Conference Proceedings of 5th International Conference on Countermeasures to Urban Heat Islands (IC2UHI) 2019
December 2-4, 2019, Hyderabad, India
https://doi.org/10.37285/bsp.ic2uhi.12

Assessment of variation in Intra Canopy Layer Urban Heat Island Intensity in Residential areas --- A case study of Nagpur City

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ABSTRACT:

Urbanization of recent times has brought many climatological changes in cities around the world, a major one being rise in temperature. Central Indian city of Nagpur is no exception to this phenomenon. Outdoor thermal discomfort is a major outcome of Urban heat island effect. Present study focuses on urban canopy level heat island in city of Nagpur, and aims to understand the temperature distribution in urban canyons, as most of life occurs in this layer and is directly affected by the rise in temperature. This paper reports spatial and temporal variation of air temperature within selected residential areas of Nagpur. Field surveys were carried out, wherein actual physical measurements of outdoor air temperature & humidity were done using fixed station method. Data regarding Urban morphology such as H/W ratio, vegetation, building material & built-up density was recorded by visual observation and mapping. The study shows intra-urban variation in air temperature at canopy level in all seasons and existence of daytime as well as nocturnal urban heat island in city of Nagpur.

Key Words : canopy layer, urban heat island, Nagpur, intraurban, temperature variation, vegetation, Height-width ratio, materials

Introduction:

Cities and people residing therein, are major contributors to climate change. Microclimatic changes are often brought about by manmade alterations of the urban surfaces. 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. The intensity of urban heat island effect is observed to be directly related to the degree of urbanization (Oke 1987, Santamoris 2001).

Heat islands are of two types - Surface UHI and Atmospheric UHI. Atmospheric UHI are further classified into Boundary Layer UHI and Canopy Layer UHI – i.e. UHI at micro scale. These UHIs are related to each other, but differ in their processes, observations and models.

The effect of rise in temperature is strongly felt in canopy layer where most of city life occurs. Micro-climate of urban canopy is the result of its immediate surroundings - such as land use / land cover pattern, building materials, geometry i.e. height-width ratio, percentage of vegetation etc. and any change in these parameters results in modification local climate. Thus, meteorological condition within urban canopy is much a localized phenomenon and varies significantly within cities. Hence, the urban canyon or street has been considered as a unit for investigation in the present urban heat island study.

In case of Nagpur city, most of previous UHI studies have investigated the influence of land-use, land cover on air temperature at spatial and temporal scale by using remote sensing data (LST), while only a few have used traverse surveys. These studies indicate presence of urban heat island in city.

Present study aims to investigate factors which are responsible for rise in temperature within the urban canyons. The urban factors that are important from urban designer's point of view (as they can be modified through planning) which include : Percentage of Vegetation,

Building material, Geometry of Canyons i.e. Height-width ratio, Colors of buildings, Percentage & density of built-up areas, and orientation of streets have been considered in the study. This paper focuses on analysis of air temperature variation between study areas for all the seasons in context of urban morphological factors.

STUDY AREA:

Nagpur, the second capital of Maharashtra, is in eastern part of the state. The city acquired historical importance from 18th century after its founder Gond King Bakht Buland Shah made it Capital of his kingdom. City of Nagpur originated in the eastern part known as Mahal and later spread to present south-central part of Sitabuldi and western parts. 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 that of a planned development. The city does not show much of vertical growth but is undergoing rapid horizontal & 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).

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 47° c and in Winter it ranges from minimum of 10º C to maximum 30°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. 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 *(Source: Indian Meteorological Department Regional Center at Nagpur Airport)*

RESEARCH METHODOLOGY:

Numerous earlier studies have indicated that the land use land cover (LULC) pattern has most significant influence on urban climate (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.

Literature study also 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; Emmanuel, R, 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.

Data collected during different seasons was then statistically analyzed to understand contribution of different parameters in formation of UHI at Canopy layer.

