Review of Urban Heat Islands: Monitoring, Forecast and Impacts

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ABSTRACT

Urban Heat Island (UHI) is a phenomenon where higher temperatures are observed in the city centers as compared to its surrounding areas. The UHI effect has emerged as a potential hazard for rapidly urbanizing countries like India. It adversely affects energy usage, public health, economy and also contributes to climate change. This review paper presents global literature on research on the UHI phenomena, causal factors and its impact on various sectors. Rapid urbanization, economic development and climate change are key factors responsible for UHI. UHI intensity varies with climate, population density, anthropogenic heat and the green canopy, land use, and urban morphology. It calls for city-specific comprehensive studies to develop appropriate mitigation strategies. City Heat Action Plans should include measures to mitigate UHI impacts at the ward level. For this, the country needs to develop high-resolution UHI monitoring and forecasting capabilities. Mitigation and adaptation of UHI involves urban planning, green building codes, energy consumption, air pollution and would require a national plan for harmonizing UHI-related measures taken by central ministries, state governments and municipal corporations.

Keywords: *Urban Heat Island (UHI), Climate Change, UHI Impacts and UHI Forecasting.*

1. Introduction

The global urban population has witnessed unprecedented growth, growing rapidly from 751 million in 1950 to 4.2 billion in 2018. Nearly 68% of people will live in cities by 2050 compared to 55% in the year 2018 (UN, 2018). In India, the urban population has increased from 285.3 million in 2001 to 377.1 million in 2011 (Jaysawal and Saha, 2014, Census of India, 2011), which will be 600 million by 2030; and by 2050, more than 50% of the total population will reside in urban areas (WUP, 2018).

Increased urbanization has modified many biophysical processes influencing energy balance, infiltration, storm-water runoff, precipitation, temperature, air quality, carbon storage, and local biodiversity of an area (dos Santos et al., 2017). One of the alarming concerns of urbanization is a rapid increase of local air temperature as well as land surface temperature. Higher temperature in urban areas, relative to the surrounding peri-urban /rural areas, gives rise to what is popularly known as Urban Heat Island (UHI). UHI has been increasingly reported due to relative temperature difference within the city ranging up to a few degrees. There are several reasons attributed to the UHI effect within cities attributed to concrete structures, high building density, low vegetation, industrial areas, busy traffic zones and local geology. Busy commercial zones and areas with high building/concrete density are often responsible for the UHI effect because of vehicular pollution, heat exhausts, and air conditioning exhausts. (Phelan et al., 2015; dos Santos et al., 2017).

The intra-city urban heat islands form when the land cover dominated by natural vegetation, crops and water bodies is replaced by heat-absorbing impervious surfaces composed of materials like concrete and asphalt (Simwanda et al., 2019; Buyantuyev and Wu, 2010). These urban heat islands occurring continuously over the same area for a few days create heat waves and adversely affect human health.

There is preponderance evidence that anthropogenic activities have been primarily responsible for global warming. IPCC's Sixth Assessment Report (IPCC, 2021) states that it is virtually certain that hot extremes (including heatwaves) will become more frequent and more intense across most of the land regions in the coming years. Associated with the warming global temperatures, a warming trend in UHI intensity is observed in different cities worldwide (Kim and Baik, 2004; Lam, 2006; Lee et al., 2020.

Globally, extreme temperature events are increasing in their frequency, duration, and magnitude. Population exposure to heat is growing due to climate change and urbanization. The incidences of heat waves are also increasing in India. Over a period of 1990-2009, the mean annual temperature across India increased by 1°C relative to that during 1961-1990 (Sharma et al., 2019; Attri and Tyagi, 2010). In particular, during the summer months of March-May, the country faces heat waves in one or more areas almost every year (Mishra et al., 2017; Rohini et al., 2016; Pai et al., 2013). UHI also accentuates impact of Heat waves in urban areas.

2. Earlier Work on UHI

UHIs have been reported in the studies as early as 1833 using surface air temperature data. The Howard study (1983) provided evidence of relatively higher air temperature in London compared to surrounding countryside (Mills, 2006). Several studies have been reported since 1900, employing various techniques (Rasul, 2017; Stewart and Oke, 2009). Before the availability of satellite data, UHI phenomena were studied and carried out using field-based observation.

First studies of UHI through satellite data were carried out in 1970s. Rao (1972) used 7.4 km resolution thermal data from the Scanning Radiometer (SR) on-board ITOS-1 (Improved TIROS Operational Satellite-1) to study the urban environment in the city of Los Angeles, United States of America (US). He concluded that the central part of the city is the warmest. The analysis showed that the heat island intensity under cloudless skies was related to the inverse of the regional wind speed and the logarithm of the population.

Carlson et al. (1977) used 1 km resolution thermal infrared data from NOAA-3 Very High-Resolution Radiometer (VHRR) to compare temperature variations in the morning and evening in Los Angeles, US. They found that industrial areas within the city have higher temperatures in the morning, whereas residential areas exhibited increased temperatures in the evening. Byrne et al. (1984) attempted to correlate the Heat Capacity Mapping Mission (HCMM) derived nighttime surface temperatures with minimum air temperatures in Melbourne, Australia. They reported that minimum air temperatures averaged within climatically similar regions (including urban and rural environments) were linearly related to HCMM derived night-time surface temperatures. Gallo et al. (1993) evaluated the relationship among several parameters such as satellite-derived vegetation index, surface temperature and minimum air temperatures for Seattle city. They found an inverse relationship between NDVI (Normalized Difference Vegetation Index) and the surface temperature. Although both NDVI and radiant surface temperature were significantly related to minimum air temperature, the NDVI accounted for the greater spatial variation observed in mean minimum air temperatures. Hafner and Kidder (1999) employed specific physical models and with satellite- derived information to study UHI. Magee et al. (1999) studied the climatological records of Fairbanks, Alaska, to characterize the heat island effect. The authors reported that Fairbanks experienced a mean annual temperature increase of 2.1°C from 1949 to 1997. They compared the temperature of Fairbanks to a nearby site named Eielson Air Force Base (AFB) and found that about 4/5th of the total warming can be attributed to general widespread warming, while 1/5th of the warming is due to an increasing heat island effect. They also found that growth of the heat island effect was most pronounced (about 1 °C) in winters, and the most significant absolute temperature increase (over 4.5°C) was observed in winters. Coll et al. (2005) validated the land surface temperature calculated using Envisat/AATSR and Terra/MODIS satellite data through ground measurements in Valencia, Spain. Ground temperatures were obtained with an estimated accuracy between 0.5°C and 0.9°C. The most significant part of these uncertainties was attributed to the spatial variability of surface temperature. Mochida et al. (1997) studied the effects of urbanization on heat island circulations over Tokyo and compared temperature changes over a period of time (like months, seasons).

Early UHI studies in India were carried in few cities through mobile surveys. Bahl and Padmanabhamurty (1979) reported warm pockets over north and northeast Delhi and cold zones over west Delhi. Jayanthi (1991) reported three distinct heat islands over thickly populated and industrial areas; and a relatively cool pool over the ventilated and the vegetative regions of Madras (now Chennai) city. The heat island intensity on a cold night was 2.2°C for Thiruvananthapuram by Gangadharan et al. (1999). Kumar et al. (2001) reported UHIs in the interiors of Mumbai city. Mohan et al. (2009) studied the heat island phenomenon in Delhi during May 2008 through ambient air temperature observations collected through multisite Automated Weather Stations. The study found that UHI effects were most dominant in areas characterized by densely built-up and intense human activities.

