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Urban Heat Island – A Strong Contributor to Climate Change – Case Study of Jaipur with Emphasis on Urban Forestry and Sustainable Development

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Abstract
Urban sectors are posing serious challenges presently and are likely to become an issue of great global concern in future. Around 55 percent of the total global carbon footprint is contributed from the urban sector resulting in climate change. The resulting contributing factors are mainly on account of continuous increasing urban population, non-optimization of concreting to non-concreting urban surface and vertical to horizontal spread of urban area coupled with other environmental parameters of relevance. These environmental issues are in the form of insufficient urban air ventilation, increasing urban heat island, inadequate carrying capacity of road network leading to traffic congestion resulting in enhanced air pollution, inadequate disposal and treatment of municipal solid waste and sewage and so on so forth. To address some of the issues referred to above, present research has been made by the authors to assess the urban heat island with emphasis on infusion of urban forestry. A case study has been carried out for Jaipur, Rajasthan, which has been divided into 14 grids with 56 locations where temperatures were recorded during the months of April to June 2023. Urban heat islands were calculated for different locations in Jaipur and isopleths were drawn using Surfer-9 software. An attempt has also been made to estimate an increase in energy consumption on account of the Urban Heat Island effect in Jaipur. To mitigate such an alarming UHI which is partly responsible for climate change, various mitigating measures were described with special reference to infusion of Urban Forestry in Jaipur.

Keywords
Urban Heat Island effect, energy reduction, climate change, urban forestry, mitigating measures

1. Introduction

The contemporary challenges climate change that we face today can be traced back to around two hundred years ago when modern medicine and improvements in technology led to a human population explosion when a sudden dependence on fossil fuels such as coal, natural gas, and petroleum initiated rapid industrialization around the world. These fossil fuels which had been formed from decayed biota over millions of years and were stored inside the Earth's crust began to be burnt in excess, releasing copious amounts of carbon dioxide into the atmosphere. In the last one hundred and fifty years, the level of CO_2 in the air has increased by 33%, facilitating a greenhouse effect.

High quantities of CO_2 combined with other greenhouse gases, mainly released from industrial emissions, such as methane, nitrous oxide, chlorofluorocarbons, and ground-level ozone along with water vapor collectively trap heat in our Earth's troposphere and disallow it from escaping into space giving rise to an unusually warm global climate

(Hardy, 2003). While the gradual and continuous change in the Earth's climate is a natural phenomenon, this human-induced rate of change in climatic conditions has not been observed in millions of years leading to an abnormal heating of our atmosphere, land, and oceans (NASA, 2019; Westerhold et al., 2020).