MONITORING SITES:

Residential areas were further sub-classified based on 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. To study urban heat island at canopy level, three street canyons were selected from each study area (Ref. Table 1). Out of these three, one street canyon was commercial while other two were residential. In order to monitor and record air temperatures within the canyons, fixed point measurement method was used. No. of monitoring points in each canyon varied as per the canyon length. Table-1 below shows details of Street Canyons where measurements were taken :

TABLE 1

Area	Street No.	Length of Road	Width of the Road	H/W	Orientation	Land use	Road Material
Mahal	1	90m	6m	2.25	NE_SW	Resi	Concrete
	2	486m	17.5m	1.06	E-W	Comm	Asphalt
	3	90m	9m	1.8	N-S	Resi	Asphalt
Dhan-toli	1	165	6m	2.5	N-S	Resi	Asphalt
	2	435m	10m	2.1	N-S	Mixed	Asphalt
	3	288 m	10m	1.35	NW-SE	Resi	Asphalt
Dhara-mpeth	1	285m	4.5m	2	E-W	Mixed	Asphalt
	2	968m	24m	0.75	NW-SE	Comm	Concrete
	3	478m	9m	1.66	N-S	Resi	Asphalt
Shankar Nagar	1	140m	7.5m	1.2	N-S	Resi	Asphalt
	2	118m	9m	1	N-S	Resid	Asphalt

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. 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. Road widths are 6m, 9m and 12m. This area consists of an open arrangement detached midrise buildings (3-9stories),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 Westside of Nagpur it has Medium dense built up area with a built up area of40%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 midrise buildings (3 to 9 stories) and compact 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 low rise buildings (1-3stories) with 22 percent of vegetation. Percentage of pervious land-cover is more. Construction materials are mainly bricks, cement plasters and concrete.

INSTRUMENTATION:

Instruments for recording temperature and humidity were selected on basis of their accuracy, minimum error and easy in handling. Field measurements of Air temperature and relative humidity within the street canyons were recorded by instruments such as :HTC wireless data logger and Lutron hand held 4-in-one instruments, Hand held Kusam-meco infrared thermometer Model IRL-300 was used to measure the horizontal and vertical surface (street, pavements and adjacent facades) material temperatures. The temperature range is -30˚C to 550˚C.

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 for all the four seasons such as summer, monsoon, post-monsoon, and winter so that seasonal variations along with the diurnal variations in temperature can be studied. Temperatures were recorded at all monitoring points in all study areas on the same day simultaneously at 3 hours intervals from 12 pm in the morning to 10 pm in night. 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 0.8 m/s, and therefore has not been considered for analysis in this study. 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.
Effect of anthropogenic heat on air temperature in canyons was beyond the scope of this study.

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.

RESULT AND ANALYSIS:

As urban heat island intensity is not constant but shows fluctuations in strength during day and night, analysis of data is done considering study areas, seasons and temporal scale.Comparison

of average ambient air temperatures among study areas during various time slots is done. Since all values of average temperature are very close to the average street Measurement point temperature for Summer, Monsoon, Post-monsoon, winter obtained from Indian Meteorological Department (IMD)Regional Centre at Nagpur Airport, it can be said that period of observation was representative of the particular season. Comparative analysis of average temperature for particular season for each time slot of all the 4 study areas was carried out. In each study area, three canyons/ streets were selected for recording ambient air temperature, and temperature of horizontal and vertical surfaces. It was observed that in all areas, there was no significant difference in the average air temperature on different streets for all the 3-time slots. Therefore, we can consider average temperature of all streets of a study area as temperature of that area.

Analysis of air temperature at different locations within study areas shows that, all urban locations (study areas) show higher temperatures than that recorded at meteorological station at Nagpur Airport (baseline temperature) at the same time in all the seasons. This strongly indicates formation of Urban Heat Island over city of Nagpur during most of the time of year.(Refer Fig.1,2,3).Analysis of variance (ANOVA) a statistical method was carried out to test whether observed air temperature differences within different four study areas were statistically significant during three different time slots. Two-way analysis of variance (ANOVA) was performed to study (a) whether there is significant difference in average temperature of four study areas and (b) whether there is significant difference in average temperature in different time slots. The two null hypotheses tested were :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.