Sharma and Joshi (2013) employed Landsat images to study the LST pattern in Delhi, India. The authors prepared LST maps using monthly data for nine months (January-November, 2010) of the year (excluding March 2010 for which cloud-free image was not available). The observed high-temperature areas during winter months are in and around built-up areas of the city, majorly located towards interior parts. In contrast, during summer months (April to June), UHI pattern was skewed towards southwestern parts of the city. The authors reasoned that this trend is because peripheral northern, western and southwestern parts of the city are agricultural lands and during summer months, these tend to lay fallow. Such fallow lands have an inclination to exhibit high surface temperatures.

Mohan et al. (2013) studied UHI phenomena in Delhi using in situ measurements and satellite-based observations during March 2010. The highest UHI was recorded in the dense urban regions and highly commercial areas with maximum hourly magnitude increasing to 10.7°C and an average daily maximum UHI reaching 8.3°C. The Field-based UHI observations and Land Surface Temperature (LST) collected through satellites were compared. The researchers used a Moderate Resolution Imaging Spectroradiometer (MODIS) sensor to obtain the satellite data. The results depicted that the satellite-based observations overestimate the temperature during the daytime, whereas it underestimates the temperature during night-time.

A study carried out by the Indian Institute of Science, Bangalore for Greater Bangalore, shows an increase of ~2°C to 2.5°C in air temperatures in the past decade. The study also shows a growth of 632% in the urban area of Bangalore from 1973 to 2009 and a 76% and 79% decline in vegetation cover and water bodies, respectively, in Greater Bangalore (Ramachandra and Kumar, 2010). Another study conducted by TERI for Bangalore highlights 1.5°C higher temperature in Commercial Street, a high-density area, compared to the city's outskirts.

Chennai also observed the existence of heat islands. Increasing temperatures have been noted from the suburbs towards the city centre in a radial pattern indicating the heat island/dome. The mean maximum heat island intensity observed has been 2.48°C during summers and 3.35°C during winters (Devadas and Rose, 2009). At Thiruvananthapuram city center, a maximum UHI intensity of 2.4°C was recorded compared to the city suburbs. In this case, the regions exhibiting the higher temperatures fell under high-density categories of the built environment, including compact, low rise and compact midrise developments. The studies carried out at Nagpur have indicated the influence of land use and land cover on the air temperature of the city associated UHI impact. Mapping the city's air-temperature contours, a temperature difference of 7.5°C was highlighted. Land cover types like water and vegetation were identified to have lower temperatures; and high-density areas to have higher temperatures (Katpatal, Kute and Satapathy, 2008)). Higher land surface temperatures were reported in areas with higher built-up and human activities compared to those with green vegetation cover in

Ahmedabad city (Mathews et al., 2016; Mohammad and Goswami, 2021; Singh and Surati, 2021). Joshi et al. (2015) reported higher surface temperature near industrial areas and dense urban areas as compared to other suburban areas in Ahmedabad city.

In Vishakhapatnam, heat islands were noticed over the thickly built up areas with intensities varying from 2°C to 4°C. It was also observed that the rate of decrease of temperature during winter nights was 0.3°C/hr in urban areas compared to 0.5°C/hr in rural areas (Devi, 2006), possibly contributing to the observed high intensities in the former areas. Bhan and Saxena (2014) using observations from a fixed network of 19 weather stations over the National Capital Territory of Delhi reported that the zones of warmest temperatures were located in the thickly populated northeast and north districts of the territory. The patterns of distribution of both the maximum and minimum temperatures were similar. The maximum intensity of Urban Heat Island at maximum temperature epoch was found in the month of January (3°C) and that at minimum temperature epoch in the transition months of March (5.5°C) and October (4°C). Population density and prevailing winds were reported to determine the temperature distributions over the area.

Fallmann et al. (2014) employed the numerical mesoscale Weather Research and Forecasting Model (WRF) 3.4 to analyse the urban climate on a regional scale. The analysis allowed an assessment of UHI mitigation strategies through simulating different urban planning scenarios. The results showed that a change of the reflective properties of surfaces has the highest impact on near-surface temperatures compared to an increase of urban green areas or a decrease in building density.

Li et al. (2015) analyzed observations from two flux towers in Beijing, China and found significant differences between the responses of urban and rural (cropland) ecosystems to heatwaves. It was found the UHIs increase significantly during heat wave events, especially at night, implying synergies between heat waves and UHIs. The study reported that the urban site received more incoming shortwave radiation and longwave radiation due to heatwaves as compared to the rural area, resulting in a larger radiative energy input into the urban surface energy budget.

Chapman et al. (2017) reviewed the impact of urbanization and climate change on urban air temperatures. The authors found that most studies investigated climate change and urban heat islands in isolation. There has been little impetus given on how climate change and urban growth will interact in the future and what will be the impact of such interaction on heat stress. The authors cited that this may seriously risk underestimating future urban temperatures and consequently hamper the process of adaptation to the changing climatic conditions.

Zhao et al. (2018) used a climate model to investigate the interactions between the UHI and heat waves in 50 cities of US under current climate and future warming scenarios. The authors examined UHI2m (defined as the urban-rural difference in 2m-height air temperature) and UHIs (defined as urban-rural difference in radiative surface temperature). They found significant interaction sensitivity between UHI and heat waves to local background climate and warming scenarios. Sensitivity also differed between daytime and nighttime. During the day, cities in the temperate climate region showed significant synergistic effects between UHI and heatwaves in the current climate, with an average of 0.4 K /-272.75 °C higher UHI2m or 2.8 K/-270.35 °C higher UHIs during heat waves than during normal days. These synergistic effects, however, diminished in future warmer climates. In contrast, the synergistic daytime impact for cities in dry regions was insignificant in the current climate but emerged in future climates. At night, the synergistic effects were similar across climate regions in the current climate and were found to be stronger in future climate scenarios.

Pramanik and Punia (2019) used Landsat-8 and Sentinel-2 data to evaluate urban greenery's cooling effects in Delhi, India. Landsat-8 data was used to map the city's land surface temperature, whereas urban greenery was mapped using Sentinel-2 data. The composition and configuration of various types of urban greenery were measured by computing several metrics. Statistical parameters like ordinary least square regression, multiple linear regression, and spatial auto-regression model were employed to quantify the cooling effect of urban greenery. The authors reported that amount of urban greenery (percentage of land cover, average size of green patch etc.) is very important to reduce the urban heat island intensity.