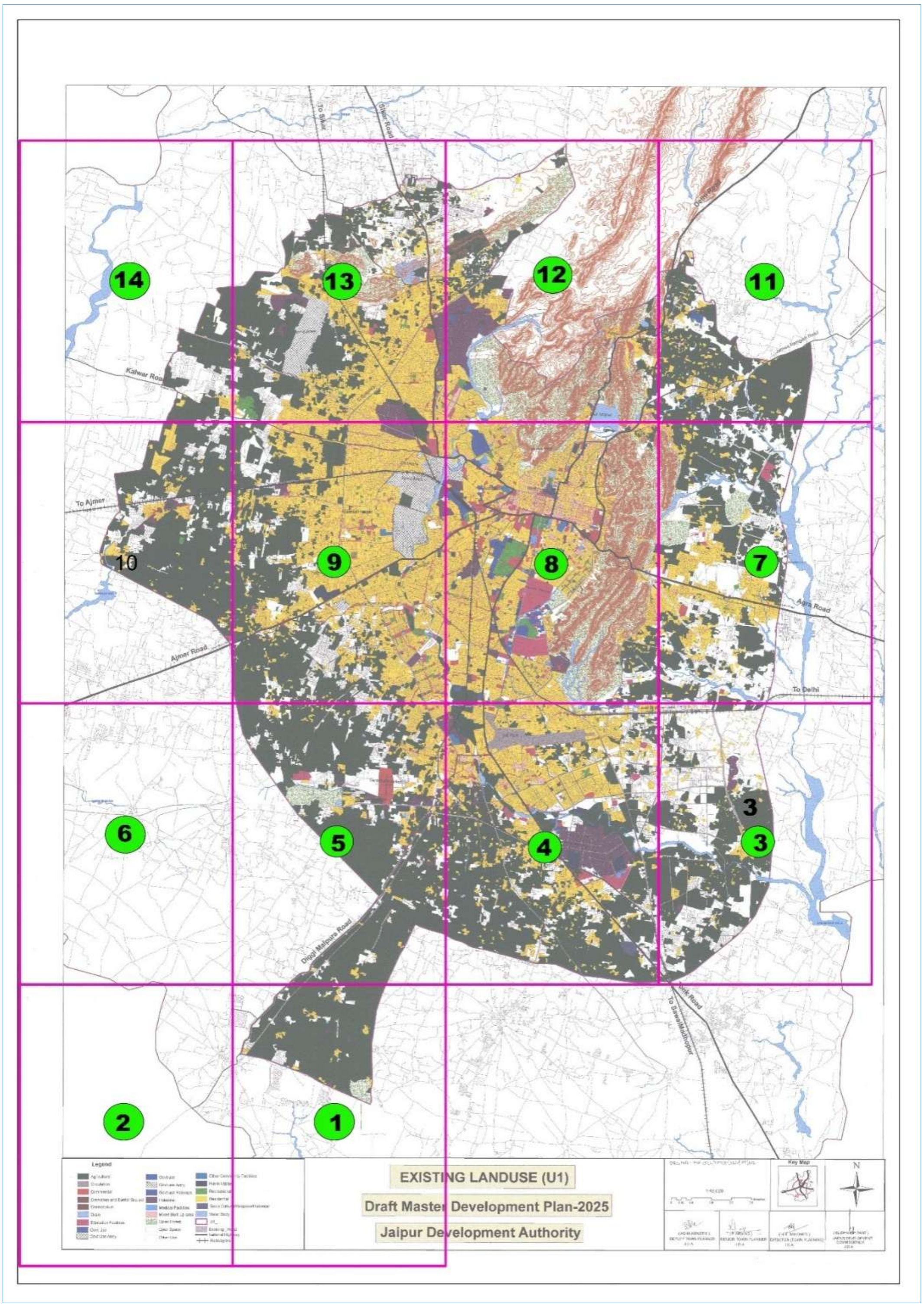

Fig. 1. Existing land use plan of Jaipur as per Draft of Master Development Plan 2025 (Authority, 2025)

It has also been observed that urban areas such as towns and cities contribute to over 70% of the effects of climate change around the world. The UHI effect is one such major contributor that occurs within cities, giving rise to warmer global conditions. The UHI effect occurs when the temperature of certain areas in a city is significantly hotter than its surrounding areas and is usually attributed to man-made activities in the area that give rise to a difference of around 2^{o}C or more when compared to its surroundings. The sources of this rise in temperature are a combination of vehicular exhaust, air pollution, industrial activities, power plants, hard-paved surfaces, low albedo construction materials, landfill emissions, and degraded or depleted green cover in the area. Another important factor of contribution is the presence of densely built spaces that do not allow proper wind flow and trap the heat within the city instead of allowing the natural wind-cooling processes (Nuruzzaman, 2015).

The consequences of such a UHI effect are manifold. Due to the significantly hotter pressure points that occur in the cities, the energy required to cool these spaces also increases creating a larger demand for the generation of electrical power which in turn contributes to increased release of greenhouse gas emissions and a degenerating climate (Nuruzzaman, 2015). Moreover, in India over of our electrical power is generated from burning coal which further magnifies air pollution and greenhouse emissions into the atmosphere. The detrimental effects of the UHI are observed most in the summer seasons when the pre-existing heat waves (caused by natural phenomena) are exacerbated leading to unbearable living temperatures in the cities. Record-high temperatures have been noted around the world and in India in the current year and have led to a multitude of ill effects such as heat strokes and deaths, increased dependency on air-conditioners and thus fossil fuels, agricultural loss and damage, droughts and water shortage, and more (Nuruzzaman, 2015).

To address the mitigation of climate change through sustainable development, it is necessary to pacify the consequences of the UHI effect on local scales which in turn will minimize the global impacts caused therein. The United Nations defines sustainable development as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” The mitigation strategies for the UHI effect are diverse and primarily consist of re-evaluating the methods of urban planning that have been utilized until now. Newly defined measures can be introduced in its stead which may include high albedo construction and paving materials that minimize the absorption of solar radiation, optimizing the ratio of hard to soft landscapes, increasing the number of water bodies that reduce ambient temperatures through evaporation, improved urban air ventilation to promote swift cooling action, improved management of solid wastes to reduce methane and hydrogen sulphide gas emissions, and finally, significantly increasing the green cover of cities in the form of dense foliage trees and native urban forest ecosystems (Nuruzzaman, 2015).

