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Urban Heat Island Effect: A Case Study of Jaipur, India

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ABSTRACT

Rapid growth of population and resulting urbanization is gaining momentum where urban areas are developed in significant proportion in India leading to changes in existing landscape, buildings, roads, and other supporting infrastructure. Such a change replaces open land and vegetation in the form of permeable surfaces with concrete surfaces which are impermeable and dry in nature which leads to the formation of urban heat islands whereby urban regions experience warmer temperatures than their adjacent rural surroundings. Such heat island effect increases energy consumption in urban areas along with other negative impacts. The authors of the present paper focus on reduction of heat island effect in urban areas along with compatible strategies in Indian conditions partly to address higher energy consumptions and partly to reduce other negative impacts being caused on account of such heat island effects. The authors have carried out a case study of Jaipur a pink city of India.

1. Introduction

The world has experienced major urbanization and by 2050 about 66% of the world population is expected to be urbanized. Henceforth, urban spaces have become crucial areas for environmental changes which would disturb the biodiversity, water cycle and the climatic situations (Grimm et al., 2008). It is observed as per Intergovernmental Panel on Climate Change that the night time temperature in Urban Heat Island (UHI) rise more than day time temperature as compared to non-urban spaces (IPCC, 2001). For example, the daytime maximum temperature of Barcelona, Spain is 0.2 °C (0.36 °F) cooler whereas the minimum temperature at night 2.9 °C (5.2 °F) as compared to the nearby rural station (Moreno-Garcia, 1993).

Studies in the United States proposes that the relation between extreme temperature and mortality changes from one location to another. Studies state that the UHI effect is responsible for warming of the climate by nearly 30% (Huang and Lu, 2015; Zhao, 2011). There is a relationship between the effects of UHI and mortality rate. Certain researches of United States suggests that the link between extremes of temperature and mortality differs from one location to another. For example, the heat increases the risk of mortality in the southern parts of United States (like - Chicago, Denver and New York) as compared to the northern parts of the country.

Concluding the various further studies of United States shows that people residing in this country have the capacity to adopt hotter temperatures gradually towards north by passing of each decade, because of better infrastructures, modern buildings with better designs with better public awareness (Davis et al., 2003). As far as developing countries are concerned the urbanization is these countries is occurring at a constant steady pace, having an average urbanization of 2% (Song, 2014). There is a rapid growth in the Asian cities in terms of population and physical area as well, because of

increase in the urbanization. However, it is very necessary to observe the changes in the trends and the differences in UHI intensity values based on its urban spaces is because of its varying features of topography, population and economic situation (Hinkel et al., 2003). Thus, quite significant correlations were found in all the Asian cities based on these parameters on an urban area of over 300sq kilometers in 2010 (Lee et al., 2019).

In a city with high latitudes, the UHI intensity is seen to be quite high in winters as compared to summers which occurs due to the decrease in solar radiation, due to which the vertical turbulent transport and boundary layer depth reduces (Spence et al., 2008).

Also, the anthropogenically released heat during winters can be one of the considered factors, one of the best examples of such phenomenon the city named Beijing. In case of the cities named Dhaka and Karachi, no correlations were found UHI intensity and urban space with size as per observations. As, the developing countries like Bangladesh although productive industrialization take place, but still these countries lack urbanization in their towns. Due to which certain cities of these countries often experience lower economic achievement which results into the inability of these cities to achieve the structural shift from rural based activities to urban based industries. This results into being the reasons of the UHI intensity and the urban size of these cities being non correlated (Chang, 2016).