The results of analysis shows that p-value is less than 0.05. Thus we can 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-value0.000289).The same analysis was done for other 3 seasons viz, monsoon, post-monsoon, and winter. For Monsoon, p value is found to be 0.0005 for localities and 0.00 for various time slots. For Post-monsoon season, p value is found to be for localities 0.0002 for various time slots value of p is 0.00.

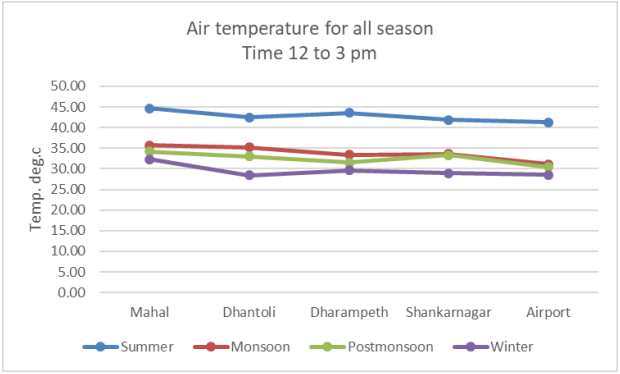


Fig.1 Air temperatures for all seasons (12 to 3 PM)

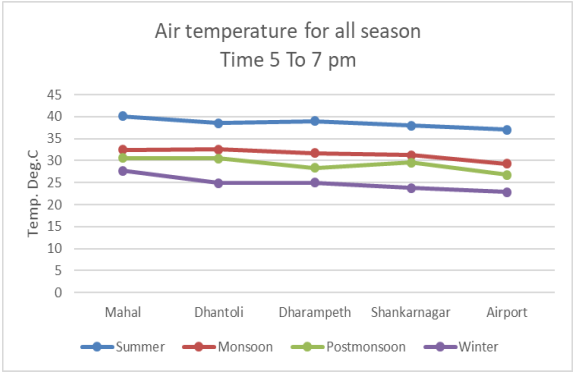


Fig.2 Air temperature of all Seasons (5 to 7 PM)

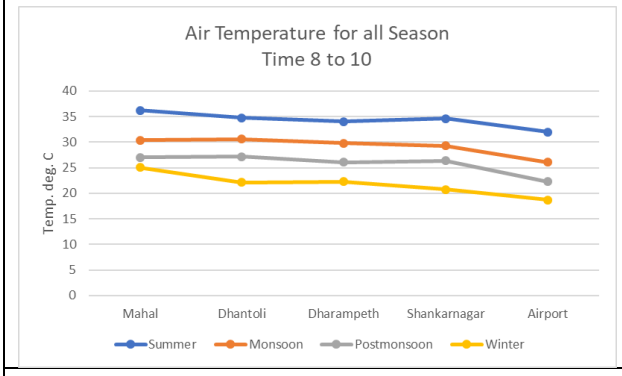


Fig.3 Graph Showing Air temperature of All Seasons (Time 8 to 10 PM)

For Winter, p value is found to be 0.0001 for localities and 0.00 for various time slots, indicating that there is a significant difference in the average temperatures of different localities as well as in various time slots.

Effect of this temperature variation on humans' outdoor comfort was also studied. Experience of outdoor thermal discomfort is a major impact of UHI phenomenon, that is strongly felt in canopy layer. Evaluation of outdoor thermal comfort was carried out by using random sample surveys during Summer, as it is the hottest season. A guided questionnaire was used for user survey which addressed user's experience of thermal condition - i.e. thermal sensation and feeling of comfort and with other information such as name, age, location (area), and address. The participants were asked to classify sensation of thermal comfort based on ASHRAE thermal comfort 7 point scale. The results of questionnaire survey were analyzed and following inferences were derived:

1) As regards experience in outdoor spaces in summer during different slots, 74% of respondents felt outdoor spaces are Hot in Summer during 12 to 3 pm , while 26% felt Warm. Responses for time slot 5 to 7 pm and 8 to 10 pm were more or less same with 67% respondents feeling Warm, 28% feeling Slightly warm and 5% choosing not to mention their rating.

2) 55% people strongly felt that they could experience temperature difference while moving from one locality to other, 30 % respondents agreed to having felt such a difference while 15% people said they didn't find any change in temperature.

