Urban Heat Island Studies and its Effects Across the Different Cities of the India – A Review

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Abstract
Rapid urbanization in India has provided people with improved quality of life, but this excessive and uncontrolled rise of urbanization has also fostered the urban-rural temperature difference. This difference of temperature is termed as Urban Heat Island (UHI) effect which makes cities more susceptible to climate change. Cities in India are experiencing extensive urban development, with urbanization rate increase of 4% from last decade (Onda et al., 2019) and deteriorating climate conditions. As the research publication to calculate UHI in Indian cities have doubled in last 5 years, a complete review of the results and showcasing the directions in which research has been progressing is necessary to add more clarity for the scientific community. This paper comprises of a review of 50 research articles published across peer reviewed journals in last decade, covering 38 cities. It was found that Delhi, Mumbai & Ahmedabad are most frequently studied, and satellite-based method to calculate UHI has been used predominantly. Some studies have shown significant implication of UHI in terms of determining variation in micro climatic zones across cities, increased demand of energy consumption and degradation of the environment. Some studies have also talked about different mitigation techniques that can be followed by the cities to minimize the effect of UHI on its residents. With similar type of urbanization, climate, cities can mutually benefit from collaborative approach for research to undermine the effects of Urban Heat Island.

1. Introduction

Urbanization provides cities with potential to transform the lives of people residing in it (World Bank Group, 2015). But as the population of cities expand exponentially, the demand for basic facilities for each one is also increasing. With unplanned urban growth we are bound to see damage on natural resources, increase in urban sprawls and development of UHIs. The development of UHI is mainly attributed to urban structures which absorb heat during the day and dissipate during night. UHIs are also result of anthropogenic heat elements present in today's world like automobiles, air-conditioning systems (Roy et al., 2011). India is home to nearly 18% of the total population of the world, with population density close to 460 per km^2). It faces urban growth challenges on various aspects making it most vulnerable on climate change As some of cities of India have become megacities with huge influx of people from rural to urban areas, these cities face some widespread destruction of the environment with its corresponding effect over human health, urban microclimate and increase in anthropogenic heat emission. (Kumar and Shekhar, 2015).

Urban heat Island Effect has been described as the temperature difference between urban and rural areas (Oke, 1982). Intensity of urban heat varies according to built-up areas such as densely surrounded urban areas have higher temperature, which can act as an asset to reduce energy load in high-latitude countries where there is heavy load on heating elements; but in mid/low latitude countries, UHI leads to heating discomfort among the city dwellers and higher load on air conditioning systems. Although many researchers hold the opinion that an increase in urban heat is due to rapid urbanization, there are also several other factors which directly or indirectly have contributed to this phenomenon. Factors such as absorption of solar radiation by ground surfaces as well as by building walls, have led to higher ground temperatures. The UHI is a thermal anomaly having its effect in vertical, horizontal and temporal dimensions.

Although urban heat island studies have been done across the world in different regions, but much of its effect has been felt over the areas which are near to tropics and far away from pole (Tzavalli et al., 2015). While it is mostly a nocturnal phenomenon, it also occurs during the daytime with a spatial and temporal pattern strongly controlled by the unique characteristics of each urban area (Escourrou,1991).

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Table 1: Classification of Urban Heat Island Types with Scale and their likely impacts

UHI Type - Scale	Impacts
Subsurface; Micro (1–100s m)	Engineering design for water pipes, road construction, permafrost, groundwater characteristics, and carbon exchange between soil and atmosphere
Surface; Micro (1–100s m)	Thermal comfort, planning and mitigation measures, temperature of storm water runoff, and health of aquatic systems
Local (1- <10Km)	Thermal comfort, building energy use, water use (irrigation), thermal circulation if winds are light, air quality, urban ecology, and ice and snow
Meso (10s Km)	Air quality, photochemical pollutants, local circulation, precipitation and thunderstorm activity downwind, and plant growing season

Due to complex structures and design of our cities, the Urban Heat island has been classified in four different scales as described in (Table 1) – Micro-Subsurface, Micro-Surface, Local/Urban and Meso (Erell et al., 2011 and Roth, 2012).