Table 1. Reduction strategies and technologies of UHI effect

No	Strategies and techniques	Definition	Benefits
1	Green roof	A green roof is an addition to the existing roofing system of an existing building for the purpose of growing flora (URL1, 2018).	✓ Green roof reduces the necessity for the accumulation of Storm Water ✓ In an urban environment it reduces the UHI effect by covering many of the concrete surfaces or other surfaces that might have the possibility to generate heat. ✓ The plants in the green roof catches many pollutants that helps to reduce pollution. Also, it reduces the amount of noise being generated.
2	Cool roof	A roofing system that provides higher reflectance and higher thermal emittance as compared to other type of roofs is known as a cool roof. Thus, a cool roof has the capacity to reflect visible, infrared and ultraviolet wavelengths of the sun which in turn reduces the amount of heat being transferred into the building. Roof can also be able to radiate the absorbed or non-reflected solar energy (URL2, 2021).	✓ Reduces use of Energy resources – Less energy is transferred to the building through a cool roof which results into less consumption of energy and reduces the need for artificial cooling of the building through methods like air conditioning. ✓ As the energy consumption reduces the emission of gases such as greenhouse gases and others which results into air pollution reduces simultaneously. ✓ Because of the reduction of the air temperatures within the building due to cool roof, it also reduces the risk for illness and deaths related to heat.
3	Cool pavements	Cool pavements remain cooler as compared to other traditional pavements in the sun. Cool pavements can be permeable or reflective in nature. The reflectance of a pavement can be enhanced by using reflective aggregate such as a clear binder or a reflective surface coating (URL3, 2021).	✓ Cool Pavements help to reduce the outside atmospheric temperature due to which the air conditioners consume less energy for cooling buildings. As cool pavements also act as an alternative to street lights in some places, thus it helps in reducing the energy consumption through electricity of street lights. ✓ Cool temperature reduces the amount of heat absorbed by the earth's surface reducing the surface temperature and also reducing the warming effect caused by greenhouse gases. ✓ Light coloured pavements or cool pavements provides better reflectance of Street lights and vehicle headlights at night thus providing a better visibility to the drivers at night.
4	Increasing trees and vegetation cover	It is the process of increasing the green areas by increase in the amount of tree plantations and vegetative covers in a specified site or area.	✓ It reduces Albedo effect reducing the reflectance of solar energy from the earth's surface, results into the reduction of the atmospheric temperature and also decreases UHI effect. ✓ Vegetative Covers are also responsible for the reduction of soil erosion, energy intakes and biogeochemical fluxes which in turn determines the ecological conditions (Schowalter, 2017).

There is a rapid increase in the urbanization within the last few decades in India and the country is under a progressive continuation of urbanization. As in recent times the government of India declared the development and implementation of 100 smart cities, which leads to rapid growth in urban population and urban infrastructure and services as well (Dholakia et al., 2016). These results into the increase of the UHI intensity, which becomes responsible for phenomenon such as extremes of temperatures, public health and energy requirements for residential cooling (Mazdiyasni et al., 2017; Panda et al., 2017). Eventually, there is an increase in the emission of heat waves in India and with this rate if the amount of heat waves emitted increases, the future consequences would lead to high quantity of heat stress and mortality (Murari et al., 2015). Despite of India's increasing urban growth, the major resulting factors of surface UHI intensity in India majorly remain unexplored in earlier studies (Mohan et al., 2011; Borbora and Das, 2014; Shastri et al., 2017).

As per a recent study by IIT Kharagpur, due to the UHI effects in India, the urban areas have warmer temperatures as compared to the suburbs. Also, the urban spaces may contain potential health hazards because of the emission of heat

waves and pollution as well. It is very disappointing to observe the climate of Bengaluru, which was known for its clean and comforting climate, presently contains UHIs even in places like Koramandala and Jayanagar. The formation of Electronic City and Whitefield in Bengaluru has led to the increase in the number of buildings, industrial parks and other associated high rise residential apartments, thus resulting into expansion of urban areas towards the suburbs, which becomes one of the main reasons for the unpleasant climate. There is a similar condition of the city named Hyderabad which due to its rapid expansion of industrial parks, factories and other related buildings towards the suburbs have gradually converted a part of the city into Cyberabad. Such phenomenon has led to the formation of not only UHIs but also have resulted into polluting the environment because of the major reduction in the Air Quality Index because of the emissions from industries and automobiles. The rapid increase of urbanization has resulted into the formation of UHIs even in mega cities like Delhi, Mumbai and Kolkata to a large number (Balasubramanian, 2020).

Densely populated urban pockets in the city generally form the UHIs where the presence of packed residential buildings and paved roadways becomes responsible for the temperature being higher than the other parts of the city. In order to accommodate more and more urban population large amount of natural vegetation are being converted into concrete structures and asphalt which becomes the main reason for formation of UHIs and Jaipur is one of the prominent examples of it. As per the weather report of Jaipur of 2018, the summer temperature of Jaipur was at an increasing rate over 40 degrees Celsius. The city experienced the hottest day as April 26 with the recorded temperature of 43.2 degrees Celsius (as per 4 June 2018). Heat trapped within the tarred roads and densely placed cluster of buildings increases the temperature by 2 degrees within the city core as compared to the entire city of Jaipur. And this city expected to experience worst scenarios in future due to UHI effects (Bhaduri, 2018).