COMPARISON OF AIR TEMPERATURE OF URBAN LOCATIONS WITH REFERENCE SITE I.E. IMD AIRPORT STATION NAGPUR:

All urban locations i.e. study areas show higher air temperature when compared to the IMD Airport station, Nagpur, for all seasons and various time slots. The intensity of UHI is a function of time during day i.e. it changes according to temporal scale. During a large part of the year, the day time UHI intensity i.e. difference between mean temperature of all residential areas and IMD is more than 2.5 deg. C expect for summer is 1.85º C. This is because the open land/borrow land in and around IMD Airport Nagpur has the heat holding capacity and it absorbs more solar radiation. But during the night in summer season, the difference of mean temperature of all residential areas is 2.88ºC and winter it is 3.86 deg. C more than reference site, as IMD observatory is in open area, whereas during night radiant heat loss is more. On the other hand, residential areas of Nagpur city consist of compact mix of midrise and low-rise built-up area with roads of Asphalt and concrete. Both daytime and Nocturnal Canopy level UHI exist in residential areas of Nagpur.

COMPARISON OF INTRA-URBAN HEAT ISLAND INTENSITY OF STUDY AREAS WITH BASELINE UHI :

The intra urban UHI intensity has been calculated as difference between higher temperature recorded at a given study area location and the lower most temperature recorded at the same time amongst all stations in all the study area.

Table No.2: - Intensity of Urban heat island (Intra-urban)

INTRAURBAN HEAT ISLAND INTENSITY			
Season/ Time slot	**12 to 3 pm**	**5 to 7 pm**	**8 to 10 pm**
Summer	2.84	2.08	1.61
Monsoon	2.04	2.08	1.11
Postmonsoon	1.0	1.06	1.0
Winter	3.38	3.85	4.26

The Intra urban UHI for Mahal area (which recorded highest temperature amongst all the 4 study area) varied substantially for all the seasons and three time slots.

It is observed that Mahal area (which is part of the old city) has high Intra urban UHI intensity during noon i.e. 12 to 3 PM for summer and monsoon. For post monsoon it is almost the same for all 3 timeslots. During winter it is highest in 8 to 10 pm time slot.-Earlier research on UHI has indicated that higher densities are likely to have higher temperature due to their physical structure (Givoni, 1998; Oke, 1988).

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.

INTRA URBAN UHI INTENSITY: -

It is observed that there is substantial difference between mean air temperature within the residential study areas in all seasons and during all time slots. It is observed that Mahal area recorded highest ambient air temperature amongst the 4 residential areas and Shankar nagar lowest. The mean temperature difference between Mahal and Shankar-nagar during summer is almost 3ºC during 12 to 3 pm timeslot and during night it is 1.61(i.e. Temperature at Mahal is 1.61ºC higher than Shankar nagar). During daytime intensity is higher may be due to larger impact of radiant surface temperature during the day because of the solar heat. During night difference is less this may correspond to highest energy use for ACs and coolers due to which anthropogenic heat increases which further add to increase in air temperature.

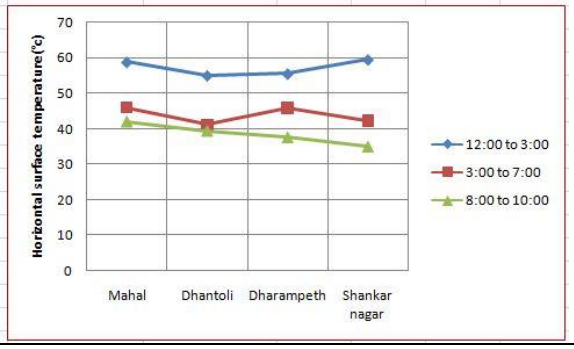
During Winter, the temperature difference between Mahal and Shankar nagar is 3.38ºC between 12 to 3 pm timeslot and during night (8 to 10 pm) it is 4.26ºC. This may be due to the fact that reradiation from canyon is fast as H/W ratio is less, percentage of vegetation is more as compared to other study areas and Also Shankar nagar is attached by a farmland on one side the cumulative effect of all this is responsible for drop in ambient air temperature. The surrounding area is also influencing temperature with in urban areas. The mutual difference between residential

areas is more in winter and summer as compared to monsoon and postmonsoon as in postmonsson days are comfortable and nights are cooler. The substantial difference in intra urban heat island intensity or temperature variation within the study areas of Nagpur city indicates that land-use, percentage of built-up area, vegetation, Materials of Surfaces and other urban characteristics has an influence on the urban heat island intensity.