As there are various scales at which urban heat island might exists within a city, there are number of various approaches and models which have been studied by researches to undermine the effect of UHI (Kumar and Shekhar, 2015). The temperature changes at local level or at Urban scales are mostly studied using thermal scanners onboard the satellites. Other types of UHI like at Subsurface and Meso levels are mostly measured using sensors fixed with the vehicles or fixed stations present with the weather departments (Arnfield, 2003 and Shastri et al., 2017). The statistical and Numerical modelling approaches have also been formulated to understand the effect of Meso Scale Urban Heat islands.

Urban Heat island is a global phenomenon which has been affecting the urban climate at a considerable rate. With continuous change in temperature, this topic has been one of the important research areas as it is clearly visible with amount of studies being published across various research journals. However, studies done on Indian cities have been limited to change in Landuse Landcover(LU/LC) and Temperature. The Urban Heat island also has effects over Energy Consumption, increase in thermal discomfort and Adversely affecting the health of the humans, which also needs to be studied to provide better mitigation plans for the cities. This paper aims to review current studies relating UHI with energy consumption and provide more systematic overview to scientific community so that more clear understanding of UHI and its effect can be stated and more research in these areas can be done.

2. Methods

The studies reflecting the change of Land Surface temperature and Urban Heat Island in India has been in research since early 1980s. The topic has seen consistent interest of researchers as there has been continuous increase in published articles every year (Figure 1). The initial research started by finding articles of UHIs studies across India and total of 200+ articles were found. The search was narrowed down with more focus on finding articles which studied the relationship of Land surface temperature, Urban Heat island and Energy Consumption (Figure 2). After defining the criteria only 50 papers were found which had focused in area of UHIs, LST and its impact. The selected studies were found to be based majorly on the megacities like Delhi, Mumbai and Chennai, but it was also observed that cities like Bhubaneswar, Jaipur & Ahmedabad have also been studied by the researchers (Mathew et al., 2018).

3. UHI Studies and Impacts

Various studies which were focused on understanding UHI and its effect has been further classified into methods used by various investigators to explain the relationship between Land Surface Temperature, Urban Heat Island using Indices like Normalized Difference vegetation index (NDVI), Normalized Built up Index (NDBI) , increased energy usage and deteriorating human health.

3.1 Timeline of UHI Study in India

The earliest study conducted on UHI were in 1980s with focus on major cities like Delhi & Mumbai. All these studies documented the effect of excessive urbanization over local climate zones of the city. As cities developed small hot spots areas in highly concentrated urban areas compared to other areas (Deosthali, 2000).

