Study of Summer-Time Intra Urban Heat Island Intensity in Residential areas of Nagpur

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Rapid urbanization of recent times has brought many climatological changes in cities around the world, a major one being a rise in temperature. The phenomenon, wherein air temperature in urban areas is found to be higher than surrounding open-spaces and rural areas is called urban heat island effect. This rise in temperature, which can be attributed directly to urban development, directly affects comfort level and quality of life of residents of the area. Central Indian city of Nagpur is no exception to this phenomenon. This paper discusses findings of study undertaken to determine the Intra urban heat Island intensity in residential areas of city of Nagpur. The study involved taking measurements of ambient air temperature at canopy level in 4 residential areas of city, and analyzing the same in context of variation in percentage of land-use, percentage of built-up area and vegetation cover. Statistical Analysis of temperature data indicates that there is a significant difference in the average summer temperature of different localities in various time slots. It is also observed that there is a strong correlation between ambient air temperature and percentage of built up area as well as vegetation cover.

Keywords: Urban heat island, percentage of built up area, vegetation cover, urban air temperature, Land use.

INTRODUCTION

Urbanization brings many changes in cities, one important thing being formation of urban climate – i.e. climatic conditions that differ from neighboring rural areas and can be attributed directly to urban development (Rose et.al, 2008). An increased rate of urbanization also results in high growth rate of vehicular population, residential and commercial complexes and industries. This causes significant changes in land use land cover (LULC) pattern and significant increase in anthropogenic heat emission (Mohan et.al, 2012). In most of the cities, the natural landscapes are changing very fast and being replaced by structures at the cost of open-spaces and vegetation. The built up and paved surfaces act as obstacles for proper dissipation of heat energy to the surrounding environment on account of their higher heat absorption and retention capacities. Because of this, air temperature in urban areas is observed to be more than that in surrounding open areas. This is referred to an Urban Heat Island (UHI) effect, a distinct feature of urban climate.

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Major causes that lead to formation of UHI include reduced vegetation in the urban areas, heat absorbing properties of materials used in urban setup, heat trapped by urban geometry, and anthropogenic heat in the form of heat emitted by air conditioners, engines of vehicles, etc (Lisa gartland, 2008). These causes differ from city to city, and also as per the season and time of the day.

The understanding of alterations to urban climate has been described by Oke (1976) using the concept of urban atmosphere as one having two distinct layers - urban boundary layer and urban canopy layer. The Urban Boundary Layer (UBL) is overall atmospheric system that extends for many kilometers above the cities and whose characteristics are partially determined by the city below. On other hand, the Urban Canopy Layer (UCL) or urban canopy is layer of atmosphere where most life occurs - i.e. from the ground level up to mean height of roofs, where incoming solar radiations are gradually absorbed and specific conditions of air temperature and humidity may exist, which are different from those prevailing in the surrounding space.

This paper focuses on study of Intra urban heat Island intensity in residential areas of central Indian city of Nagpur by measuring ambient air temperature at canopy level and discusses the same in the context of variation in percentage of land-use, percentage of Built-up area and vegetation cover.

Climatic effects of urbanization are strongly felt in the urban canopy. Oke (1976) stresses that the urban canopy is a micro-scale concept i.e. the specific climatic condition within the canopy is the result of its immediate surroundings such as land-use, land-cover, building materials, geometry, percentage of vegetation, color of the buildings etc. and any changes in these parameters can modify the local ambient climate. Thus, meteorological condition within the urban canopy is very much localized. Due to varying height of buildings, upper boundary of urban canopy often varies from one location to other. Even human comfort and energy use of buildings are affected by the local climatic conditions within the urban canopy.

STUDY AREA

Nagpur (Figure 1 and Figure 2) is one of the best-known cities of central India located in state of Maharashtra. It acquired historical importance from 18th century after its founder Gond King BakhtBuland Shah made it Capital of his kingdom. Nagpur originated in the eastern part known as Mahal and later spread to now south central part of Sitabuldi. Mahal is the traditional city centre of Nagpur and is of historical importance. This part of the town grew organically in the beginning (Godbole S, 1999).

The present scenario of Nagpur city indicates that it is developing in all directions. The urban pattern of Nagpur reveals its transformation from an old congested city form to one with planned development.

Topography of Nagpur

Nagpur is situated in a west plateau formed in the Western slopes of Satpura ranges. Being a plateau, a large area of district is a rocky terrain, with a part of it
under dense forest cover. Land on the northeast, east and southeast is a vast plain. This region can be split into 2 zones - Metamorphic land on the eastern side and Rocky terrain on the western side (Godbole S, 1999).