Table 1. The temperature of the city of Jaipur for the months of April, May and June

Grid no	Land use characteristics (Green and concrete areas)				
	Green area (km^2)	Green area %)	Concrete area (including road)	Concrete area (km^2)	Concrete area (%)
Grid 1	20.1	16	Very low	5	6.1
Grid 2	Vacant	Vacant	Vacant	Vacant	Vacant
Grid 3	24.6	20	Very low	10	12.2
Grid 4	47.1	38.5	Medium	50	61.1
Grid 5	48.4	40	Low	20	24.4
Grid 6	Vacant	Vacant	Vacant	Vacant	Vacant
Grid 7	30.9	25	Low	30	36.7
Grid 8	7	6.4	Very high	90	110
Grid 9	8	32	Very high	80	98
Grid 10	38.9	24	Insignificant	4	4.9
Grid 11	29.4	17	Insignificant	3	3.7
Grid 12	21.2	27	High	60	73.3
Grid 13	35.5	20	Medium	50	61.1
Grid 14	8	6.5	Insignificant	2	2.4

Increasing the level of natural vegetation in the city is observed as one of the most effective methods of reducing the impacts of UHI as large trees, shrubs, and plants allow for maximized sequestration of heat, pollution, and greenhouse gases such as methane and carbon dioxide hereby reducing ambient temperatures. At the same time, they allow for cooling through the provision of shaded spaces, improved hydrological cycles and rainfall patterns, pervious surfaces, and evapotranspiration which further alleviates trapped heat in the cities, together mitigating the local and global effects of climate change (Elizabeth and Barnes, 2019).

2. Literature Study

The importance of climate change is no longer a fact of theory or something which is distant from reality (Bose, 2024). As the occurrence of wildfires and hurricanes, the world facing stronger storms is the day that passes by at regular intervals, also the happening of serious drought conditions, ultimately resulting in loss of biodiversity, destruction of food supplies and existence of many landscapes also get destroyed. Thus, it is a very serious matter which should be considered very seriously (Lustgarten, 2020; Watson, 2023).

Due to rapid urbanization, the Urban Heat Island effects at Metropolitan areas are mostly due to overuse of land areas in the form of paved surfaces, which mostly is used to trap the heat within the surfaces (Oke, 1973; Oke, 2003). Early reports state that climate change and increasing temperatures have adverse effects on human health and comfort in many urban spaces. For example, in cities like Hong Kong, Bangkok and Delhi there was an increase in the mortality rate from 4.1% to 5.8% at increase in each degree of temperature from the threshold temperature of 29 °C (Aleksandrowicz, 2017). As per a report during 2016, almost half of the world’s population resides in urban areas and by the end of the year

2030, it is being projected that the urban population will constitute almost 60 percent of the world's population, one out of three people would be residing in urban spaces (WHO, 2016). This would increase the risk of UHI effects, thus disturbing the functionality and habitat adaptability of the ecosystems of urban spaces. Henceforth, it has an adverse impact on health and comfort, air quality index, energy management and urban planning (Mohajerani et al., 2017; Jabbar et al., 2023).

3. Case Study

To give a sustainable solution to climate change, the case study of the city of Jaipur has been done in terms of temperature, UHI effect and Energy Consumption. For this, firstly the existing Land use plan of the city of Jaipur (Fig. 1) is being divided into 14 grids with temperature and characteristics of 36 points to be considered. Then the Temperature data was taken for each individual grids for the month of April, May and June.

The grids were named and divided based on the core area of the city and the surrounding area of the city with the possibility of further development. Thus, utilizing the above-mentioned data, the UHI intensity has been calculated and then finally the average UHI Intensity has been calculated (Bhattacharjee, 2021).