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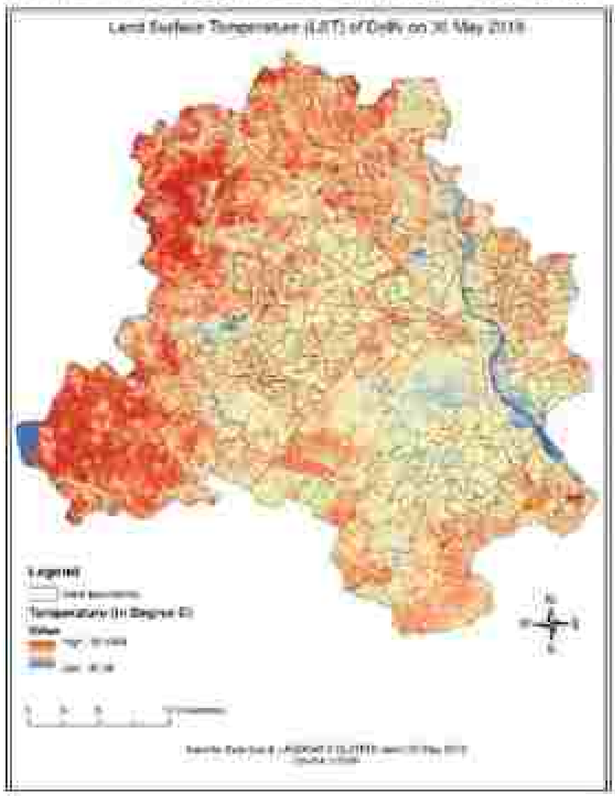
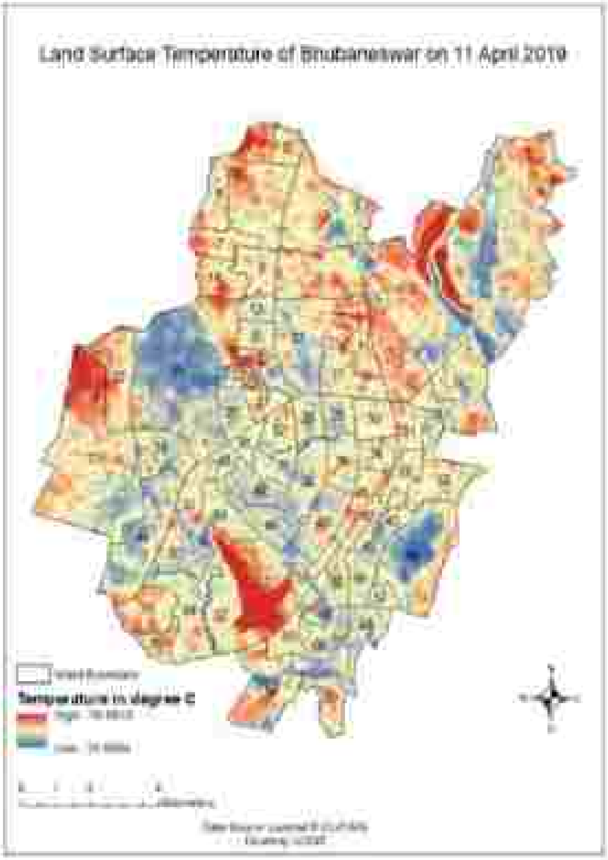
3. UHI Mapping

Satellite remote sensing provides a compelling alternative as the satellites cover a large swath of the earth's surface. In particular, the land surface temperature measured by satellites in thermal infrared region of electromagnetic spectrum has been used by various researchers across the globe (Zhang and Cheng, 2019; Wang et al., 2017; Jin, 2012; Zhang and Kainz, 2012; Yuan and Bauer, 2007; Chen et al., 2006); and in some instances, these satellite-derived Land Surface Temperatures (LSTs) have been correlated with ambient air temperatures (Mutiibwa et al., 2015; Unger, 2009; Vadasz, 1994).

Between 2018-2021 Integrated Research and Action for Development (IRADe) undertook a study to identify ward level UHIs for Delhi, Rajkot (Magotra et al., 2020) and Bhubaneswar (Magotra et al., 2020) as a part of project supported by International Development Research Centre (IDRC) on developing Climate Adaptive Heat Action Plans. LSTs and Air Temperatures are known to exhibit wide spatial variability in urban areas because of land use, urban geometry and density of buildings. Therefore, the study identified potential UHIs using Landsat-8 satellite data which experienced LST higher than certain thresholds. Wards identified under a higher threshold are more prone to heat stress and need to factor in issuing ward level heat wave warnings and taking mitigation measures on priority. The LST map developed using this data set is shown in Figure 1.

As there is no established threshold for identifying UHIs using LST data, we adopted a percentile based approach. UHIs were identified at the ward level for the three cities based on a percentile (95%, 90%, 85 %) of highest LST observed, and UHIs





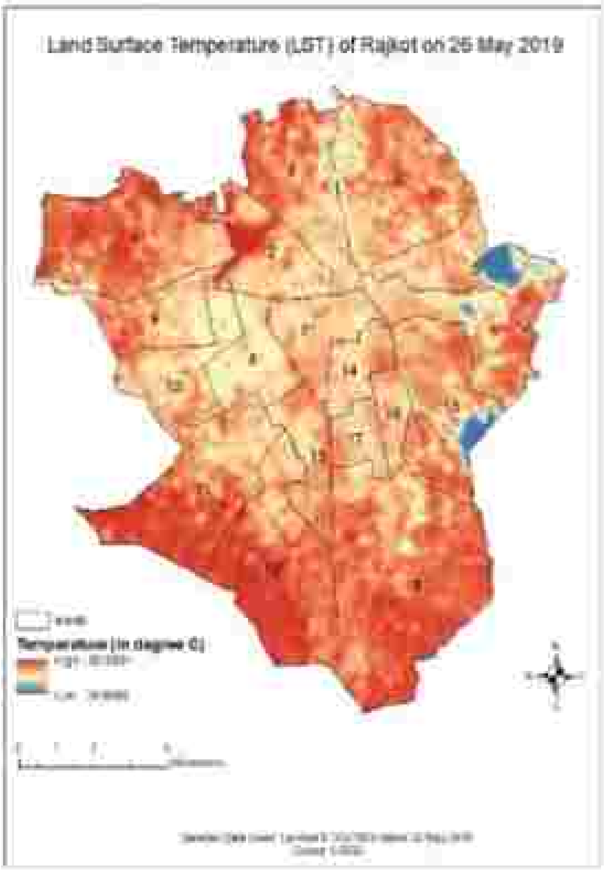


Figure 1: LST maps of three cities developed using satellite data.

were identified at the ward levels. The wards were grouped into four categories: Category I wards having more than 50% of the area as a thermal hotspot, Category II contains wards having 25-50% of the area as a thermal hotspot, Category III having 10-25% of the area as thermal hotspot and Category IV having less than 10% of the area as a thermal hotspot. For example, the analysis for Rajkot revealed that ward numbers 11 and 12 have areas falling in Category II at 95% of the highest LST observed on 26 May 2019. These wards had roughly 26% and 34 % areas with LST over 53.77 ^{0}C. A total of 16 wards out of 18 in Rajkot showed thermal hotspots at 90% of the highest LST range observed on 26 May 2019. The above analysis revealed that ward numbers 1, 2, 3, 11, 12 and 18 have significant areas falling in Category I and II of hotspots. Ward number 12 has nearly 68% area covered as a hotspot, the maximum percentage spatial distribution recorded for 90% on 26 May 2019. Ward numbers 18, 1 and 11 are next in order as these wards have nearly 63%, 62% and 58% area under thermal hotspot. At 85% of the highest LST range (i.e. 48.11^{0}C), all the 18 wards in Rajkot have some areas as thermal hotspots. All these hotspots experienced LST>48.11 ^{0}C. Except, 7 and 8 all the wards have hotspot areas in Category I and II. As all wards are showing LST> 48.11 ^{0}C.

The above study helped identify the Urban Heat Islands which were further used for vulnerability assessment and mitigation interventions for the municipal corporations.

4. Physics of UHI

The physical mechanism of UHI involves several factors which contribute to the formation of UHI in the cities, which includes small-scale processes as human metabolism and mesoscale interactions of the atmospheric forces (Mirzaei & Haghighat, 2010). The combination of the following physical mechanisms contributes to the formation of an urban heat island.

4.1 Day and Night-time temperature variations

The timing and magnitude of energy exchanges across the urban landscapes differ considerably on account of changing pattern of receipt and loss of solar radiation (Nunez and Oke, 1997). In rural areas, the temperature may drop at night, allowing the potential cooling of surroundings. In cities, however, the nights can be warmer than usual (sometimes warmer than the days) due to energy dissipation by urban infrastructure (Nuenz and Oke, 1997). Such phenomena result in the generation of night-time UHIs, and do not provide sufficient time for cooling. This may potentially lead to enhanced heat stress and consequent mortality, particularly among the vulnerable section of the urban human population. For example, in August 2003, the Paris metropolitan area experienced daytime temperature above 38°C for nine consecutive days (Dousset et al., 2009). During this period, an increase in night-time temperature was also observed by about 5°C. This resulted in 4867 more deaths in Paris during this period.