**Climate of Nagpur**

Nagpur witnesses a very hot and dry summer from March to May. Well distributed rainfall occurs during the southwest monsoon from June to September, while period from October to November is the post monsoon season. Winter is cool and dry from December to February. During Summer, temperature ranges from minimum 29º C to maximum 47º C and in Winter it ranges from minimum of 10º C to maximum of 30º C. Average rainfall is about 45inches (1150 mm). Relative Humidity is about 90% during monsoons and around 20% in the summer. Winds are generally light to moderate, with some increase in the speed in the later part of the Summer season and the Monsoons. (Source: Indian Meteorological Department Regional Center at Nagpur Airport). Although Nagpur is in the composite zone, the climate is somewhat warmer than other northern cities, mainly because of the rocky terrain that surrounds the city (Katpatal et al., 2008).

**RESEARCH METHODOLOGY**

Earlier studies have indicated that the land use land cover (LULC) pattern has most significant influence on urban microclimate (Givoni, 1989; L.W.A. Vanhove, 2015; Eliasson, 2000; Roth, 2013). Based on spatial organization of city, it was therefore decided to consider Land use Land cover as the main variable influencing the urban climate in city. In the present research, fixed point monitoring stations were located in study areas for recording ambient air temperature. The data collected during summer season was then statistically analyzed to understand contribution of different parameters in UHI of Canopy layer.

**Criteria for Selection of Measurement Sites**

The spatial structure/urban form of city are such that the north south railway line divides it into East and West parts. These parts hold distinct urban characteristics East Nagpur has higher built-up density than the western part of Nagpur. Approx. 70% of East Nagpur consists of mix of low rise and midrise buildings (having 1 to 6 stories) that are attached or very closely spaced with very small open spaces and vegetation in between. West Nagpur consists of about 50% open arrangement low-rise and midrise detached houses or apartments. Only 10 to 15% of buildings in West Nagpur are high rise, which are scattered in different areas. Percentage of open spaces and vegetation is more in Western part of Nagpur as compared to Eastern part. The city does not show much of vertical growth, but is undergoing rapid horizontal and radial growth. City has moderate industrial activity and is dominated by presence of residential areas. It also has major retail commercial areas at its center, while few
commercial sub centers are spread all over the city. Wholesale markets are concentrated in Eastern part (Godbole S, 1999).

Literature study reveals that Land Use/Land Cover pattern and geometry of urban areas are important factors for development of UHI (Borthakur et al., 2012; Eliasson et al., 2005; Li.Reuben Mingguang et al., 2009; Rohinton E, 1997; Mohan et al., 2012; Z.Bottyan et al., 2003). Hence following two land use classifications were selected for this research – i.e. Purely Residential zone (R1) and Residential zone with retail commercial areas (R2). In Nagpur too, the commercial activity mostly goes on along the main road like in any other Indian city, and it is surrounded by residential areas. Therefore, survey was carried out in selected residential areas which are representative of zones mentioned above, to understand its geometry i.e. Height/Width ratio of urban canyons, its density and type of buildings forming the canyon.

A street canyon is defined as a place where the street is flanked by buildings on both sides creating a canyon like environment within an urban canopy. It is a basic unit of modern cities (shishegar, 2013). Street canyons are classified according to their geometry. The geometry of the street canyon is expressed as ratio of the canyon height (H) to canyon width (W), i.e. H/W which is termed as aspect ratio. In Nagpur, Geometry i.e. H/W of urban street canyons varies from 0.1 to 2.68. Commonly found H/W ratio 0.2; 0.67; 0.75; 1.6; 2.68 etc. In this study, urban street canyons having H/W ratio 0.75 to 2.25 were considered. Street canyons having H/W ratio less than 0.75 were not considered in this study area as they will not play significant role in rising ambient air temperature. Residential areas were further sub-classified on the basis of urban structure i.e. built-up density into following categories: High density, Medium density and low density. Based on these, following 4 study areas were selected.

**Description of Study areas**

**Mahal**

This oldest part of Nagpur is located on eastern sides and is considered as origin of city. It is a congested area with organic pattern of growth dominated by residential and commercial activities i.e. mixed land use (Figure.4). It can be classified as that having compact low-rise and midrise buildings with a few open spaces, narrow lanes of organic pattern and few trees. Land cover is mostly paved. Bricks, cement plasters, cement concrete are construction materials. Population density is 700-850 pph, while percentage of built-up area is around 76 percent.