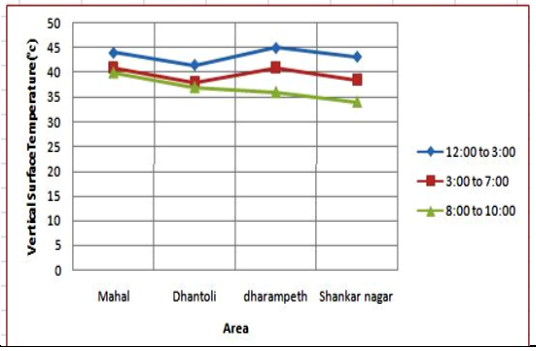
RELATIONSHIP OF UHI WITH VARIABLES OF CANYON:

RELATIONSHIP WITH BUILDING MATERIAL:

The surface temperature of facades (Vertical) and Streets (horizontal) varied considerably depending upon their exposure to solar radiation. In these study areas, streets were mainly of Asphalt & Concrete and facades were of brick with cement plaster and painted with color. It was found that horizontal surfaces of streets had a high temperature between 50 and 60 deg C in the afternoon during summer (Refer Fig.4). These materials are dense; dark in color (asphalt) with low albedo and therefore absorb more heat than material for facades. Temperatures of facades were found to be less than surface temperatures of horizontal surfaces during summer The difference was much more pronounced during noon, and gradually reduced during evening and night time. This was because of orientation of facade and light color of the facades (i.e. high albedo).The horizontal surfaces (streets) and vertical surfaces (facades) were always observed to be warmer than air temperature in canyon – both during daytime & night time almost in all season.



horizontal Surface temperature



Vertical Surface temperature

Fig.4 Graph showing temperature of horizontal and vertical surfaces in Summer season

B) RELATIONSHIP WITH PERCENTAGE 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. Their percentage varied from 7 to 25% (Ref. Fig.5). 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 in summer 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.

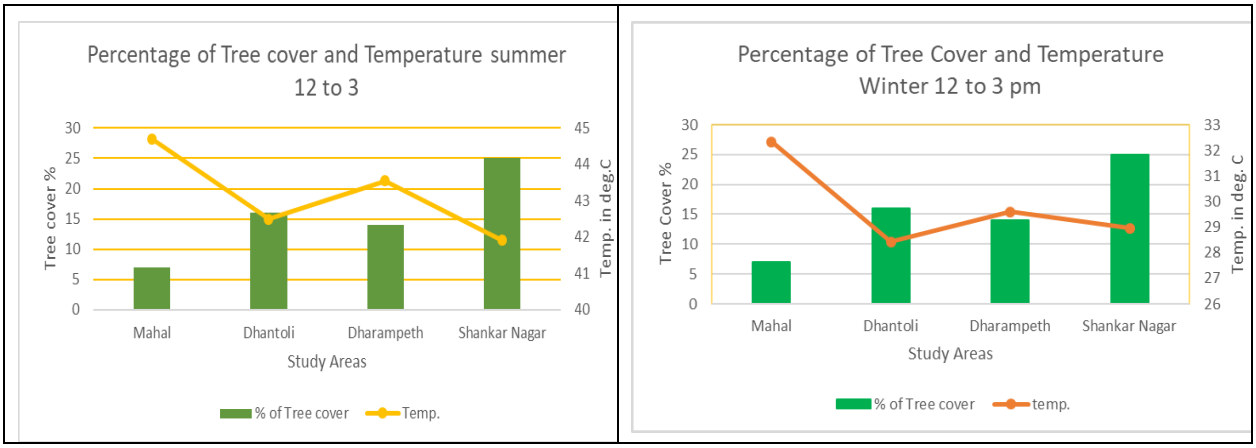


Fig.5 Observed summer air temperature in study areas against percentage of tree / vegetation cover in Canyons