Table 2. The temperature of the city of Jaipur for the months of April, May and June

Grid no	Area name	Typology	Temperature (°C)		
			April	May	June
Grid 1	Diggi Village	Rural	33.4	36.8	39.2
Grid 3	Khatipura Rd.	Sub urban	36.1	39.1	40.3
Grid 4	MGM Hospital	Wellness (Institutional)	39.6	42.8	45.3
	Jaipur Airport	Transportation	39.6	42.8	44.9
	Pratap Nagar	Residential	37.9	41.6	44.8
	IMD	Weather Station	35.8	39.5	42.6
	Sitapura Industrial Area	Industrial	37.7	41.2	43
Grid 8 (A)	Chand pole	Mixed Use (Walled City)	40.2	43.5	44.3
	Choti Chaupar	Mixed Use (Walled City)	38.5	43.5	44.3
	Badi Chaupar	Mixed Use (Walled City)	38.5	43.5	44.3
	Subhash Chowk	Commercial (Walled City)	41.2	45.7	46.8
	Ghat Gate	Commercial (Entrance) (Walled City)	40.2	45.3	46.8
	Sanganeri Gate	Commercial (Entrance) (Walled City)	41	45.1	47.2
	Ajmeri Gate	Commercial (Entrance) (Walled City)	38.6	44.9	46.7
	Sanghi Farms, Tonk Road	Commercial	39.1	42.6	44.8
	University of Rajasthan	Educational	38.5	41.9	44.5
	Panchvati Circle, Raja Park	Residential	38	42.8	45
	Gaurav Towers	Commercial and Recreational	39.3	43.6	45.2
Grid 8 (B)	Jawahar Circle	Traffic Junction (Green Space)	33.6	38.8	40.2
	Central Park	Green Space	30.5	32.5	35.8
	Golf Club, Rambagh	Green Space	30.6	32.5	36.2
	Secretariat	Administrative	36.1	41.5	42.3
	Jaipur Railway Station	Transportation	38.2	40.8	45.2
Grid 9	Vaishali Nagar	Residential	39.5	43.6	44.8
	Jhotwara	Residential	38.9	44.5	45.6
	Pratap Nagar	Residential	38.7	44.2	45.3
	Purani Chungi	Residential	35.6	44.4	45.8
	Shyam Nagar Police Station	Community Facilities	35.7	41.5	42.6
	Chitrakoot Stadium	Recreational	33.5	37.6	40.8
	Amrapali Circle	Traffic Junction (Transportation)	34.4	38.3	41.5
Grid 10	Sirsi Road	Sub -urban	-	-	-
Grid 12	VKIA	Industrial	35.7	40.3	42.6
	Trident Hotel	Recreational	35.8	40.8	41.5
Grid 13	Jhontwara Industrial Area	Industrial	37.5	41.1	43.5
	Akerpura Village (7 km ahead VKIA)	Rural	35.1	39.8	43.1
Grid 14	Kalwar Road	Sub -urban	34.3	38.1	40.6

Table 3. The average temperature of the city of Jaipur for the month of April, May and June divided by 14 grids (as shown in Fig. 1) (source – author)

Grid no	Typology	Average temperature (°C)		
		April	May	June
Grid 4	Surrounding Area	37.8 (TS4.1)	42.1 (TS4.2)	44.1 (TS4.3)
Grid 8 (A)	Core Area	39.4 (TU1)	43.9 (TU2)	45.4 (TU3)
Grid 8 (B)	Surrounding Area	33.8 (TS8.1)	37.2 (TS8.2)	39.9 (TS8.3)
Grid 9	Surrounding Area	34.5 (TS9.1)	39.1 (TS9.2)	41.6 (TS9.3)
Grid 12	Surrounding Area	36.7 (TS12.1)	40.95 (TS12.2)	42.5 (TS12.3)
Grid 13	Surrounding Area (Rural)	36.3 (TS13.1)	40 (TS13.2)	43.3 (TS13.3)

The existing land use map of Jaipur, that has been adopted from the draft of Master Development plan 2025, is divided into 14 grids of equal size 1.960x12.694 sqm each. In reference to the land use plan (Fig. 1) the existing areas of green spaces and the area of the concreting spaces (including the roadways) have been shown in Table 1. Then, the above-mentioned temperature readings are being recorded at the selected locations for the months of April, May and June.

The readings were taken from a time window of 12:00 PM to 3:00 PM, for three consecutive months. Subsequently, the monitoring was undertaken in respect of identifying 36 locations marked within the grids of the existing Land use map during the months of April, May and June and presented in Table 2.