The impervious nature of urban infrastructures built of concrete, asphalt etc. often results in waterproofing of soil and thereby reduces the natural evaporative sink. This leads to relatively higher ambient temperatures during night (Asaeda and Ca, 1993). As the depth/thickness of such infrastructure increases, it leads to more absorption of solar radiation during the daytime and, subsequently, more heat dissipation at night (Arnfield, 2003).

In many cases, the UHI is strongest at night; for example, a study in Paris showed that the magnitude of the night-time UHI was up to 7°C more than the daytime UHI (Lac et al., 2013). However, the daytime UHI is still a significant phenomenon but is far more complicated to characterise. For example, it was found that urban temperatures tend to be slightly warmer than rural ones during the daytime in London, with morning urban and rural temperatures being similar However, the scenarios also exist where urban temperatures can be cooler than surrounding rural areas (Bohnenstengel et al., 2011). Systematic reviews of the UHI literature are available in (Arnfield, 2003; Stewart, 2011) and both document a range of studies that have investigated both nocturnal and daytime temperature differences.

4.2 Urban geometry

The UHI phenomenon is considerably influenced by the arrangement of streets and buildings within a city (Sobstyl et al., 2018). For example, citizens dwelling in a city like, New York or Chicago, have been found to experience more heat build-up within the city than those living in cities like Boston or London (Chandler, 2018). This is because cities like New York and Chicago, are developed very precisely like a grid and are pretty crystalline in their morphology (Chandler, 2018). On the other hand, cities like Boston and London are arranged more chaotically like disordered atoms in a liquid or glass; thereby providing more space to dissipate the accumulated heat (Chandler, 2018). It was found that differences in the spatial arrangements of buildings within the city are the most important determinant of city's heat island effect (Chandler et al., 2018; Sobstyl et al., 2018). The geometry of the built-up space has a larger impact on urban heat island intensity, which increased with increasing building density and building height variance and increased with increasing sky view factor. Also, the urban geometry has greater impacts on the road temperature than on building temperature, and the effect of the geometric parameters on road surface temperature changes with the time of the day and the season (Yang et al., 2020, 2021).

4.3 High building density

Urban areas are densely populated and densely constructed. The high density often leads to the phenomenon of waste heat that escapes from vehicles, factories, and air conditioners that adds warmth to their surroundings as it has nowhere to go. It lingers in and between buildings, exacerbating the heat island effect (Balasubramanian, 2020). As a result, nighttime temperatures are severely affected and remain high (EPA, 2018). This is because buildings, sidewalks, and parking lots block heat and it gets trapped on lower levels where the temperature is warmer (Mohan et al., 2012). Building and street canyons reduce wind ventilation and more radiation trapping contributing to UHI (Li et al., 2020). Yuan and Chen (2011) reported that an increase in sky view factor by 0.1 led to a decrease in daily mean temperature by 0.4 °C. However, the relationship between Building height and urban thermal environment is complex and is a net effect of climate zone, population density, building forms, land use, landscape index, terrain and socio-economic factors (Wang and Xu, 2021).

Sati and Mohan (2018) analysed the change in land use and land cover pattern over the last five decades and observed that Delhi's near-surface temperature has increased by 1.02°C due to an increase in urban-land use from 1970 to 2010s.

Li et al. (2020) studied the influence of density and morphology on the Urban Heat Island intensity. They found that in addition to the size, the UHI intensity of a city is directly related to the density and an amplifying effect that urban sites have on each other.

4.4 Natural vegetation and water bodies

'Green' infrastructure such as forest, vegetation, gardens and 'Blue' infrastructures like water bodies cool the ambiance through transpiration and

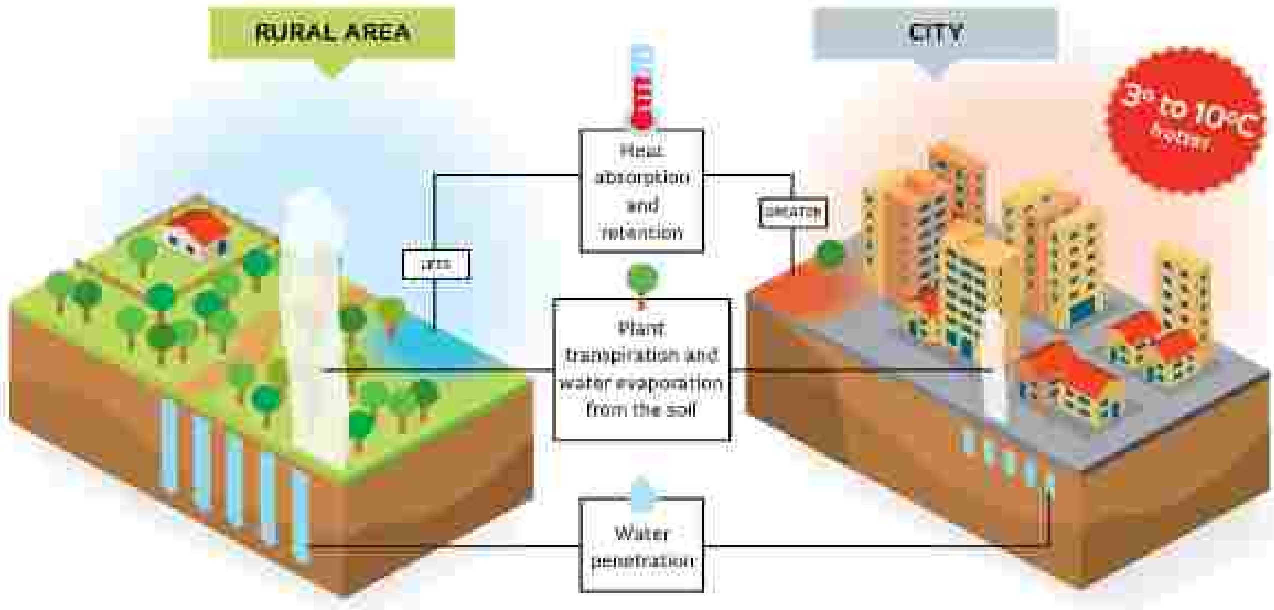


Figure 2: The increase in temperature due to infrastructural differences between rural and urban areas. (Source: https://land8.com/how-landscape-architecture-mitigates-the-urban-heat-island-effect/)

evaporation processes, respectively. Natural blue green architecture provides shade and moisture, which also helps in lowering temperature (Figure 2). Trees and vegetation lower surface and air temperatures by providing shade and through evapotranspiration. Shaded surfaces were considerably cooler than unshaded materials and resulted in cooling energy savings of around 30%. Case studies (Kurn et al., 1994; Laechelt and Williams, 1976; Buffington, 1979; Parker, 1981; Akbari et al., 1997) have documented dramatic differences in cooling-energy use between houses on landscaped and un-landscaped sites. Urban trees can modify the climate of a city and improve urban thermal comfort modifying the ambient conditions around individual buildings through shading and wind-shielding elements. Considered collectively, a significant increase in the number of urban trees can moderate the intensity of the urban heat island by altering the heat balance of the entire city (Akbari, 2002).

Relative cooling of water bodies by evaporative procedure has been found to be an important way to mitigate UHI in urban areas with the cooling effects extending up to 800 meters decreasing urban temperatures of the surrounding environment around 2 - 6 °C. (Manteghi et al., 2015; Wu and Zhang, 2019). Compared to other land use types, water body corresponds to lower LST (Yang et al., 2015).