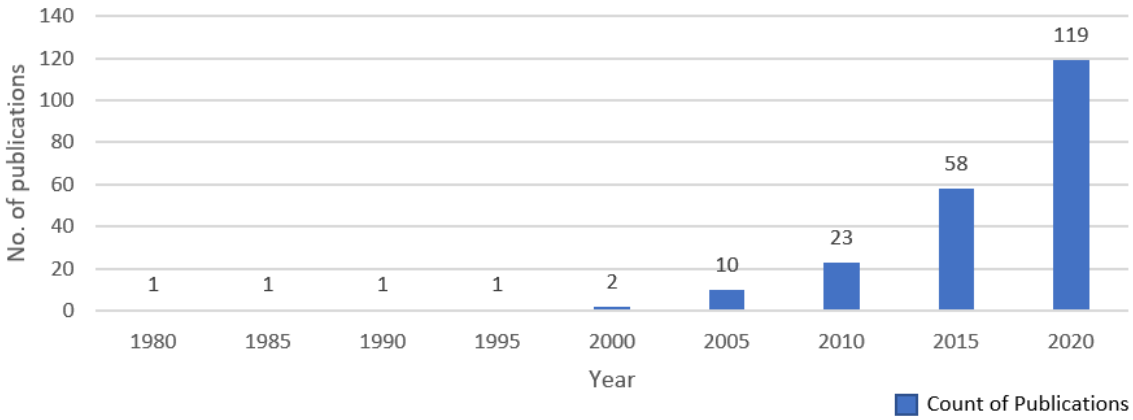

Figure 1: Cumulative count of study on UHIs in India across 4 decades

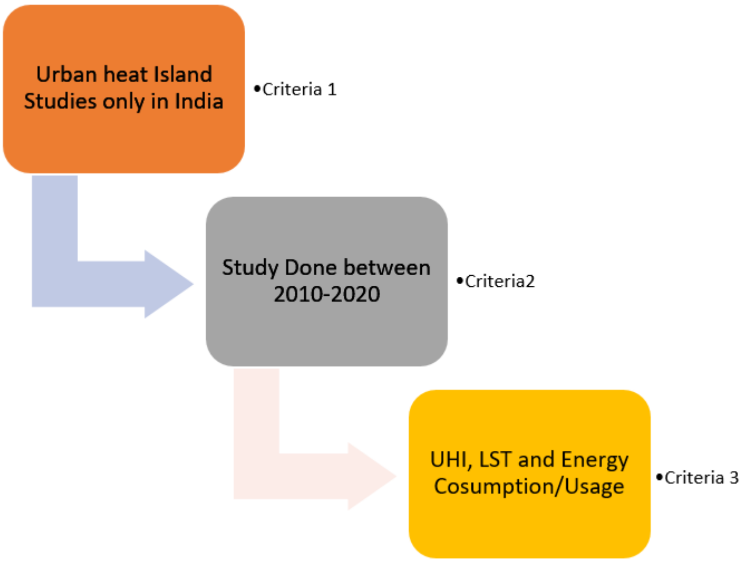

Figure 2: Methodology for selecting studies for review

More studies were done over the period of 90s, and it was established that not only Delhi or Mumbai, but cities like Pune, Vishakhapatnam, Chennai, Ahmedabad are all reeling under the effect of UHI (Gadgil & Deosthali, 1994). With the easier availability of thermal images and more observational studies being done, there was a massive increase in the amount of studies which were conducted by researchers to determine the relationship of Land surface Temperature and Urban Heat Island by the end of 2000. The earlier studies solely relied on change is Landuse Landcover to correlate the change in temperature, but by 2000s, it was also clear that emissivity also plays major role in determining warm areas of the city (Prasad and Badrinath, 2003). With more and more studies being done of Landuse/Landcover effect of UHI, there has been consistent gap on studies focusing on changes in energy usage w.r.t to UHI trends. This Gap needs to be addressed with ever increasing urban population.

3.2 Tools and Methods for Calculating UHI

UHI studies have been carried out through multiple methods with each of the technique having its own merit & demerit. These techniques are majorly divided into satellite based, mobile/fixed station-based surveys and statistical & numerical models. With the advancement of more satellite images being available around 80% of the studies being studied in this review were done using satellite based thermal sensors.