Table 4. The UHI Index (Urban Heat Island Index) of the city of Jaipur for the month of April, May and June divided by 14 grids (Fig. 1) (source – author)

Grid no	UHI in April (TU1 – TSn.1)	UHI in May (TU2– TSn.2)	UHI in June (TU2– TSn.2)
Grid 4	1.6	1.82	1.28
Grid 8 (A)	5.6	6.7	5.5
Grid 9	4.9	4.8	3.8
Grid 12	2.7	2.95	2.9
Grid 13	3.1	3.45	2.3

Along with other important features like grid numbers, typology and description of the location. Then utilizing the temperature data, the average temperature for all the three consecutive months (April, May and June) has been calculated. Which helped in the calculations of UHI intensity of the individual.

Henceforth, it has been observed that Grid 8 has a maximum UHI intensity. As energy consumption plays one of the vital roles in climate change, UHI effects global warming. Thus, per capita energy consumption separately for the core area of the city and the surrounding developing area of the city is being calculated using the following formulas.

$$CP = (ECn \ / \ Pnc) \quad (1)$$

where; *CP* = per capita energy consumption of the city core, *ECn* = energy consumption in KWh, *Pnc* = population of the area.

$$DAP = (ECn \ / \ Pnd) \quad (2)$$

where; *DAP* = per capita energy consumption of the surrounding (developing area, *ECn* = energy consumption in KWh and *Pnd* = population of the area.

Also, the per capita energy consumption between the core area and the developing (surrounding) area is being compared to getting the knowledge of the amount of increase in the energy consumption in between the core area with maximum concrete surfaces and the lack of open and green surfaces and the developing areas which have a scope of development with the presence of open and green surfaces. For this, the formula referred are,

$$PC\ (\%) = AI = ((CP - DAP) \ / \ DAP) \times 100 \quad (3)$$

As it is observed, the UHI intensity of the core area of the city is maximum. So, the average UHI is being calculated using the formula,

$$UHIAV = (UHI1 + UHI2 + UHI3) \ / \ Ln \quad (4)$$

where; *UHI1* = UHI of the core area for the month of April, *UHI2* = UHI of the core area for the month of May and *UHI3* = UHI of the core area for the month of June.

Then the relationship between Urban Heat Island effect and energy consumption is based on the formula,

$$UHI \ / \ °C = AIn \ / \ UHIAV \quad (5)$$

where; *AIn* = percentage of increase of energy consumption corresponding year per capita consumption.

AIn is calculated using a three-step formula.

$$AIp = (AImax - Aimin) \ / \ n \quad (6)$$

$$AIn = AImax + AIp \quad (7)$$

4. Inferences

1. The average temperature for the month of April, May and June are found to be maximum at Grid 8 (core area of the city) and minimum at Grid 4 and Grid 12 (Table 3).
2. The UHI intensity is found to be maximum at Grid 8 (core area of the city) and minimum at Grid 4, Grid 12 and Grid 13 (Table 4).
3. The isopleth graph as shown in Figs. 2-4 clearly shows that the core area temperature is maximum at Grid 8, and it decreases from Grid 3, Grid 4, Grid 9, Grid 12 and Grid 13 (Figs. 2-4).
4. By the calculation of per capita energy consumption using the above-mentioned formulas it is clearly observed that the energy consumption of the core area is much higher than the developing or the surrounding area (Table 5).

5. Mitigating Measures

To address the UHI effect, certain mitigating measures have been spelt out in the present paper partly to reduce UHI and partly to address the issue of sustainability. Special emphasis has been made on Urban Forestry along with other measures**.** Some of the general mitigating measures are listed.

- Providing adequate urban air ventilation,
- Optimization between concrete to non-concreting urban surface area,
- Optimization between vertical to horizontal spread of buildings,
- Green buildings,
- Green roofs,
- Eco-friendly pavements and roads in the walled city of Jaipur,
- Trees having sufficient shadow along roadsides,
- Providing parks and gardens at environmentally compatible locations,
- Reduction in carbon footprints in urban areas and
- Infusion of urban forestry.