4.5 Urban building construction material, roads and pavements

Urban building infrastructure which is highly thermal absorbent, with low vegetation cover, is one of the most crucial cause of UHI. The construction material comprising cement, bricks, glass, tiles used for buildings have high thermal absorbent properties leading to the build-up of heat and causing a rise in the temperature of the surroundings. In addition, road networks in the city made up of black colored asphalt act as heat absorbent pads leading to an increase in land and surface air temperatures.

As a result, urban structures absorb a large quantity of thermal energy during the day. They slowly re-emit this stored energy during the night causing an increase in night temperatures as well. The excess heat energy that is absorbed due to urban landscape features and low vegetation density raises the temperature of the urban areas by several degrees over that of peripheral non-urbanized regions (Figure 2).

Ibrahim et al. (2018) found that the four types of pavements - asphalt, concrete, permeable, and industrialised building system (IBS) contributed most to the UHI effect. Green walls, cool roofs, vegetation and trees were found to help in mitigating the UHI effect. Pavements occupy up to 40% of urban land cover and play an important role in absorbing and storing of solar energy leading to an increase in surface temperatures. Reflective pavements and increased urban green cover can help to significantly reduce the thermal stress load on pavements and urban environments (Sen, 2016; Cheela et al., 2021).

4.6 Cooling infrastructures: Residential and Commercial ACs

A consequence of urban heat islands in summer is an increase in air conditioning in urbanized areas, which, while cooling the insides of buildings, releases waste heat into the atmosphere (De Munck et al, 2013). The growing use of Air Conditioning in an increasingly hot climate can be problematic (Lundgren-Kownacki et al, 2018). Thermal loads could be doubled by the heat island effect, while the coefficient of performance (COP) of air conditioning systems could be reduced by 25% (Martin and Maystre, 1988).

With the current trends, the coverage and energy demand for air conditioning is expected to rise significantly by 2050, with a large part of the increase coming from the fast-growing and dense cities in areas in tropical and subtropical regions (Parkpoom and Harrison (2008), Dahl (2013), (Reese, A. 2018). UHI directly relates to cooling demand as the urbanization that results in UHI has become a serious issue in the hot and humid geographies. The maximum observed UHI intensity in India is 8-9°C (Veena et al, 2019).

There is positive feedback between air-conditioning and urban warming which is expected to further increase in warming urban climates. Takane et al. (2019) calculated the impact of the feedback during the July 2018 Japanese heat waves to be 0.11 °C. A study on the threshold of air conditioning use which can increase air temperatures for a city like Paris, compared the scenarios with heat released in the street and the baseline case without air conditioning. A systematic increase in the street air temperature was observed with a greater increase at night-time temperatures. (Lundgren-Kownacki et al, 2018)

4.7 Transport

Cars and vehicles contribute to heat emission in urban areas (Kamruzzaman et al., 2018). The total heat emitted by vehicles may remain trapped in poorly ventilated urban canyons, thereby reducing the thermal comfort of city dwellers (Louiza et al., 2015). Further, the exhaust emissions from cars and weather conditions are the main factors determining the level of pollution in the urban atmosphere (EPA, 2020). These conditions lead to heat transfer and radiation occurring between the air and the soil surface (Koorevaar, 1983). These exchanges give rise, in urban areas, to the effects of heat islands that correspond to the appearance of excess air temperature between the city and its surrounding space (Louiza et al., 2015). Zhu et al. (2017) found that in Hongkong city, vehicular flows in some places were the influential dominating factor in making the UHI phenomenon more remarkable. Louiza et al. (2015) demonstrated that transport constitutes one of principal factors to the urban heat island increase in cities making the UHI phenomenon more remarkable.

4.8 Weather and geography

Weather conditions may exacerbate or mitigate UHI effects in cities. Strong winds and clouds may cool the ambiance and thereby suppress the UHI effect. On the other hand, calm and clear weather may exacerbate the UHI effect as more solar radiation reaches the surface. In addition, the geography of the city also impacts heat island formation. For example, a city in the vicinity of a mountain may experience more UHI phenomena as the mountain may block wind flow to the city. A bowl-shaped topography of the city may result in the accumulation of more aerosols in the air and consequent reduction in temperature.

It should be clear now that the determination of urban heat islands requires measuring temperatures at different locations within and outside the city boundary. Both air and land surface temperatures

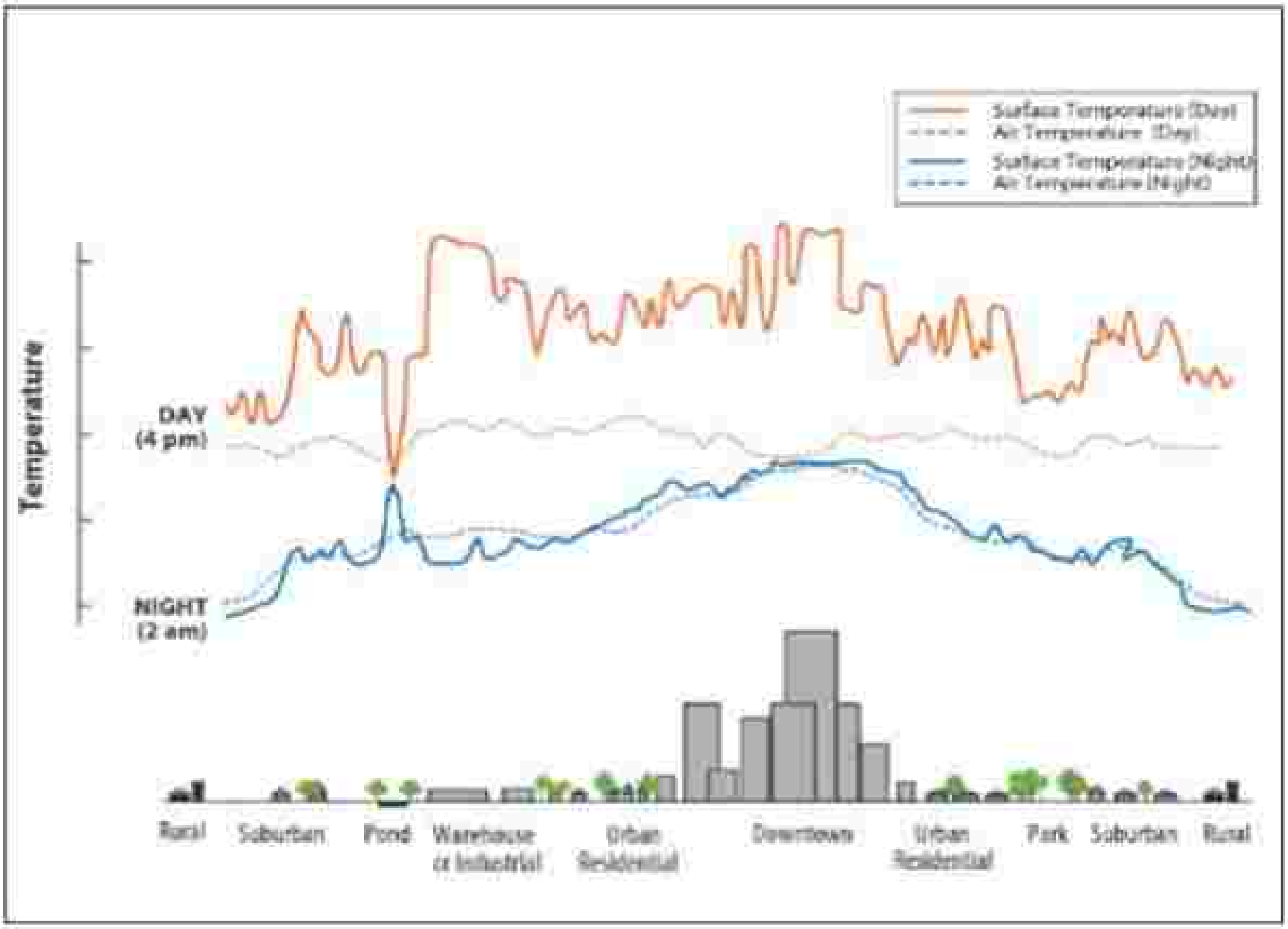


Figure 3: Distribution of UHI effect across different land use types. (Source: https://www.epa.gov/heatislands/learn-about-heat-islands)