C) RELATIONSHIP WITH H/W RATIO OF STREET CANYON:

The study found that in summer during 12 to 3 pm, area with lowest H/W ratio of street canyon (Shankar nagar) recorded lowest temperature (Ref. Fig.6). while Mahal which is having highest among the study areas shows more temperatures. Above table shows that temperature in Dharampeth is more than dhantoli though its H/W is less than dhantoli one of the reason may be percentage of vegetation as percentage of vegetation in dharampeth is less than Dhantoli. Seasonal variation is seen in temperature of summer and winter but highest H/W ratio shows more temperature as compared to lowest H/W.

At broader level above mentioned factors found to be playing role in formation of urban heat island. This matches with the results of earlier studies.

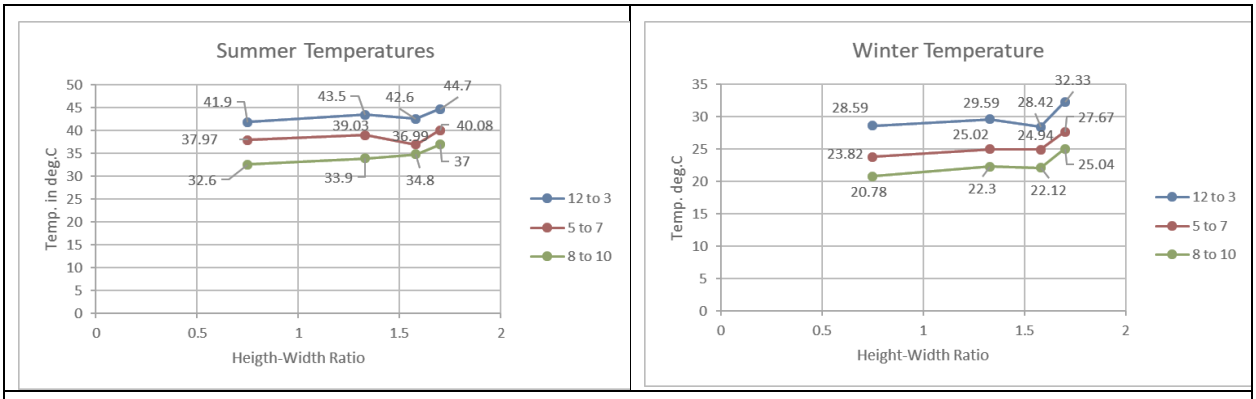


Fig.6 Graph Showing relationship between Mean H/W of Areas with Air Temperature

CORRELATIONAL ANALYSIS

To study the pattern of relationship between air temperature (as an indicator of UHI) and other variables commonly observed in the urban canyon (as an indicator of urban morphology), correlation analysis was carried out for all study areas as per season and 3 different time slots. Correlation is used to measure the strength of the association between numerical variables and is obtained by using Karl Pearson's correlation coefficient (r). In this analysis, temperature was taken as dependent variable and other variables such as extent of vegetation, (building)height / (road)width ratio of canyon, material of horizontal and vertical surfaces, density of built-up were

taken as independent variables. Correlational analysis shows that, there is a strong correlation between average air temperature in urban canyons and surface temperature of materials used for streets and facades. The main reason for this is thermo-physical properties of materials. However, it is also observed that in certain cases where percentage of vegetation is more and height / width ratio is lower, air temperature is slightly lower. These factors also have correlation with air temperature, but it is not that significant.

CONCLUSION:

The results show that there is existence of Day time as well as Nocturnal canopy level /canyon level Urban Heat Island in city of Nagpur, and intensity of said UHI varies with seasons. There is also a variation in Intra-urban heat island intensity at canopy level, due to local urban structure, urban characteristics and land use. The UHI seems to have considerable impact on outdoor thermal comfort as well as health of residents of Nagpur city.

This study indicates that urban factors like material used for horizontal and vertical surfaces, percentage of built area & land-use / land cover have influence over spatial air temperature at canopy level within study areas, resulting in day time as well as night time UHI.

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