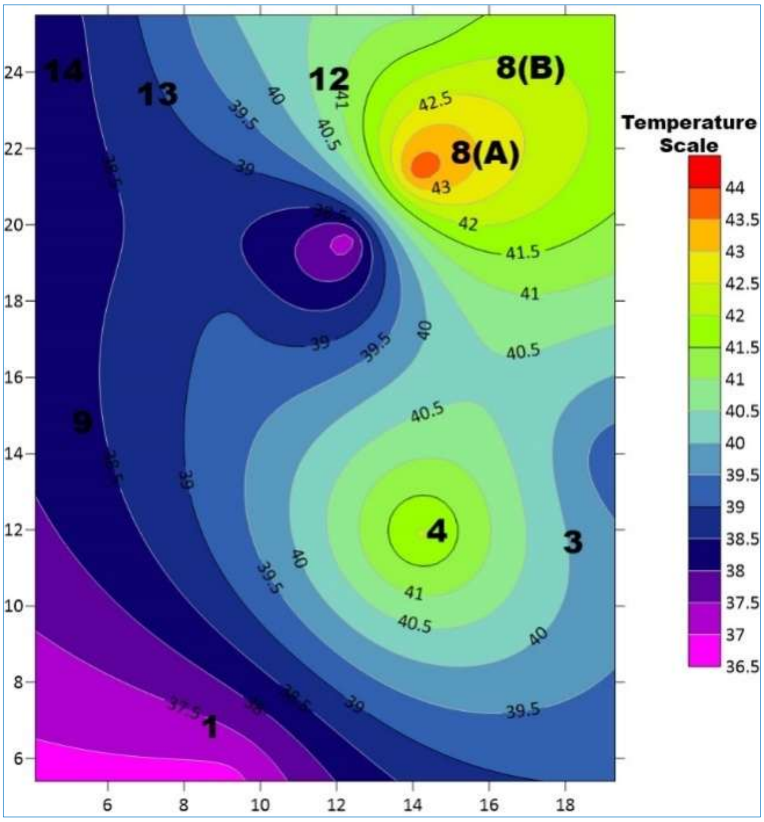

Fig. 2. The isopleths of the city of Jaipur in reference to the existing land use plan for the month of April 2024 (in reference to the Fig. 1) which indicates the decreasing UHI intensity from the core area to the surrounding area of the city

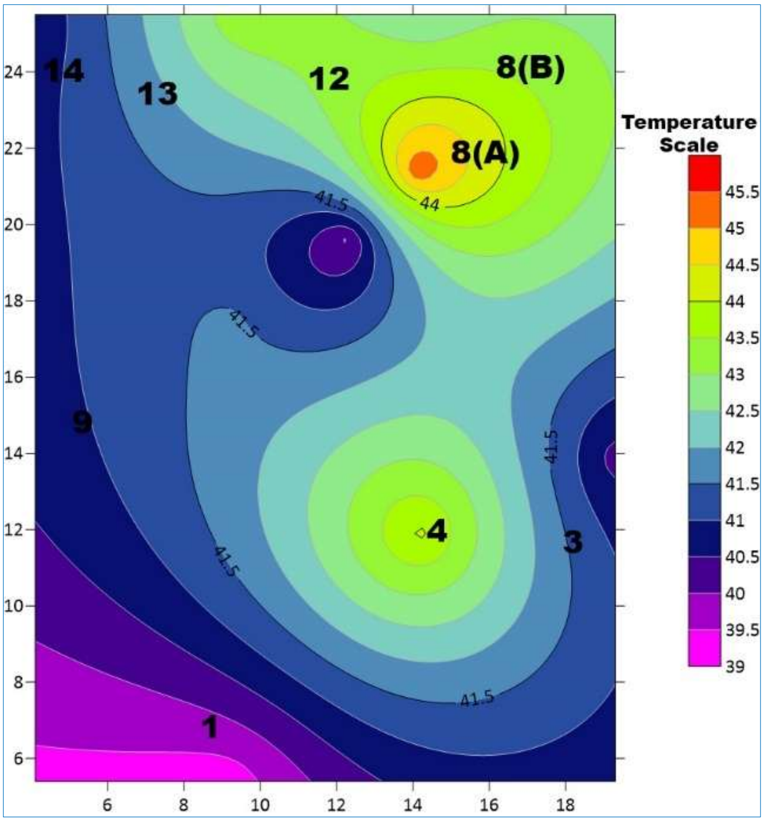

Fig. 4. The isopleths of the city of Jaipur in reference to the existing land use plan for the month of May 2024 (in reference to Fig. 1) which indicates the decreasing UHI intensity from the core area to the surrounding area of the city