vary within the cities depending on the distribution and density of land use types (Figure 3). Parks, open land, water bodies form cooler areas within the cities, whereas highly concentrated buildings and industrial regions have substantially higher UHI effect (Figure 3). In addition, the diurnal variation in land surface temperature is higher than in air temperatures. However, during night these are fairly similar (Figure 3). Accordingly, there are two types of urban heat islands that differ in how they are formed, the methods used to detect and measure them, their impacts and the methods to mitigate them (https://www.epa.gov/heatislands/learn-about-heat-islands, page accessed on 07/10/2021). Surface Heat Islands (SHIs) are formed because of the warming of land surfaces like roads, pavements etc. Such surfaces usually have greater potential to absorb solar energy than natural surfaces like those of water bodies and canopies of dense vegetation. SHIs tend to be more intense during the daytime under clear sky conditions. Atmospheric Heat Islands (AHIs) form when air in urban areas heats up more compared to surrounding non-urban regions. AHIs vary much less in intensity compared to SHIs. SHIs are usually associated with land use, whereas advective processes play a significant role for canopy UHI (Azevedo et al., 2016).

5. Impacts of UHI

UHI has affected human health directly through increased and prolonged exposure of the inhabitants to higher temperatures. The indirect effects include increased energy demand for cooling, deteriorated air and water quality, and exacerbated heat waves. A review of the implications of UHI is presented in the following sections.

5.1 Human health

Heat stress-induced deaths in 2100 are estimated to be about 85 per 100,000 (Climate Impact Lab 2019). Extreme temperatures are considered among the most dangerous natural hazards adversely affecting the health, livelihood, and productivity of people; but rarely received adequate attention. The impacts are further aggravated in urban areas where residents are exposed to higher and nocturnally sustained higher temperatures due to the Urban Heat Island (UHI) effect (Magotra et al., 2021).

UHI can impact the health of citizens both directly as well as indirectly. Indirectly, UHI can exacerbate health impacts by affecting rainfall patterns (Collier, 2006), interacting with and worsening air pollution (Xu et al., 2014), increasing flood risk, and decreasing water quality (Hester and Bauman, 2013). The direct impact of UHI on human health is through exposure to increased temperature (Heaviside et al., 2017). Exposure to heat may result in a variety of adverse health outcomes. Respiratory or cardiac problems may be further aggravated by exposure to high temperatures. The risk is significant even at moderately high temperatures (Gasparrini et al., 2015). The age factor is also important as older people are more vulnerable to increased temperature exposure. Also, there is evidence that vulnerability varies by gender (WHO, 2012). With temperature anticipated to arise in the future in response to anthropogenic climate change, heat- related mortality and morbidity is also expected to increase (Hajat et al., 2014; Li and Bou-Zeid, 2013). Heat islands may impact some people more than others especially the vulnerable. As cities face higher temperatures, longer and more intense heat waves, a stronger heat island effect is expected (EPA, 2018).

5.2 Mental health

Residents living in a UHI region or in its vicinity are at increased health risk (Tomlinson, et al, 2011). Various studies have shown that citizens in UHI areas suffer from heat-related illnesses, e.g., digestive diseases, nervous system issues, insomnia, depression, and mental illnesses (Huynen et al., 2001; Tan et al., 2010). In a systematic review by Thompson et al. (2018), increased risks of mental health-related admissions and emergency department visits in higher temperatures areas were found. Other findings by Jenerette et al. (2016) demonstrated that the symptoms of heat-related illness were correlated with parcel-scale surface temperature patterns during the daytime in an urban ecosystem. A study in Kuala Lumpur by Wong et al. (2017) stated that more psychological and social health issues associated with UHI, such as depression and the restriction of social activities were observed in the hotspots. A recent study by (Mirzaei et al. (2020) in the Isfahan Metropolis, Iran, observed that the citizens showed severe significant responses in non-physical health sub-scales i.e., anxiety, sleep, social functioning, and depression.

5.3 Vulnerable groups

Populations with low income are at greater risk of heat-related illnesses due to poor housing conditions, including lack of air conditioning and small living spaces, and inadequate resources (EPA, 2018). This is further aggravated by the phenomenon of UHI. It can exacerbate these adverse impacts in cities by amplifying heat exposure during the day and inhibiting the body's ability to recover at night (Chakraborty et al., 2019). The UHI can have differentiated impacts across populations, particularly those of lower socioeconomic status, with pre-existing health conditions, or living in dense urban areas that are exposed to higher levels of UHI and its negative health outcomes (Solecki et al., 2005). In a study to find the relationship between distributions of both income and UHI at the neighborhood scale for 25 cities worldwide. It was observed that in most cases (72%), poorer neighborhoods experience elevated heat exposure, an incidental consequence of the intra-city distribution of income in cities (Chakraborty et al., 2019). The study findings were justified for both developed and developing cities worldwide.

5.4 Weather

Apart from the temperature changes UHIs also produce some secondary effects on local meteorology, including altering local wind patterns, development of clouds and fog, humidity, and precipitation rates (ABR, 2007). In a study based in Pearl River Delta, China (Wang, 2015) , the UHI intensity decreases with increasing low cloud cover, relative humidity, wind speed and precipitation. Another study based on the complex environment in Northern Taiwan found that the impact of UHI on rainfall could be either enhancement or initiation thereof, depending on the size of the city and its surrounding geographic features (Lin et al., 2011). It presented a contrasting result where UHI could affect precipitation over upstream plain areas, quite different from other places with urban areas located over large plain areas resulting in increased rainfall downwind of the city (Steiger and Orville, 2002) (Shepherd et al, 2002). Further, study comparing UHI intensity according to Urban Area Change in Asian Mega Cities found that the UHI of Mumbai appeared to be stronger than that of Delhi (Lee et al, 2019) a similar metropolitan city. This was because of Mumbai's coastal environment with low tree cover and the dense horizontal and vertical growth of buildings (Grover et al, 2015). Another significant impact exhibited by UHI is displayed on the fog cover. UHIs may warm a region's land area sufficient to dissipate the fog. Gautam and Singh (2018) observed holes in the fog layer over the Indo-Gangetic Plain (IGP) using satellite images (Figure 4).

Figure: Satellite image showing fog holes over India and Pakistan with extensive holes over Delhi and several other cities [Lahore (1), Amritsar (2), Jalandhar (3), Ludhiana (4), and Patiala (5)] throughout the IGP, seen from spaceborne MODIS instrument on 30 January 2014 at ~10:30 a.m. local time (Source: Gautam and Singh, 2018).

The authors reported that the persistence of fog in rural areas is relatively longer than in Delhi, where fog dissipation occurs 3 hours earlier. The LST distribution over Delhi was also found to be higher than the surrounding regions by roughly 4 K (Gautam and Singh, 2018).