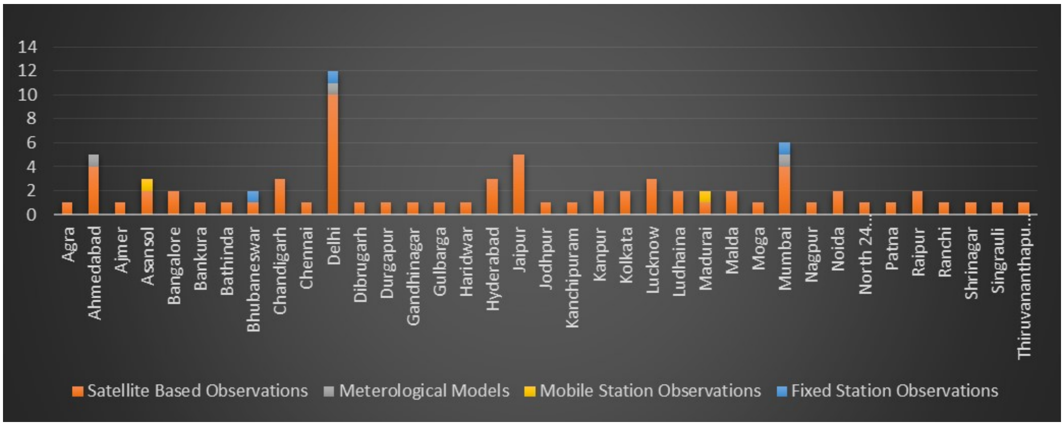

Figure 3: Count of Studies done using various methods across cities

Most used satellite data was Landsat followed by Moderate Resolution Imaging Spectroradiometer (MODIS) & Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (Mohammad et al., 2019). While station based surveys were done initially for cities like Delhi and Mumbai (Mirzaei and Haghighat, 2010), but recent studies have relied majorly on thermal data obtained from thermal sensors, therefore has been increase in the studies being done on various other cities of India like Nagpur, Bhubaneshwar, Lucknow and Kanpur (Rani et al., 2018, Swain et al., 2017 and Sultana and Satyanarayana, 2019). As satellite-based studies are also cost effective and provide greater spatial extent which can be covered depending on researcher's area of interest. But satellite images have its own demerit attached to it, like satellite images with cloud cover presence in the scene, time of collecting the image, might provide some erroneous results. Hence critical analysis of the raw satellite image is necessary to calculate UHI. Though Station based surveys are complex and time consuming as they also do not provide data over extended time period, they have their own merits attached to it like, they help in collecting accurate, real world observations of heat flux, temperature changes and magnitudes by which different urban material corresponds of the heat. Below (Figure 3) showcases how studies have varied across different cities across last decade.

3.3 Summary of Existing Research Across Various Cities in India

The existing literature on Urban Heat Island studies across India has majorly focused on mega cities of India like Delhi and Mumbai. As around 15% of the reviewed articles have focused on these 2 cities, followed Jaipur, Ahmedabad & Hyderabad (Figure 3). With availability of better remote sensing satellite and free access to data, there has been increase in study across Tier2 cities of India like Moga, Malda, Madurai and Asansol (Mukherjee et al., 2017, Subhashini et al., 2016 and Choudhury et al., 2019). The current review focuses on such cities were in minimum of 5 studies have been found in the literature.

3.3.1 Delhi

While Delhi had been extensively been studied across many years, but the recent studies have now also started including National Capital region (NCR) due to unprecedented development in the outskirts of Delhi and modernization of cities like Noida which form the part of NCR (Suhail et al., 2019). Early studies on Delhi region were focused on understanding the diurnal temperature change between daytime and night-time (Mohan and Kandya, 2015). In one of the studies over Delhi, a very important comparison of landlocked city vs coastal city was done by comparing Delhi & Mumbai. The comparison highlighted that Delhi has very few UHI hotspots due to extensive green cover across many pockets of the city and city only faces more heat areas in its outer periphery due to absence to such tree covers. Also, as Yamuna flows from within the city it negates the effect of UHIs present due to anthropogenic heat as core areas of Delhi are densely populated. But when compared to Mumbai, it has many spots which real under the effect of UHIs due to large number of High-rise building, dense urban agglomerations and very less tree cover. Being a coastal city, the waterbodies should act as sink, but fails to act, as heat is trapped due to high rise buildings and there exists negative correlation between NDVI and UHI (Grover and Singh, 2015).

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In another study using non-parametric approach to calculate UHI, it was highlighted that Delhi has both positive and negative trends of monthly land surface temperature. (Panwar et al., 2018). This study was done to over a period of 14 years to understand the pixel wise temperature change over Delhi.

In last 5 years the studies across Delhi have focused on analysing land surface temperatures with dense urban landscape and variation in UHI with season change along summer and winter months. One of the researchers studied spatial relationship between LST and landcover types were analysed during winter season (Sultana and Satyanarayana, 2019). This study was conducted using Landsat 7 ETM+ images which resulted in identifying that Delhi possess the highest UHI intensity range of 13.4–14.0 °C and in comparison, to other cities Kolkata had the least variation in UHI intensity range of 10.5–11.7 °C.