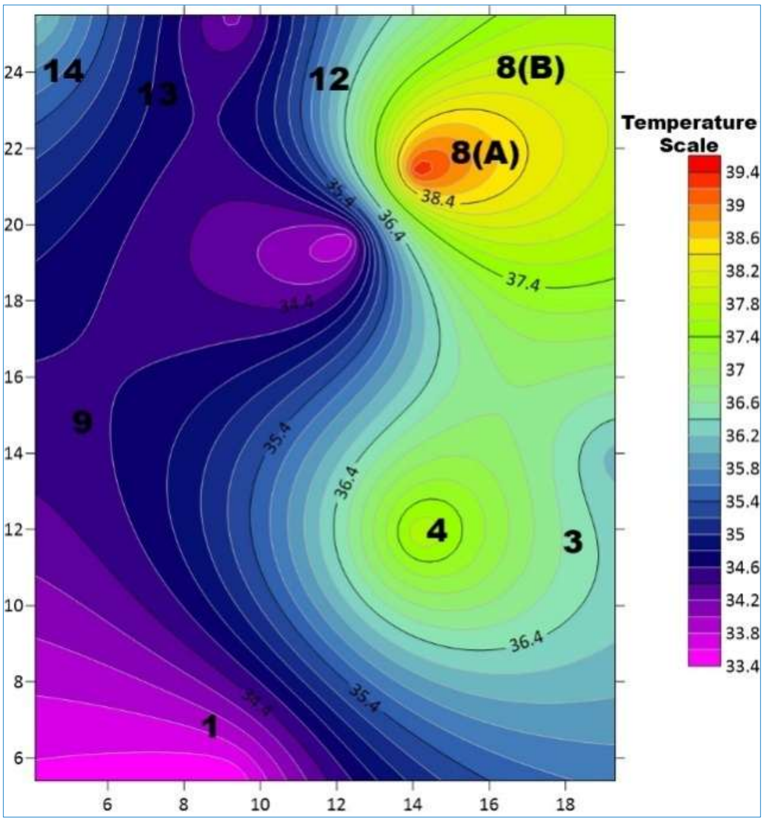

Fig. 4. The isopleths of the city of Jaipur in reference to the existing land use plan for the month of June 2024 (in reference to the Fig. 1) which indicates the decreasing UHI intensity from the core area to the surrounding area of the city

6. Urban Forestry

Urban forestry is generally defined as the art, science and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits . Urban forestry and urban greening are one of the most substantial factors for sustainable urban development, which can contribute towards a good quality of life and sound environment including reduction in UHI. It includes planning and managing woodland, parks, gardens, street and square trees, and other green areas within urban agglomerations. Urban sites are often harsh, characterized by many pressures and threats, from limited growing space to adverse climatic conditions and air pollution.

6.1. Proposal of Urban Forestry

6.1.1. Green Trees on Both Sides of the Entire Outer Ring Road of Jaipur

The shadow trees are proposed to be planted 10 meters distance from each other. The trees would have a top diameter of 5 meters approximately. Thus, the Top Green area to be considered for one tree is almost 25 m^2. The approximate length of ring road is 500kms. Therefore, if we consider tree plantation on all sides of ring road, the trees shall be planted in a stretch of 1000 kilometers (500 kilometers on each side). Thus, the total green area from the trees on both sides is 500 hectares.

6.1.2. Green Belt of 50-meter width all Around Ring Road

Green belt surrounding the entire city of Jaipur with 50-meter width is proposed to be provided having 150 kms circumferential length of Jaipur and having an urban forestry of 950 hectares.

6.1.3. Green roofs of all buildings in Jaipur

It is proposed to Convert all the existing roofs of the buildings of the city of Jaipur to Green Roofs. As per a report of 2014, the number of existing buildings of Jaipur was 4.5 lacks which have been increased to around 15 lacks at present. Considering around 40 m^2 on an average basis, the roof green covers involved in the form of green roofs would be around 6000 hectares.

6.1.4. Green Parks and Gardens

The existing and proposed Green Parks and Gardens would be approximately 500 hectares. Henceforth, the total proposed area for Urban Forestry would be = 500 + 950 + 6000 + 500 = 7950 hectares. In case 7950 hectares of urban forest is developed in Jaipur, the urban temperature would be reduced thereby significant reduction in UHI.