2. Literature Review

In order to know the generation of UHI, we need to know the source of the heat that is generated and contained in the urban areas, is mainly from the solar radiations and from anthropogenic heat which is generated from industrial power plants, automobiles, air conditioners and others. Most of the anthropogenic heat immediately enters into the environment in the direct form. Whereas, only a part of the solar radiations entering the environment directly is responsible for the heating effects, the remaining solar radiations are being absorbed by the urban built structures and becomes responsible for heating up the environment indirectly. The basic heat transfers and the energy conservation processes play their significant roles in the heat exchange processes (Rizwan et al., 2008).

Table 2. Shows the temperature recorded during the three summer months of the 7 prominent ponits within the core city area of Jaipur also known as Walled City of Jaipur and also the average temperature calculated during summer of these points (Source: Author) (the points are placed as shown in Fig. 1)

A	Location Walled city (core area)	Temperature (˚C) May	Temperature (˚C) June	Temperature (˚C) July	Temperature (˚C) Average
1	Chand Pole	43	45	44	44.00
2	Choti Chopad	45	48	44	45.67
3	Badi Chopad	45	48	44	45.67
4	Subhash Chowk	42	45	43	43.33
5	Ghat Gate	43	45	43	43.67
6	Sanganeri Gate	44	45	43	44.00
7	Ajmeri Gate	45	47	44	45.33

Table 3. Shows the temperature recorded during the three summer months of the 15 prominent ponits within the Surrounding city area of Jaipur and also the average temperature calculated during Summer of these points (Source: Author) (the points are placed as shown below in Fig. 1)

B	Location Outer city (surrounding)	Temperature (˚C) May	Temperature (˚C) June	Temperature (˚C) July	Temperature (˚C) Average
8	C-Scheme	37	42	37	38.67
9	Ramniwas Garden	36	37	35	36.00
10	Sethi Colony	39	41	38	39.33
11	Adarsh Nagar	39	40	38	39.00
12	Golf Club	33	35	33	33.67
13	Tilak Nagar	40	41	39	40.00
14	Bapu Nagar	38	40	38	38.67
15	Gandhi Nagar	37	40	38	38.33
16	Malviya Nagar	37	39	36	37. 33
17	Jagatpura	38	40	37	38.33
18	Pratap Nagar	38	44	37	39.67
19	Sanganer	40	42	39	40.33
20	Mansarowar	41	43	40	41.33
21	Nirman Nagar	40	44	40	41.33
22	Vaishali Nagar	39	43	39	40.33

The amount of solar radiation captured by structures of urban spaces on ground level such as walls and roof facets, non-irrigated green areas, irrigated garden spaces, lawns and paved areas and others are at a different level. Such high

amount of radiation is continuously absorbed and accumulated in the form of heat energy from the natural and manmade urban structures from morning till late afternoon. Later, as the sun sets, gradually the environment starts to cool down. Thus, the heat which is stored in the urban structures is now released in the environment. The process and the amount of heat released by the urban structures depends on certain factors which can be controlled, these factors include building materials and the sky view factor. In an urban area, huge amount of construction materials is kept in small spaces which absorbs high intensity of solar radiations (Giridharan et al., 2004). The ability to release heat through long wave radiations in urban areas is quite low because of decreased sky view which results into large amount of heat accumulation within buildings. It is also being observed that the albedo, which is the comparison between reflected light and the incident light, is quite low in urban areas, because of the typical street canyon configurations and becomes one of the main reasons of air temperatures being significantly high (Kondoh and Nishiyama, 2000). The design parameters of albedo and sky view factors are hence considered to be two very important factors in the making of UHIs.

Table 4. Shows the average temperature of the core city area of Jaipur and the average temperture of the surrounding area of the city of Jaipur for the summer months of May, June and July and then the UHI intensity is calculated for the summer months as per the formula given earlier (Source: Author)

Month	Tu (City Core) (°C)	Ts (Surrounding area) (°C)	UHI intensity (Tu – Ts) (°C)
May	43.86	38.13	5.73
June	46.14	40.73	5.41
July	43.57	37.6	5.97

Fig. 1. Showing city of Jaipur and its surroundings indicating sampling points (URL4, 2021)

The UHI effect is formed mainly due to increase in the built-up urban fabrics which occurs due to various factors including increase in the population density of built-up areas and presence of vegetation in fractions, which leads to increase in the absorption and trapping of solar radiation (Grimmond, 2007). Hence, the increased built-up areas of

urban spaces can have effects such as changes in albedo, thermal capacity change, increase in roughness and there is a significant modification in the surface-energy budget (Arnfield, 2003).

Also, the urban space is also responsible for the increase in the anthropogenic carbon dioxide emissions, generated due to the burning of fossil fuels for heating and cooling effects, due to certain industrial processes and also because of vehicular transportations (Grimmond, 2007). Researches concludes that continuous urbanization leads to progressive increase in the UHI intensity and the other studies depict that urban impact have a significant effect on the recent warming trends (Zhou et al., 2004; Hamdi, 2010; Diensta et al., 2019).