In only study relating to local climate zones (LCZ), researches empathized on climatic zones which are created over various parts of the city due to variation in the heat intensity. The evaluated that the greatest number of climatic zones were formed during monsoon period over Delhi followed by summer and winter months (Budhiraja et al., 2019). The study revealed that range of average LST values in LCZs is s ±2° C from the mean. The Urban heat island is significantly affected the method used to calculate LST. As the study observed some differences in LST when calculating using Landuse/Landcover approach.

In another study conducted over Delhi to determine the effect of UHI over total energy consumption and cooling energy demand, it was highlighted that negative correlation exists between vegetation and night-time LST. On performing the simulation using building energy model, it was found that parts of central Delhi had much higher consumption of energy in comparison to site located at rural areas. The researchers also specified that maximum cooling demand was observed during the summer season. With lower annual LST, the demand for energy was also lower and vice versa. Like for annual UHI ranging from 0.9 K to 5.9 K had annual electricity consumption upto 425.12 MWh/y and Similarly for UHI ranging 0.1 to 5.o0 (K), the annual electricity consumption was 401.21 MWh/y (Kumari et al., 2020).

3.3.2 Mumbai

Mumbai has been consistently studied, with earlier studies being conducted by Indian Meteorological Department (IMD) researchers (Kumar et al., 2001), but lately there has been marginal increase in the number of studies being done on this city. It being one of the most densely populated cities of the world, there is dire need of studies to undertake various issues related to increase in minimum temperature across city areas. Landsat 5 based study was conducted over the city of Mumbai which examined the linkage between UHI, LST NDVI & NDBI. The study highlighted that due to high concentration of buildings across various parts of the city, it experiences varied UHIs zones in it. Also, as mangroves and marshy lands are being converted into concrete zones, the suburbs of Mumbai have also started feeling the heat intensity across it. And lastly the Greenest areas across Mumbai are present near the coastal areas which are covered by Mangroves or the Sanjay Gandhi national park (Grover et al., 2016).

In another recent study on Mumbai (Dwivedi et al., 2019), the structure of urban areas was examined to have natural cooling effect. This research was one of its kind as it focused on reducing the heat load by reducing the energy consumption of the air conditioning system. Thermal images of structures across various locations of Mumbai were captured. The study envisaged the usage of Thermo IMAGER TIM160 and it was observed that stone and concrete areas had temperature range from 48-55 °C and that of green surface was found to be around 30-35°C. The research also focused on using structural ways of cooling the concrete material by using pipes, storage tank, pump and making some changes in the design of our building which would ultimately reduce our dependency on air cooling systems (Dwivedi et al., 2019).

3.3.3 Ahmedabad

Ahmedabad has seen continuous increase in urban areas from the last decade. This increase has not only attributed to conversion of green areas into urban, but also increase in Anthropogenic heat. Early studies that were done on Ahmedabad focused on defining the relationship between LST and UHI. But with better availability of thermal sensor data, the study conducted using Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor data analysed LST and also developed model to predict LST based on previous 10 years data. MODIS Sensor was used to provide LST product, Enhanced Vegetation Index (EVI) product.Along with LST & EVI, Road Density network with elevation data from ASTER was provided as an input to Model to predict LST for future years.

The study found that average UHI Intensity for Ahmedabad for 10 years was 6.54K. The study reported that with continuous increase in Urban areas, the core/central part of Ahmedabad has seen consistent increase in temperature compared to rural areas (Mathew et al., 2016).

In another recent study over Ahmedabad, researchers focused on Sabarmati river to determine the variation in microclimate near that and it was reported that average dip of 1.57 °C and 1.71°C is observed during summer and winter months. Landsat 5 TM multispectral images from summer and winter months for 3 consecutive years was taken into consideration (2009-2011). The LST showcased higher temperature in radial manner due to large number of industries present on the outskirts of the city. As city exercised almost negative surface urban heat island, it was concluded that this is due to Sabarmati river flowing through the central areas of Ahmedabad (Gupta et al., 2019).

Ahmedabad being one of the largest urban agglomeration city still needs to be studied on the effects of UHI on energy usage, human health in relation to rising temperature, as it would help authorities plan and mitigate the UHIs already present across the city.

