the formation of daytime UHII of ≥1.5 °C are fairly common (Table 1). Instances of daytime UHII of ≥1.5 °C showed seasonal variation with more frequent formation in the later part of the summer season (Fig. 3).

UHII between URB and RUL1, reprensented under UHII1, were frequent during July, August, September and Octber; not so in May and June. Similalry, daytime UHII of magnitude ≥1.5 °C between URB and RUL2, reprensented under UHII2, were most frequent in the months of August, Septemebr and October; low for the months of May and June, and was absent in July. In terms of magnitude too, highest values were recoded in the months of August and September. The highest daytime UHII of 2.12 °C for the first pair (UHII1) was recorded on 25th August, i.e. 237 Year Day (YD); and for the second pair (UHII2), 2.11 °C, was recoded during 4th September, i.e. 248 YD. In case of nighttime UHII, this seasonal trend, compared to daytime UHII, is reversed (Fig. 4). UHI events with a UHII of ≥1.5 °C, for both the pairs were most frequent during the month of May. While for the part of summer comprising of the months of June, July and August, the nighttime UHII of 1.5 °C and above were less frequent. In terms of magnitude, the highest nighttime UHII was 1.77 °C on 128 YD (8th May) for the first pair (UHII1) and was 2.29 °C on 143 YD (23rd May) for the second pair (UHII2). August and October recorded absence of nighttime UHII of 1.5 °C and above for both the pairs. This pattern of seasonal variation in formation of UHII is mainly due to variation is cloud cover conditions and humdity brought about by monsson that sets on in the month of June in this region.

Table 1
UHI events with UHII ≥1.5 °C.

Month	Daytime		Nighttime	
	UHII1	UHII2	UHII1	UHII2
May	2	1	8	8
June	2	1	0	2
July	6	0	0	1
August	6	5	0	0
September	5	11	1	3
October	5	8	0	0

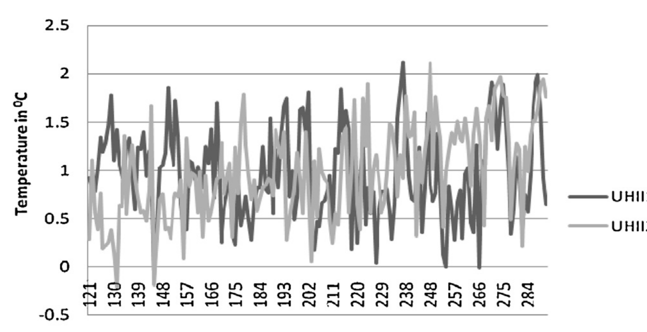

Fig. 3. Daytime UHII during May to October, 2009 in Guwahati city.

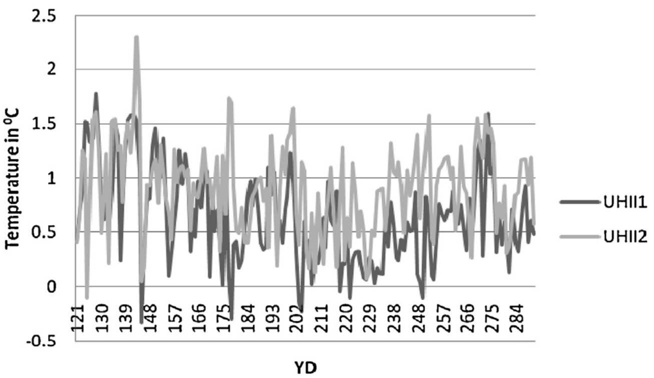

Fig. 4. Nighttime UHII during May to October, 2009 in Guwahati city.

It was also observed that the first pair showed higher frequency of occurrence of daytime UHI events, while the second pair showed higher instances of nighttime UHI events, with intensity $\geq$1.5 °C. This along with the varitions in UHII between first (UHII1) and second pair (UHII2) shows the influence of physiography on temperature pattern. It may be recallled that the two rural stations are located in areas that are distinctively different in terms of physiography. North Guwahati (RUL1) is located in proxitmity to Brahmaputra while Basistha (RUL2) is located at the foothills of Meghalaya with green surface cover conditions.

Relative humidity is negatively correlated with temperature. With the increase of temperature relative humdity decreases without any chage in actual amount. Corresponding differences in relative humidity for the observed UHII values between the urban and the rural stations were compared against the UHII values. High relative humidity difference was observed in the month of July and August which corresponds to the higher frequencies of larger UHIIs. Expectedly, it is found that during large UHI event, humidity difference between both the stations grew consistantly, reached the peak during the day of highest UHII and then slowly declined. To see this corresponding differences in relative humidity for the observed UHII for Guwhati during the studied months in quantitave terms, the pearson coefficient of correlation between the UHIIs and the relative humidity differences were computed. The values ($r = -0.896$ and $r = -0.807$ for day and night respectively for first pair; $r = -0.830$ and $r = -0.696$ for day and night respectively for second pair; all these values are significant at 0.01 level) show strong negative correlations.