The temporary variables have a significant effect on the UHI that is being formed, including anticyclone conditions, which in turn result into the increase of UHI intensity (Pongracz et al., 2006). Many researches and studies depict the influence that the wind speed and cloud cover have on UHI, and certain results show that there is a negative correlation between UHI and wind speed and cloud cover (Kim and Baik, 2005). Reduction strategies and technologies of UHI effect is given in the Table 1.

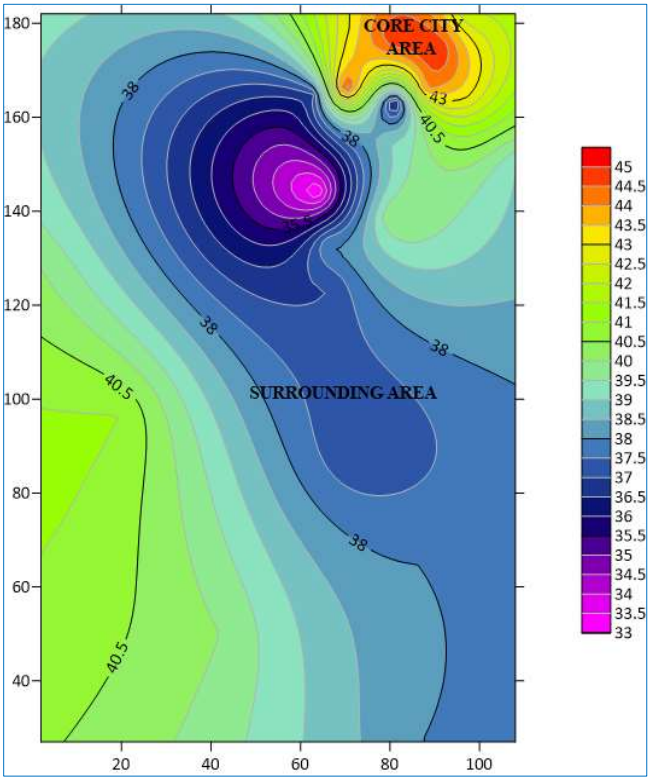

Fig. 2. Showing temperature contours of Jaipur within the city core and the surrounding city used for the calculation of the UHI intensity for the month of May (Source: Author)

3. A Case Study of Jaipur

Jaipur is a city which has a hot semi-arid climate which is influenced by monsoons. It has long and extreme hot summers, also short and mild winters. Jaipur is one of the prominent UHI zone similar to many other major cities of the world (Mukhopadhyay, 2016).

The UHI effect depends positively on the anthropogenic inclusion of the natural landscapes within a designated urban area (Oke, 1987).

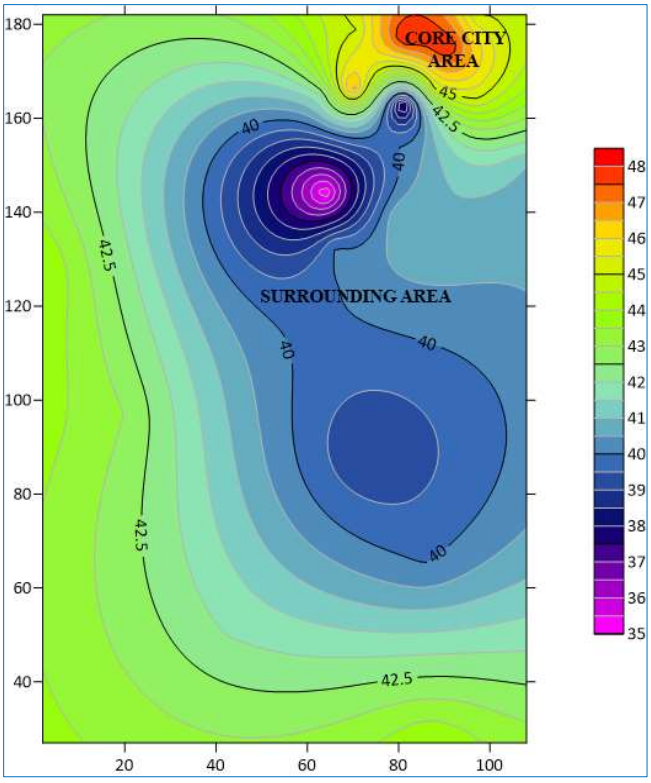

Fig. 3. Showing temperature contours of Jaipur within the city core and the surrounding city used for the calculation of the UHI intensity for the month of June (Source: Author)