3.3.4 Jaipur

Jaipur also known as Pink city is the 10th largest city of India. With ever increasing population, there has been studies which have mentioned that Jaipur city also realms under the effect of UHI. With recent study on Jaipur, it was established that negative Surface Urban heat island (SUHI) effect exist in city during Daytime, whereas during Night-time there was high SUHI effect which can be attributed to more urban areas and heat being trapped in the concrete the entire day. Hence SUHI was considered to be a nocturnal phenomenon (Mathew et al., 2018).

In another significant study over Jaipur to understand the different UHI intensity due to extensive urbanization, it was mentioned that, from 2002 to 2012 there was rise of 29% in the urban areas. Also, as Jaipur has mostly sandy and loamy-type soil, therefore undeveloped land also reported higher temperature than urban areas. The study reported that UHI phenomena exists in Jaipur city, but it is overshadowed by extensive heating of surrounding sandy and rocky areas (Sultana and Satyanarayana, 2018). Another study based on Satellite captured thermal data found that with extensive change in Landuse/Landcover from 2008 to 2011, Jaipur has witnessed significant rise in temperature for all LU/LC classes taken into the study. The study also evaluated impervious surface area (ISA) from Landsat 5 TM images of 2008 and 2011. For LULC classes during summer season, the study highlighted that there was rise of 1.45°C in residential area and 1.11°C in industrial section of the city. Imperviousness had also increased across LULC classes, with maximum being in roads and commercial areas due to newer roads expansion plans and more commercial areas being built up(Gupta et al., 2020).

As most of the studies in Jaipur have concentrated to showcase the need to study how LULC has impacted on development of UHIs across the city areas, there is still lack of research knowledge to understand the effect UHI plays on overall city by impact the energy demand and consumption and also highlighting the concerns over human health which, if investigated will provide us with answers on how to mitigate situation of developing UHIs.

3.3.5 Significant studies in other major cities - Hyderabad, Chandigarh and Lucknow

Hyderabad, Chandigarh and Lucknow have one major thing in common, all these cities are landlocked cities, but have source of water bodies present in centre of the city. Hyderabad has Hussain Sagar lake, Chandigarh has Sukhna Lake and Gomti river flows through central part of Lucknow. Water acts a sink for Heat generated across the city and it helps in maintaining relatively cool areas within its vicinity.

In recent studies on Hyderabad, Thermal sensors onboard Landsat 5 & Landsat 7 were used to study the variation of UHIs across greater Hyderabad region in correlation to biophysical compositions across different LULC classes. The study evaluated development in Hyderabad region from 2002 to 2015 and found that urban increase was 41.35 % to 62.87% with 4.01 km^2 $year^{-1}$ expansion rate. The study explained that LULC and biophysical indices like NDVI, NDBI are equally important to address the uncertainty of estimating UHI. It was concluded that integrated approach of using indices in composition with different LULC classes can be good indicator to control anthropogenic heat sources across the city (Sannigraphi et al., 2018).

Recent studies over Chandigarh were done to establish a prediction model to calculate UHIs areas across the city. The research envisaged the use of Support vector regression (SVR) model to estimate the areas n the city which are hotter when compared to rest of the city.

The study focused on utilizing LST data from MODIS from 2011 to 2013 as input to SVR model in which other variables like Enhanced vegetation index (EVI), Road Density were provided as independent variables, but it was found that each variable affects LST in its own unique way. But with sensitivity analysis done during the study, it was established that LST was most sensitive to road density followed by EVI. SVR model estimated Values and observed value had error less than 2K. hence it was concluded that SVR model can be an effective tool to better understand the heat sources across the city and plan accordingly (Mathew et al., 2019).

In the studies done over Lucknow, it was established that with change of city dynamics there is also change in heat sources across the city. The study conducted over the period of 2002 to 2014, it was found that mean land surface temperature of the city increased by 0.75°C. The urbanized areas in Lucknow increased from 93.97 Sq.km^2 in 2002 to 130.33 Sq.km^2 in 2014. The study highlighted the fact ecological evaluation index was less than 0 for many areas in central part of Lucknow, which directly correlated to increased level of heat across the structure (Singh et al., 2017).