5.5 Air pollution

UHI and air pollution are known to drive one another (Singh et al, 2020). UHI affects Air Pollution as urbanization changes urban meteorology, which in turn influences ambient air pollutants (Nidhi et al. 2020). The spatial temperature difference between cities and suburban areas (Rao et al. 2014) causes the rising air from the city centre to move towards suburban areas following temperature gradient (Singh et al. 2020). This recirculation process causes elevated inversion and inhibits dispersion of air pollutants upward in urban areas (Oke 1977). It also creates higher temperature "domes" over an urban or industrial area by hot air layers forming at building-top or chimney-top level (Shi et al. 2021). This dome is about 5°C to 7°C warmer than the air above it and the ground-level temperature and can trap all polluting emissions within its confines (Rizwan et al. 2008) (Huang et al, 2018). In addition, UHI increases the possibility of the formation of smog created by photochemical reactions of pollutants in the air (Baklanov et al, 2016). The formation of smog is highly sensitive to temperatures since photochemical reactions are more likely to occur and intensify at higher temperatures (Che-Ani et al, 2011). This complex nexus of climate change-air pollution-UHI driven by urbanization would prove devastating to human health (Heaviside, 2016). An important influencer of UHI intensity are aerosols. Aerosols are minute solid or liquid particles usually suspended in air. Because of more polluting activities in urban areas, the aerosols of urban areas are mostly black carbon (Kanakidou et al., 2011). These aerosols either scatter or absorb visible and NIR (near Infra-red) solar radiation, thereby influencing the cities' surface/air temperature (Cusack et al., 1998). For instance, a high aerosol optical depth (AOD) may decrease solar absorption by the surface by 40-100 W/m2 and thus, LST over urban areas may reduce by 1-2 K relative to surrounding non-urban regions (Jin et al., 2010). In other words, increased AOD can reduce the solar heating during the daytime, and consequent cooling of the surface may cancel the night time UHI effect (Sussman et al., 2019). On the other hand, some researchers have also reported that aerosols can enhance the UHI effect at night in semi-arid cities

(Cao et al., 2016, Fallmann et al., 2016; Lai, 2016). Overall, air pollution caused by aerosol particles can affect the UHI through changing (1) the surface energy balance by the aerosol radiative effect and (2) planetary-boundary-layer stability and airflow intensity by modifying thermodynamic structure, which is referred to as the aerosol dynamic effect (Han et al., 2020).

5.6 Energy consumption

Several studies have indicated that UHI has a significant effect on the energy use of buildings (Priyadarsini, 2011). It increases both overall electricity demand and peak energy demand (EPA, 2018). UHI could result in a median increase of 19.0% in cooling energy consumption and a median decrease of 18.7% in heating energy consumption (Xiaoma Li, 2019). Studies reveal that electricity demand for air conditioning or cooling increases in the ranges of 1.5 to 2 percent for every 1°F (0.6°C) increase in air temperatures (ranges of 68 to 77°F (20 to 25°C)), implying that the community requires about 5 to 10 percent more electricity demand to cater for the urban heat effect (Rinkesh, 2018).

In India, UHI and the rising temperatures directly impact the existing and future cooling demand. As per the report 'Demand Analysis for Cooling by Sector in India in 2027' the overall energy consumption for the Building Sector will increase more than double in the next decade, growing from around 126 TWh in 2017 to around 281 TWh in the year 2027 (AEEE, 2018). India's air conditioning coverage alone is expected to rise to 50% by 2050, which would translate into a significant increase in energy needs in addition to HFC leakage from AC units (Reese, 2018). UHI and the use of AC have a 'cause' and 'effect' relationship where the operation of these AC units will also impact our climate and contribute to the UHI.

5.7 Water resources

Urban heat islands (UHI) coupled with regional climate change have essential impacts on urban water demand and consumption (Christopher et al, 2009). The overuse of water from nearby water sources due to the increased heat can stress the water supplies and lead to massive water shortages (Geilman, 2020). This can affect quality of life, and stress water sources farther from the urban area, as the reach for water widens. As per the 'Aqueduct Water Risk Atlas' by the World Resources Institute (WRI), India is ranked 13th among the world's 17 'extremely water-stressed countries (Pandey, 2019). This can be further aggravated with the country's rising temperature and UHI hotspots.

5.8 Water quality and aquatic life

UHI impacts the quality of the water just as much as it affects the quality of the air around the city. It affects the urban aquatic system as it alters the stability of the water columns, biochemical cycles and biological activity (Ogashawara et al. 2015). High temperatures of pavement and rooftop surfaces can heat stormwater runoff, which drains into storm sewers and raises water temperatures as it is released into streams, rivers, ponds, and lakes (EPA, 2018). In one of the study carried out to measure UHI impacts man-made urban ponds (Kristien et al, 2018), strong evidence of urban-driven warming was found. The daily temperature fluctuated around 2 °C more in locally urban ponds than rural ponds in summer. Another study found that water temperature affects all aspects of marine life, especially the metabolism and reproduction of many aquatic species (Geilman, 2020).

5.9 Forest fires and urban fires

In recent years, the incidences of wildfires have increased substantially across the globe. This increase may be attributed to the ongoing anthropogenic climate change. Out of the various contributing factors, urban heat islands may contribute significantly to these fires. This is because UHIs have diminishing impact on the cloud cover, leading to depletion of ground moisture. Loss of ground moisture results in vegetation drying, which then acts as fuel for propagating the wildfires. With winds, such fires may travel to the inland areas of the cities from the outskirts, forming "urban heat island archipelagos" (https://www.lgc.org/newsletter/urban-heat-island/). These archipelagos experience unusually higher temperatures and air pollution levels, resulting in higher numbers of possible human casualties. For instance, during the 2010 heatwave and wildfires in Moscow, approximately 11000 excess deaths were recorded in 44 days in which 24-hour average temperatures varied from 24°C to 31°C and PM10 levels exceeded 300 μg/m3 on several days (Dmitry et al., 2014).

It also causes wildlife habitat loss and fragmentation, threatens wildlife populations, increases fire risk, and reduces biodiversity (Shi et al., 2005; Pickett et al., 2001). Wildland urban interfaces (WUI) are areas of concern, where homes and associated structures are built among forests, shrublands, or grasslands (Radeloff et al., 2005; Pickett et al., 2001). The WUI has received considerable attention because of recent increases in the number of structures destroyed and the area burned annually by wildland fire (Shi et al., 2005). Therefore, the impact of UHIs on wildfires should be studied with a focus on investigating the interactions between high temperatures and wildfire air pollution and the effects of such interaction on human health.

5.10 Climate change

The effect of Urban Heat Island on weather and Climate change is two-fold (TERI, 2017). The heat build-up caused by the urban heat island effect can worsen the rising temperatures. It also affects the increased heat gains in air-conditioned buildings caused by the heat build-up leading to increased electricity demand for cooling. Energy consumption in buildings is growing worldwide at an average rate of 40% because of the growing population and faster development of nations (Akbari et al., 2012). Cooling is essential for achieving many Sustainable Development Goals (SDGs) (SE4ALL, 2018). Yet, the rising demand for space cooling is already putting enormous strain on electricity systems in many countries, as well as driving up emissions (IEA, 2018). The direct and indirect emissions from room ACs alone could contribute to as much as a 0.5 °C Celsius increase in global warming by 2100 (Lalit andKalanki, 2019).

6. UHI Forecasting

Recognition and quantification of adverse effects of UHI, the issue of predicting the UHIs has been receiving increased attention from many quarters as the prediction techniques can also help design UHI-mitigation strategies and countermeasure policies. Models are helpful in developing UHI-mitigation strategies and in drafting relevant countermeasure policies (Solecki et al, 2005). A review by (Kolokotroni et al, 2006) explains that there exist a range of models varying in complexity to predict UHI. It can be classified into the four categories namely, Climatology models (Mavrogianni et al, 2009), including the essential drivers of climate, Empirical models (Swaid and Hoffman, 1990) depending upon empirical observations, Statistical regression methods (Mihalakakou et al, 2002), probability methods and Artificial Neural Networks which is an advanced non-linear analysis technique.