Henceforth, with the expansion of the urban area, the UHI intensity also increases at a rapid pace. In order to explain this process, we calculated the UHI intensity of Jaipur City as the difference between the average temperatures of the core urban area and those of its surrounding areas within the designated boundary of the city (Zhou et al., 2013) for particularly of summer season. The equation to derive UHI intensity is as follows:

$$UHI\ intensity\ (°C) = Tu - Ts \quad (1)$$

where; *Tu* is the mean temperature of the urban core area and *Ts* is the mean temperature of the surrounding area. Water bodies have been excluded as it effects the temperature of an area immensely (Miles and Esau, 2017).

For calculating the average temperature for summer season of Jaipur City, the formula to be considered is:

$$T\ average\ (°C) = (T1 + T2 + T3)/3 \quad (2)$$

where; *T1, T2* and *T3* is the average temperature for the month of May, June and July, respectively.

The temperature recorded during the three summer months of the 7 prominent points within the core city area of Jaipur was given in the Table 2.

At the same time, the temperature recorded during the three summer months of the 15 prominent points within the Surrounding city area of Jaipur was given in the Table 3.

UHI intensity for the months May, June and July has been calculated based on actual observations recorded during these months at different identified locations as per Table 4. It would be evident from the table that the UHI intensity during these months are in the range of 5 to 6 °C which is quite significant.

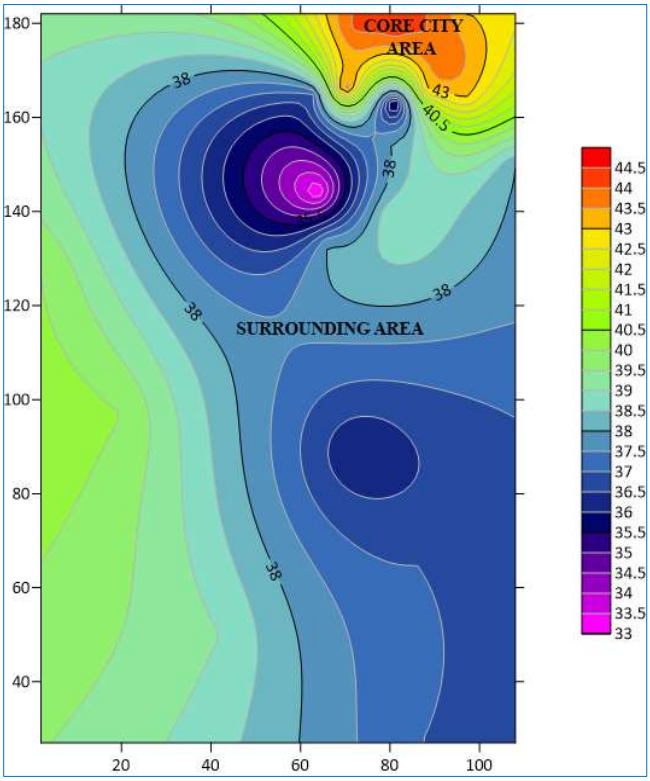

Fig. 4. Showing temperature contours of Jaipur within the city core and the surrounding city used for the calculation of the UHI intensity for the month of July (Source: Author)

An attempt has also been made by the authors to prepare a map of walled and outer city of Jaipur as has been shown in Fig. 1 where the locations of all the sampling points were mentioned. Subsequently, Surfer 9 software was used to prepare isopleths of temperature for the months of May, June and July and reflected in Figs. 2-4, respectively.

It would be quite evident from these figures that there is a clear heat island reflection within the walled city of Jaipur mainly due to extensive concreting of walled city, minimum green surface area and generation of air pollutants from automobiles and other sources with least atmospheric dispersion of such pollutants.

4. Conclusion

UHI phenomenon is quite usual in urban areas because of extensive concreting, less open spaces with green cover, significant generation of air pollutants from automobiles and other sources, least air pollutant dispersion ability, unbalancing of albedo effect etc. Such UHIs lead to extensive power and water consumption in cities, activation of air pollutants by extensive heat, and causes diseases to urban population. Therefore, the UHI needs to be addressed on a scientific scale linking forward and backward issues in an integrated manner. The authors of the present paper have highlighted the indicators responsible for creating heat island, its consequences and estimation. A case study of Jaipur was undertaken by the authors' where they revealed the fact that walled city of Jaipur has significantly been prone to heat island. A comprehensive integrated planning needs to be taken up to address this emerging issue.

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