**Dhantoli**

This is well planned area with open spaces and parks, having gridiron pattern of roads dominated by residential and commercial activities i.e. mixed land use (Figure.5). Road widths are 6m, 9m and 12m. This area consists of an open arrangement of detached midrise buildings (3-9 stories), with few low-rise buildings. Percentage of Built up area is 50%. Percentage of pervious land is less with scattered trees (percentage of vegetation is 20%). Construction material mostly is Brick, cement plaster and concrete. Built up area mostly consists of residential buildings, hospitals and commercial.

**Dharampeth**

Situated in the West side of Nagpur it has Medium dense built up area which constitutes 40% of total area. Built up...
area mostly consists of shopping centers, shops, vegetable markets, commercial areas etc. Area is dominated by residential and commercial activities i.e. mixed land-use (Figure 6). Land-cover is mixed i.e. pervious and impervious type, impervious area is more than pervious one. This area is a combination of open arrangement of detached midrise buildings (3 to 9 stories) and compact detached low-rise buildings with few trees. Land cover is mostly paved.

**Shankar Nagar**

This is well planned colony with Parks, Playgrounds and Residences. It is a purely residential area (Figure 7) Built up area is 23% of total area. This area can be termed as open detached low rise buildings (1-3 stories) with 22 percent of vegetation. Percentage of pervious land-cover is more. Construction materials are mainly bricks, cement plasters and concrete.

To study urban heat island at canopy level, three canyons /streets were selected from each area (Figure 8).

In order to monitor and record air temperatures within the canyons fixed point measurement method was used. Number of monitoring points varies as per the canyon length.

**Fixed Stations and Measuring Instruments:**

Field measurements of Air temperature and relative humidity within the street canyons were recorded by the HTC wireless data logger and Lutron hand held 4-in-one instruments. The data loggers are equipped with a high accuracy temperature and humidity sensors, providing fast response and stability. Positions of field measurement stations were identified by GPS instruments. All the instruments were calibrated before taking readings/observations.

Air temperature measuring instruments were installed at a height of about 1.5 m to 2.0 m above ground level as per WMO guidelines. The Air temperature, relative humidity and temperature for surface material were recorded during the summer season in the month of May.
Temperatures were recorded at all monitoring points in all four areas on the same day simultaneously at 3 hours intervals from 9 am in the morning to 10 pm in night. The ambient air temperatures were recorded during May 2015, which is hottest month of summer season. Data was recorded for 8 days at measurement stations located on three streets in each of the four study areas (Mahal, Dhanotli, Dharampeth and Shankar Nagar). These 8 days were further spread out into two blocks of 4 days each. First block consisted of 4 days in second week (10,11,12and13th May), while second block consisted of 4 days in last week (25,26,27and28th May). Air temperatures were recorded simultaneously at all stations at half hour intervals between 12 pm to 3 pm and mean of same for each station was considered as representative average temperature of that station for time slot of 12 pm to 3 pm for purposes of analysis. Similar procedure was followed for determining representative air temperatures at all stations for other two time slots – i.e. 4 pm to 7 pm and 8 pm to 10 pm. These timings were considered for analysis because most human activities take place during these periods. During entire period of survey, sky was clear and winds were calm. Wind speed was very low at 0.4 to 0.8m/s, and therefore has not been considered for analysis in this study.

In order to compliment continuous measurements by HTC data loggers, instantaneous measurements of air temperatures were also done manually at each station in these time slots with the help of Lutron LM-8000A temperature and humidity measuring instruments. Other important variables which affect Air temperature within canyons – i.e. i) building height, ii) orientation and width of streets, and iii) urban vegetation were documented by visual survey. Effect of anthropogenic heat on air temperature in canyons was beyond the scope of this study. The weather data for reference was obtained from Regional Meteorological Centre, Indian Meteorological Department (IMD), Govt. of India, located at Nagpur Airport.

Calculations for UHI Intensity

Urban heat island intensity is calculated as a difference between the maximum urban temperature and nearby rural area temperature. As rightly pointed out by Stewart and Oke (2012), the classification of field sites as conventionally “urban or rural” has become especially difficult in regions where both cities and country sides are now densely populated and land uses are intensely mixed. City of Nagpur is also expanding in all four directions with urban influence, and it is very difficult to find rural site very near to Nagpur. Therefore, in the present research, UHI Intensity has been calculated as difference of the temperature at a given study area location and the temperature recorded by meteorological station at Nagpur Airport (baseline temperature) at the same time. The intra-urban UHI intensity has been calculated as difference between temperature at a given study area location and the lowermost temperature recorded at the same time amongst all stations within the same study area.