3.3.6 Studies across other cities

While UHI studies are being carried out across many Indian cities, so they formed that part of the review, with some cities like Kolkata, Kanpur, Bhubaneshwar being studied by the researches. The study done on Kanpur highlighted the correlation between NDVI and LST to estimate the UHI (Rani et al., 2018) and another study focused on diurnal temperature changes over the city with season variations. The diurnal temperature study was performed using fixed station measurements where in it was found that surface temperature and air temperature acts as strong function to change in LULC (Chakraborty et al., 2017). In studies of Kolkata also the relationship between LST, Dense Urbanization over UHI was established. In the study conducted by researchers at Nanjing University found that increase of vegetation impacts UHI and Increase in LST was also correlated to presence to high particulate matter in the study area. This study was conducted over a period of 2008 to 2017 with the help of LST products available via MODIS imageries. The research also found that average heat island in Kolkata during daytime was 1.5K and night-time was 0.4K (Das et al., 2020).

Bhubaneswar being the city on banks of tributary of Mahanadi river, has also been experiencing urban heat as a result massive anthropogenic heat due to large movement of people coming towards this city. Recent studies over this city have highlighted that fact that rapid urbanization of this city of India, has created a way for UHIs present across different parts of the city. The study was done over a period of 15 years (2000-2014) and it was reported that over exploitation of natural resources have significantly increased the land surface temperature of the area. City witnessed 83% increase in urban areas over last 15 years, and 89% decrease in vegetated land leading to thermal discomfort across the city (Swain et al., 2017). In another major study by geoinformatics department of central university Ranchi, found that Urban ecosystem services (UES), play a pivotal role in maintaining thermal comfort across the city. As city was urbanized extensively from 1992-2016, UES supply and demand gap increased sustainably (Chaudhuri and Kumar, 2020). While another set of 15 cities were studies as part of this sample, most of researches have predominately focused on finding factors attributing to this change in local temperature across the cities. Most of them have suggested n their finding that degradation of LULC with massive decrease in vegetation, unexplainable increase in urbanization has been root cause for this cause and effect relationship between UHI, LST and NDVI.

3.4 Implication of Urban Heat Islands

The selected UHI studied across the sample have documented the fact that UHI intensity has increased over the city areas in last 10 years, as most of them report out various contributing factors to this UHI intensity. The majority have examined this increase in UHIs spots to change in Landuse Landcover. Specific studies across cities like Delhi, Jaipur have taken into consideration the impact of ISA. While UHIs have different scale at which it can be present, there is clear gap of knowledge to showcase UHIs present across different scale and extent of the city. Some studies in cities like Ahmedabad, Jaipur, Mumbai have reported UHIs in outer areas or suburbs, but lack the clear explanation of this phenomena. Most of studies have showcased the temperature increase with thermal sensors, but field surveys along with thermal data can provide more concise reality in terms of finding the solution to urban heat. In this review we have tried summarizing the impacts of UHI related to energy demand, health and environment.

3.4.1 Impact on energy demand and consumption

Though in most of the studied reviewed, there has been not been clear mention of this particular impact, as due to non-availability of the data for most of the study area, it becomes bit difficult to understand and correlate the demand increase due to thermal discomfort, but a very recent study focused on Delhi performed a simulation on calibrated building which were present across 3 different LULC classes. The central part of city where the building was surrounded with dense urban areas had annual building energy consumption rate of (425.12 MWH/y), in comparison to site located in rural areas where demand for energy was (381.13 MWH/y). The study with this calibrated information was able to showcase that with increased urban heat, there is presence of thermal discomfort , leading to increased demand for electricity consumption (Kumari et al., 2020). Similar studies also needs to be done across mega cities to understand how UHIs are impacting the energy load for particular area.