Table 2
Monthly average DTR during May to September, 2009 in Guwahati city.

Months	Average DTR (in °C)		
	Urban	Rural 1	Rural 2
May	7.88	7.97	8.36
June	7.21	6.61	6.76
July	6.54	5.77	5.90
August	6.20	5.21	5.35
September	7.90	6.95	6.95

3.2. Diurnal temperature range and UHII

Diurnal range of temperature was also considered for assessing the thermal regime of the city and the adjoining suburban locations. The results show large daily fluctuations in DTR for all the months, for all the stations. The monthly averages of DTR for the typical summer months, which were computed to see the seasonal trend, are presented in Table 2.

It shows a trend where these values were largest for the month of May for all the stations; thereafter, as the summer progressed, the monthly averages of DTR went on decline through the months of June to August and started rising again in September; showing the influence of monsoon in Guwahati's air temperature regime. The city of Guwahati is located in the meteorological subdivision where

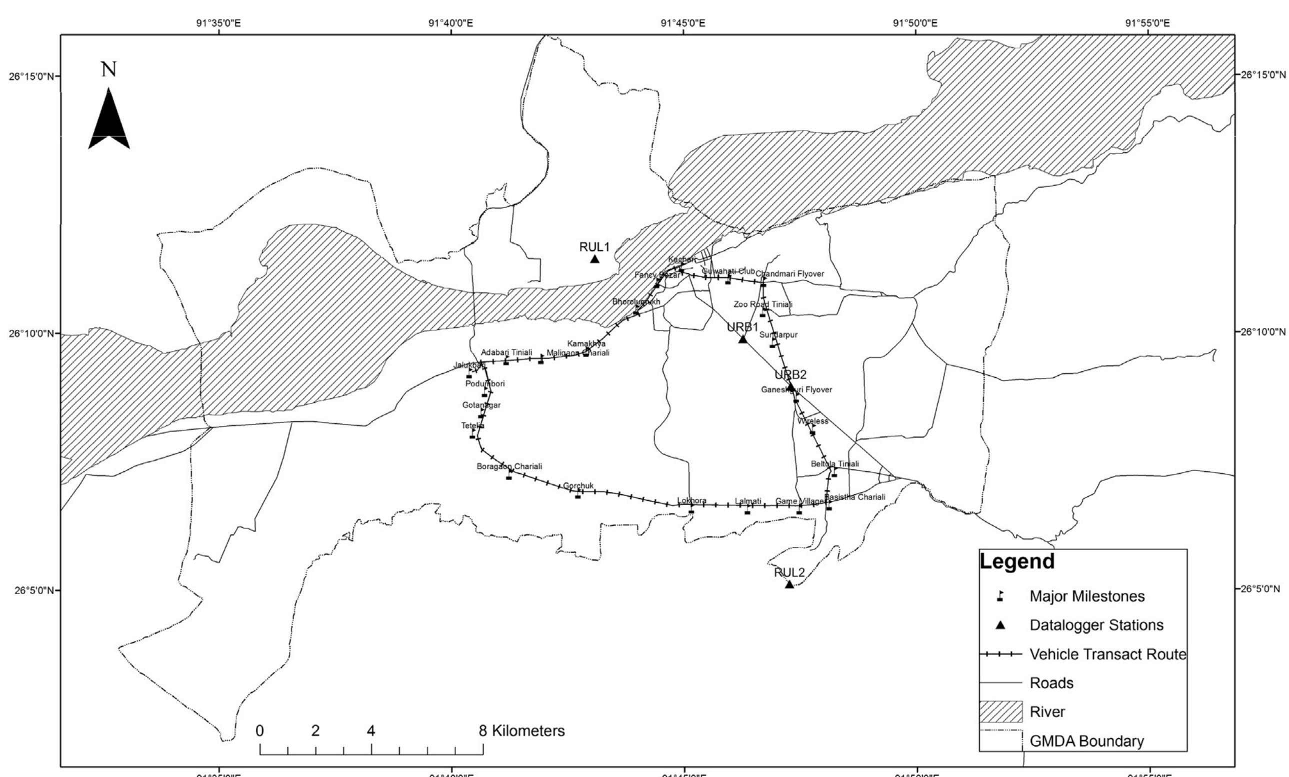

Fig. 5. Moblie transact route in Guwahati city.