RESULTS AND DISCUSSIONS:

UHI and Variation in Local Climate

Analysis of data was done with the help of SPSS (Statistical package for Social Science). Comparison of average ambient air temperatures among study areas during various time slots was done. Since all values of average temperature are very close to the average
Figure 8. Study Areas and Monitoring Points on streets

<table>
<thead>
<tr>
<th>Table 1. Summer Mean Air Temperature</th>
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<tr>
<td><strong>Mean Air temperature</strong></td>
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<tr>
<td><strong>Area</strong></td>
</tr>
<tr>
<td>Mahal</td>
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<tr>
<td>Dharampeth</td>
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<td>Shankar Nagar</td>
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<td>Dhantoli</td>
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<td>Air port</td>
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temperature for month of May obtained from IMD (Indian Meterological Department)Regional Centre at Nagpur Airport, it can be said that period of observation (May) was representative of the season (Summer). Comparative analysis of average summer temperature for each time slot of all the 4 study areas was done in two stages.

In first stage, we calculated, for each time slot, the average air temperature as follows:

Step 1: Average air temperature of each study area for specific time slot for a given day was computed by taking mean of representative average air temperature of all the 3 streets in that area.

Step 2: Mean air temperature for that study area for the month of May was determined by taking average of temperature of all the 8 days. These average temperatures are presented in table 1.

In second stage, Two-way analysis of variance (ANOVA) was carried out to test whether there is a significant difference among the average air temperatures of four localities and in the three time slots. ANOVA (Analysis of Variance) is a statistical method used to test differences between two or more means. It helps to find out if survey or experiment results are significant. ANOVA technique investigates any number of factors/variables which are hypothesized or said to influence the dependent variable.
Anova are of two types, one-way or two-way, depending upon number of independent variables in analysis of variance test. One way has one variable/factor and it investigates the differences amongst its various categories having numerous possible values and in case if we investigate two factors/variables at the same time, then it was said to be two-way analysis (Kothari C.R, 2004). Two-way analysis of variance (ANOVA) was performed on the table-1 which shows study areas and time slot wise summary of means summer air temperatures, to study whether there was significant differences in average temperature of four study areas and also whether there is a significant difference in average temperature in different time slots. The two null hypotheses were tested are as follows:

H₀: There is no significant difference between average air temperatures of study areas. Against alternative hypothesis there is a significant difference between average air temperatures among study areas.

H₀: There is no significant difference between average air temperatures in three different time slots. Against alternative hypothesis there is a significant difference between average air temperatures in three different time slots. It can be observed from ANOVA table-2 (table-2), that p-value in the table is less than 0.05 thus we reject null hypothesis at 5% level of significance, and we can conclude that, there is a significant difference in the average summer temperatures of different localities (p-value 0.000147) as well as in various time slots (p-value 0.000289).

Figure 9 summarizes the diurnal pattern of the temperature differences between study areas and Airport station which was considered as base line. The intra-urban heat island intensity (UHI) at canopy level in the three study areas of Mahal, Dhantoli and Dharampeth was calculated as difference in the average temperature in each of these study areas and the observed temperature at that hour at Shankar Nagar, which was found to be lowest amongst all the 4 study areas. Measurements show intra-urban air temperature difference up to 5°C in study areas (refer table 1).

It was observed that Mahal area (Table 1) recorded highest ambient air temperature amongst the 4 study areas. Average Intra-Urban heat island intensity in Mahal area for the summer season (May 2015) at three different times—i.e. during noon (12:00 – 15:00 hrs) was 2.8°C, during evening (16:00 – 19:00 hrs) was 5°C, and during night (20:00 – 22:00 hrs) was 4.4°C. This is old part of the city and has high built-up density.

The air temperatures recorded at urban stations in all the 4 study areas varied substantially (Figure 9). The air temperature in Mahal is higher followed by Dharampeth and Dhantoli. Shankar-Nagar recorded lowest
temperature amongst 4 study areas. This can be explained by the fact that Mahal, old and congested part of city has 78% of residential and commercial land use (Figure 3) whereas Shankar Nagar has only 62% of residential land use, and also has large patches of farmland belonging to agricultural University nearby. The substantial difference in urban heat island intensity or temperature variation within the study areas of Nagpur city indicates that land use have a strong influence on the urban heat island intensity.