3.4.2 Impact on health due to UHIs

The human health has been important focus of study when it comes to understanding the relationship between urban areas and human health. There are constant studies being conducted to provide better liveable conditions for human living, but the sample of studies reviewed in this paper have not directly showcased the impact of Urban heat on human health. Only one such study done by researchers of Delhi university was found, wherein they focused on East part of Delhi, as most of Industries are in this area. They established the fact that prolonged exposure to pollution, continuous increase in Heat or development of urban heat islands significantly deteriorate human health. The study was performed by measuring change in Landuse Landcover of the area for past 10 years from 2000-2010. The study highlighted the fact that industrialization and urbanization are necessary, but its effects should also be studied regularly to undertake proper mitigation measures (Singh and Grover, 2016).

3.4.3 Impact on environment

Studies have focused most on this impact in their research, as it becomes quite evident with drastic change in city. With one of studies conducted near the site of thermal power plant in Singrauli, it was mentioned that spatial extent of forest from 2005 to 2015 had reduced considerably. As Singrauli is also known as "Powerhouse of India "as it is home to private and public thermal power plants. The study highlighted the fact from 2005 when thermal power plant was not present, the mean average temperature was around 20°C, but as construction started and it became operational in 2015, in span of 10 years the average temperature was around 27.39°C. This suggests that there has been massive degradation of the ecology in this area (Kumari et al., 2019).

3.5 Mitigation Ideas to Minimize Effect of UHIs

The constant effort to provide thermal comfort to human beings has been in place. But there are very few studies done in recent times which focus on mitigation of the Urban heat islands which are created as part of urbanization. UHIs depend upon variety of parameters, as reviewed in this literature, for some cities they might depend upon change in LULC, for others it is mostly affected by road density and some researchers have also mentioned about choice of material being used to develop urban areas. Therefore, strategies needs to be focused in such a way which are cost effective and can be applied across region.

One such study which mentions the mitigation techniques of green roof was done in Madurai. The study was conducted for a period of 1990-2009, to understand the change LULC promoted in creation of UHI. It was found that area under high built-up density increased from 12.73% in 1990 to 36.62% in 2009 leading to gain of 8.04°C average rise in temperature. As study focused on mitigating this rise in temperature, simulation-based study was done to estimate green plot ratio (GPR) required to bring out the average temperature of the city. The study predicted that GPR of 0.45 is good for low density built up areas, whereas the areas with high density of built-up will need GPR of around 0.6 which can bring the temperature down by more than 1.5°C in which trees plays a crucial role (Chandramathy and Kitchley, 2018).

4. Discussion and Conclusion

This review tried to provide overall picture of UHI studies being done in India with their major findings and conclusion. Though most of the current literature has been focused on quantifying the changes of LULC with UHIs across the city, very few studies have explored the cause and effect relationship of UHIs. As most of studies focused on understanding changes across major cities of India. Few have been also be done on Moga, Ludhiana, Srinagar & Thiruvananthapuram. The studies in these cities have also focused on change in LULC and how it has contributed to UHIs across the city (Arulbalaji et al., 2020 and Mukherjee et al., 2017).

Most of studies conducted recently have used satellite based images to conduct their research, but overall combination of field based survey and thermal images can be used to better formulate the results, as correlation of in-situ results with findings from imagery can provide more concise outcomes and better analysis of UHIs and hotspot areas of the city. As studied in this review there is clear gap in studies on finding the Impact of UHIs in daily lives of Human, it can be related to human discomfort, energy demand or environmental degradation. As UHIs plays a pivotal role in increasing the energy demand of the city, leading to an effect on the economy. With more focus on digital age, we need to find ways to correlate various findings of UHIs relating to change in temperature, with use of more cooling systems in the cities. With increase of heat in urban areas, there is natural tendency of human discomfort taking place and to make it quantifiable, we might need to assess our ways to make it relatable to UHIs.

There are very few studies which have started working on numerical/statistical model to establish the correlation with UHI and its impact, but we need encourage research in this area. As model development will provide us with better insights on dealing with the effects of UHIs. With cities experiences excessive development in urban areas and similar changes in LULC, they can benefit from each other by collaborative approaches to provide more mitigation solutions like Green roofs and more trees cover.

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