6.1.5. Proposal of Trees for Urban Forestry

The creation of urban forests can influence and reduce the urban heat island effect through their ability to absorb carbon in tree biomass. The native vegetation of Jaipur is tropical in nature, ranging from tropical semi-arid thorn scrubs to tropical dry deciduous forests. A plant diversity study of the Jhalana forest of Jaipur, which encompasses around 17 km^2 falls in the biodiverse and ecological region of the Aravalli Mountain Range shows 40 native species of the region that are most suited to its climate and form the constituents of its indigenous forest typology (Karmakar et al., 2019). Another study aimed to understand the potential of carbon sequestration of essential trees of tropical dry deciduous forests was referred to help quantity the amount of carbon absorbed per hectare by such forest landscapes. In the study, forest trees of the Barjora Forest, Bankura, and Ballavpur Wildlife Sanctuary, Bolpur, were analyzed for their carbon sequestration potential per hectare. It was found that the average tree that exists in these tropical forests absorbs around 18,039 kg/ha of carbon in their biomass, hereby reducing the presence of atmospheric carbon dioxide and consequently the trapped solar radiation (Agarwal and Rijhwani, 2021).

Table 5. The per capita energy consumption of the core area and the developing area of the city. Also gives the per capita increase in the energy consumption in between the core area and the developing area (source – author)

Year	Per Capita Energy Consumption (City's Core Area) (CP)	Per Capita Energy Consumption (Surrounding Area) (DAP)	Per capita Increase in Energy Consumption (Core vs Surrounding)	% Increase (Core vs Surrounding) (AI)
2013	1586.96	993.74	593.22	59.7
2014	1474.60	1014.19	460.41	45.4
2015	1549.44	1063.74	486.25	45.7
2016	1626.17	1071.64	554.53	51.7
2017	1668.05	1109.19	558.86	50.4
2018	1757.61	1157.41	600.2	51.9
2019	1793.85	1210.29	583.56	48.2
2020	1829.73	1222.94	606.79	49.6
2021	1857.18	1271.86	585.32	46.02
2022	1894.32	1325.28	569.04	42.94
2023	1941.68	1384.92	556.76	40.2

Table 6. The average UHI of the core area of the city and the percentage of increase in the electricity consumption with the increase in per degree of UHI (source – author)

Average UHI (UHI AV) (City's core area)	Average % energy increase per capita	UHI/°C
6.15	40	6.5 % electricity consumption increases with per degree increase in UHI

7. Proposal for Sustainability

The reduction of UHI in Jaipur by way of infusing urban forestry as stated above would be able to reduce urban temperature which would lead to reduction in energy consumption as per the findings of the present paper. It has been found out that with 1 degree reduction of UHI, there will be 6.5 percent reduction in energy consumption. The total energy consumption in Jaipur is in the order of 325600000 per day. It thus shows that having 1 degree reduction in UHI with 6.5 percent reduction in energy consumption, there will be energy saving of 19536000 units per day. The average energy cost in Jaipur is 6.5 Rs. per unit which would tend to indicate that there will be economic saving of 12.7 crore of rupees per day or 4635 crores annually. Similarly with 2-, 3-, 4- and 5-degree reduction in UHI, there will be economic saving of 9270, 13905, 18540, and 23175 crores annually respectively. It clearly shows that there will be significant sustainability on the economic front. In addition to the above, the reduction in UHI by way of urban forestry, there will be reduction in diseases. The air pollutant generated in Jaipur will be reduced through urban forestry because urban forestry will act as scavenging mechanism to reduce air pollutants. For example, CO_2 to the extent of…. will be reduced per hectare of urban forestry which would mean that there will be 158086.3 tons of CO_2 reduction from 7950 hectares of urban forestry. Thus, it tends to show that there will be a reasonable sustainability factor on the front of physical health, economy, and air pollution.

Besides, with the scientific development of urban forestry in Jaipur, there will be a strong inflow of tourists from outside. This will enhance the economy of Jaipur, thereby leading to strong sustainability in the front of economy and tourism.

8. Conclusions

Henceforth, this paper would be concluded by the statement that the presence of concrete structures would lead to an increase in the surface temperatures resulting in the increase of the Urban Heat Island Effect within the spaces having high number of Built-up spaces. Thus, in order to reduce the temperature increase, heat island effect and energy consumption, we need to increase the number of green covers across the core area of the urban space. The idea of urban forestry should be encouraged and should be implemented, which not only increases the air quality, helps to create a comfortable environment but also helps in the sustainability of that area. Nevertheless, this paper deals with all the above-mentioned points with the effort that the proposals would make the urban areas better and more comfortable places to live in.

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