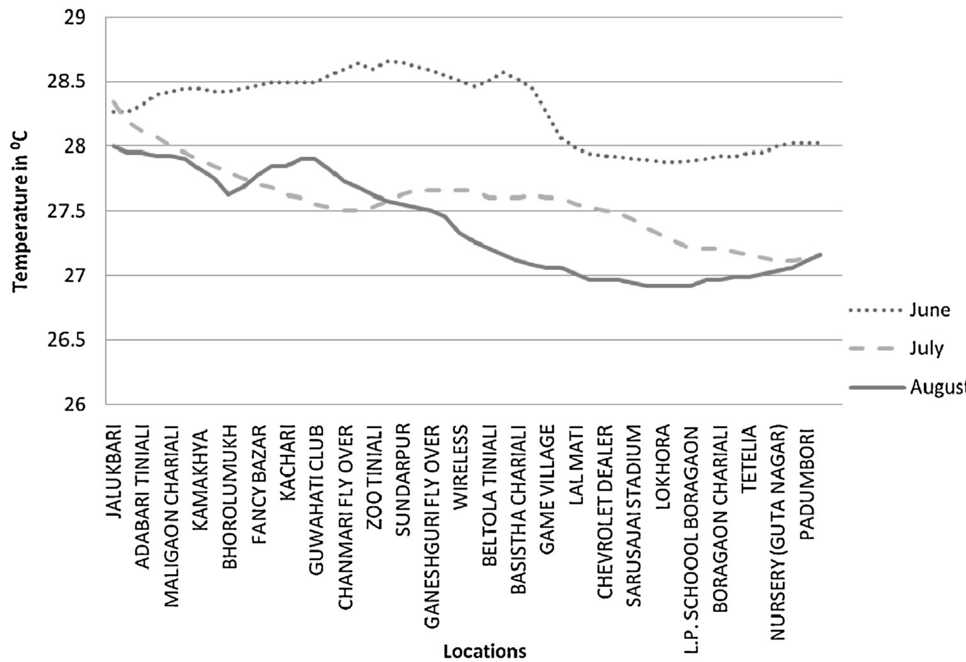

Fig. 6. Spatial temperature pattern for Guwahati during the transact run on 23 June, 25 July and 30 August, 2013.

the monsoon normally sets on in the first week of June, bringing the diurnal range of temperature down.

When compared amongst the stations to see the spatial variation in the DTR, interestingly, it is found that the monthly average DTR, except for the month of May, is higher for the urban stations. In order to explain this observation, the mean of daily maximum and minimum temperature for each month for all the stations were plotted together. It reveals that the higher monthly average DTR recoded in urban station is due to larger difference in day maximum temperature between urban and rural areas than difference in minimum temperatures. The mean of daily minimum temperature for each month are more or less uniform for all the stations, while the maximum temperature is higher for urban locations.

3.3. Spatial pattern of nighttime temperature profile through mobile measurement

On account of its ability to render high spatial resolution, the technique of mobile measurements was adopted for studying the spatial pattern of nighttime temperature profile within Guwahati. The city contains variations in the density of settlement and landuse according to the degree of development. The mobile measurements were planned on a route that covers the overall city and shows a gradient from dense urban structures as well as suburban and rural areas. Because of its unique urban form, a route consisting both peripheral and traverse approach was adopted (Fig. 5). The nighttime temperature and humidity data for a single day for the three months from June to August, 2013, was recorded with a frequency of one minute at a height of 1.5 m from ground level.

The mobile measurment were carried using data-logger mounted vehicle which was run between 1.00 and 3.30 AM at a constant speed of 40 km per hour on 23 June, 25 July and 30 August, 2013 on a route that encompass major portion of the city.

Overall, it was found that the temperature of the city, while moving from Jalukbari, at first, deceases in the settlements pockets along the river Brahmaputra and then increases as one move towards the congested urban core (Fig. 6). After entering the urban agglomeration of Chandmari upto Zoo area, representing continuous urban pockets, the temperature continued to remain relatively high. It showed a falling trend through the suburban areas comprising Lokhora, Gorchuk and Boragaon area. However, after Boragaon, while approaching the newly urbanized Jalukbari, the temperature start rising again, though less in magnitude.

The temperature difference, recorded in the mobile runs, between the urban pockets, ranged from 1.23 to 0.78 °C. However, the same study undertaken, with the same procedure and same route, during the winter months when the overall temperature is very low, yielded larger temperature difference between the urban pockets and the suburban areas.

During the transact run in June, it was found that the highest temperature of 28.66 °C was localized in the G.S. Road Corridor representing the City proper. The lowest temperature of 27.88 °C was recorded in the suburban Gorchuk area. For the months of July and August however, Jalukbari, the growing urban pocket, recorded highest temperature, while the lowest temperature was recorded in the suburban Gutanagar-Gorchuk area.

4. Conclusions

This study quantifies the Urban Heat Island effect, for Guwahati city by means of measuring Urban Heat Island Intensity of the Urban Canopy Layer (UCL). The results proved the existence of summertime Urban Heat Island Intensity above 2 °C even in a relatively small city like Guwahati. With incremental decrease in green cover associated with urbanization, the phenomenon of UHI is likely to express itself in a more perceivable manner in the days to come. Increase in air temperature in a city like Guwahati, where humidity conditions are high, especially during summer, would mean substantially higher level of discomfort for dwellers. This is an important aspect that urban planners need to take into account while planning for further development of the city. Thus, there is scope for future resaerch in this area to identify and address long term negative effects of developmental activities on human health and environment.

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