**Relationship of UHI with Percentage of Built-up Area**

Built-up area percentage was calculated by dividing area of footprint of buildings by total plot area of buildings multiplied by 100. If we correlate this percentage of built-up area with average ambient air temperature of study areas, it is seen that Mahal (Figure 10) which is having 75% of built-up area had a correspondingly higher temperature than Shankar Nagar which is having 23% built up area and a lower temperature. As stated earlier, Mahal is old congested area with closely spaced buildings of 1 to 4 storeys whereas other areas such as Dharampeth, Dhantoli consist of compact midrise detached buildings. Shankar nagar consists of low-rise detached buildings. Earlier research on UHI has indicated that higher densities are likely to have higher temperature due to their physical structure (Givoni, 1998; Oke, 1988). The temperature of the external materials in a built environment is governed by its thermal balance. Surfaces absorb short wave radiation as a function of their absorptivity and their Exposure to solar radiation, and emit long-wave radiation as a function of their emissivity and view factor (Santamouris, 2001). Givoni(1998) explained radiation balance in built-up urban areas, according to him, In urban areas most of the solar radiation strikes on roofs and on the vertical walls of buildings and very small proportion reaches the ground. In urban canyons, solar radiation falling on the vertical walls is partly reflected, mostly towards other walls of buildings in close proximity, and is partly absorbed at the wall surfaces. The percentage of solar radiation reflected from the walls varies from 20 to 80 percent, depending upon the exterior color of the surfaces of walls. In an urban area large amount of reflected radiations hits walls of adjacent buildings and this initiates the process of radiation reflecting back and forth a number of times between the walls of different buildings. Due to this, in densely built urban areas, only a small part of solar radiation falling on wall is reflected upward to sky, while most is absorbed by walls of the buildings and slowly released back to atmosphere in the evening and night hours. Thus temperature in a built environment is influenced by its surfaces, as energy is transferred through convective process (Givoni, 1998). This explains higher temperature recorded in dense areas.

**Relationship with Vegetation**

Various forms of greenery which exists in study area are gardens, trees along the road sides, and trees, shrubs, lawns within individual house lots. Extent of Tree cover was computed using Arc-Gis software. Arc GIS is a geographic information system for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of application, and managing geographic information in a database (https://en.wikipedia.org/wiki/ArcGIS). Their percentage varied from 7 to 25% (Ref. Figure 11). Greenery was acting as sources of moisture for
evapotranspiration, due to which absorbed solar radiation is dissipated as latent heat and thus helps in reducing urban temperature (Sharifi et al., 2015).

In all four study areas, it was found that air temperature increases when percentage of vegetation within the canyons is lower. For example, in case of Mahal where extent of vegetation within the canyon is less than 10 percent, the air temperature was higher when compared with the other study areas. Vegetated areas are therefore found to be few degrees cooler than their surrounding less vegetated over.

To define the relationship between temperature (as an indicator of UHI) and other variables commonly observed in the urban areas (as an indicator of urban morphology) the correlation analysis has been carried out. In this analysis, temperature is taken as dependent variable and other variables such as extent of vegetation, percentage of built-up area as independent variables. The results of correlation analysis shows that there is strong correlation of Air temperature with percentage of built up area (p-value 0.0073) and negative correlation with vegetation (p-value 0.0342).

Multiple regressions were carried out to predict a single variable from independent variables, which contributes most to the formation of urban heat island in city of Nagpur. From the analysis so far, it is emerging that contribution of percentage of built-up area is the most significant factor.

CONCLUSION

The study proves through fixed point measurements, existence of substantial difference in air temperatures at canopy level in all 4 study areas in the city of Nagpur. The maximum intensity of intra urban heat island was observed few hours after the sunset i.e between 20:00 hrs – 22:00hrs.

Study shows a maximum Intra-urban UHI intensity of 2.8°C in between selected study areas of Mahal, Dhanotli, Dharampeth and Shankar Nagar during the noon i.e. between 12:00 to 15:00 hrs. During the same time period, the UHI Intensity was observed to be 1.7°C w.r.t. air temperatures recorded at Meteorological station at Nagpur Airport.

During night (20:00 to 22:00 hrs) the maximum Intra-urban UHI was found to be 4.4°C, while UHI w.r.t. air temperature recorded at Meteorological station at Nagpur Airport was found to be 5.8°C.

The study indicates a strong correlation between ambient air temperature and percentage of built-up area as well as vegetation cover. Out of these two, percentage of built up area contributes more to rise in temperature in Summer months.

The study also indicates that intra-urban variation in air temperature is related to Land use, percentage of built-up area and percentage of vegetation cover.

This study could contribute positively in framing of urban design guidelines for developing more resilient built environment for Nagpur city, and in mitigating intensity of UHI in near future.

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Accepted 02 May, 2017


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