6.1 Statistical, Data Driven and Data Analytical Methods DL/AI/ML

With the development of data collection, storage, and processing powers that enable a better understanding of the processes through examination, organization and analysis of data the experts are able to contextualize the UHI predictive models that can forecast UHI at a given time in the future. The speed, scale, and granularity offered by the data-driven methods of artificial intelligence and machine learning are now enabling finer assessment of UHI than computer simulation programs. Oh et al., 2020 reported a significant correlation between air temperature and UHI intensity and duration. Surface albedo showed a potential correlation with UHI duration. They demonstrated that UHI could be predicted successfully using ANN and DL techniques. Earlier, Kim and Baik (2004) used UHI intensity on the previous day, wind speed, cloudiness, and relative humidity to predict UHI variations in six cities across Korea. Similarly, Pakarnseree et al. (2018) reported that urban physical characteristics in Bangkok had a significant impact on the magnitude of the urban heat island, particularly the floor area ratio and building coverage ratio. Gardes et al. (2020) established that the UHI intensity depends on the degree of urbanisation with larger values in denser urban settings. Other studies have employed statistical methods to predict the UHI intensity. It used predictors characterising the local meteorological conditions and/or the urban morphology such as wind speed and direction, surface temperature, cloud cover, Normalized Difference Vegetation Index, building density, land use and elevation (Bernard et al., 2017; Dorigon and Amorim, 2019). Kaur et al. (2021) used ANN technique to predict solar radiation and thus the intensity of UHI using maximum temperature, minimum temperature, wind velocity and relative humidity input parameters.

6.2 Geographic Information Systems (GIS) and remote sensing

GIS approaches are also deployed to map the urban areas using freely available satellite images to characterize the thermal climatic conditions (Wang et al., 2018; Zheng et al., 2018 for Hong Kong; Kotharkar and Bagade, 2017). The major drawback of this approach is that it cannot capture drivers of the UHI related atmospheric dynamics like the horizontal advection of air temperature by the prevailing wind, sea breezes for cities close to the coast, katabatic flows for cities with elevation differences, and the prevailing regional climate. Iino and Hoyano (1996) investigated the surface temperature distributions of all urban surfaces via a new index based on sensible heat flux, named the heat island potential. Simulation results were verified by the side-looking airborne multi-spectral scanner (MSS) and geographic information system (GIS), enabling elucidation of thermal effects on the atmosphere. Peijun et al. (2009) used the thermal infrared data to estimate land surface temperature and the multi-spectral data for gaining land cover information to find the relationship between LST and corresponding land cover. GIS was then used to simulate the evolution of the thermal environment and predict its trends under the specific land cover scenarios. Shorabeh et al. (2020), in a study using changes of land cover and LST, reported that the intensity of heat islands in Tehran increased with an increase in the value of UHI with an increase in the built-up land in the city.

6.3 Forecasting on urban scales

A paper by (Parham, 2015) which explores the challenges in modeling of urban heat islands, describes that the UHI models are diverse in terms of scale concerning the aim of a study, changing from building-scale for investigation of the impact of the UHI on thermal comfort of a pedestrian to urban-scale for exploring the effect of synoptic wind on urban ventilation. The Building-scale models are simplistic in representing the mutual impact of a building on its surrounding area and thus investigating the impact of UHI on building energy performance. The Micro-scale models basis is the interaction of a building with its surrounding environment in the surface layer. It explores different parameters such as building orientation, street canyon aspect ratio, surface materials, vegetation and tree planting on the calculation of surface convection, pedestrian comfort, and urban ventilation (Mirzaei et al, 2010) (Haghighat et al, 2011) (Tominaga et al, 2015) . The City-scale models are large-scale UHI variations of a city. They are adopted in urban climatology and meteorology fields. The Numerical Weather Prediction Models simulate and assess the UHI based on boundary conditions from observations and global climate models. The model can capture the temperature variations between built-up and green areas. Atkinson (2003) used a three-dimensional, non-hydrostatic, high-resolution numerical model to analyze UHI intensity in a maritime climate incorporating anomalies of albedo, anthropogenic heat flux, emissivity, roughness length, sky-view factor, surface resistance to evaporation (SRE) and thermal inertia. In daytime, the roughness length and SRE were the most important factors affecting UHI intensity; the anthropogenic heat was the most important at night. Fallman et al. (2013) used WRF model to predict the intensity and spread of UHI in Stuttgart, Germany. Atmospheric Dispersion Modelling System (ADMS) - Urban incorporates a full range of source types and complex urban morphology, including street canyons, and provides output from street-scale to urban-scale has extensively used for modeling air quality and urban climates in large urban areas, cities and towns (Maggiotto et al. 2014; Mavrogianni et al. 2011; Hamilton et al. 2014; Aktas et al. 2017; and Wang et al. 2019). Haizhu et al. (2021) used an improved urban canopy model to simulate the UHI effect in the tropical seaside city of Sanya, China by introducing an adaptive approach to estimate the airflow rate inside street canyons and the airflows in multiple connected street canyons. The simulation error of the conventional model was reduced to 0.21°C from 0.68°C in summers ,and ; from 0.84°C to 0.49°C in winters. Karlický et al. (2018) evaluated the impact of typical urban surfaces on the central European urban climate in several model simulations. The results showed that all models and urban parameterizations can reproduce the most distinctive urban effect, the summer evening and nocturnal urban heat island, with an average magnitude of 2–3 °C.

7. Way Forward

The UHI effect has emerged as a potential threat for a rapidly urbanizing country like India. Climate change and unplanned urban development will further aggravate the UHI effect. UHI is having an adverse impact on energy use, public health, and economy. While UHI is a localised phenomenon, it is becoming a significant aspect of Climate Change mitigation and adaptation as global populations urbanise, especially in the developing countries particularly those in the warmer climate zones. UHI intensity varies with climate type, population density, city architecture, city morphology, and city development etc. and, therefore, research in India would need to be more comprehensive to cover this variation. Although several research projects have been conducted, and some are in the process of being conducted in various cities in different parts of the country, they have followed differing methodologies and have had varying objectives. While the incidence of the heat island effect is clearly established, the metrics and modes of measurement differ. The empirical data from different city contexts in each of the climatic zones of the country, obtained through a uniform methodology, would enable an establishment of the UHI formation and its intensity. On this basis, a view on mitigation measures need be taken. That, however, remains among the less researched issues.

India Meteorological Department should develop a methodology for UHI mapping incorporating ground and space-based observations. It would require mesoscale surface and high-resolution satellite observations and collaboration with other agencies such as academic institutes, town planners, Indian Space Research organizations, civic bodies, disaster managers, and public health organizations.

Equally important is to develop numerical modeling capabilities for the simulation and prediction of UHI. Simulation research to help disaggregate the relative impact of various causal factors on UHI individually and in combination with other parameters, with the help of numerical models. The urban heat island phenomenon has been explained as a combined effect of climate, weather, local geography, surface characteristics, urban morphology, and anthropogenic heat. Surface characteristics, urban morphology, and anthropogenic heat are primarily a result of city development controls and building bylaws. This is of considerable relevance in India, where large-scale urban regeneration, urban expansion and new cities are on the anvil. It would be useful to quantify the relative contribution of these causal factors to the UHI effect. This would be critical for mitigation efforts in using measures with maximum efficiency. For this City Heat Action Plans need to include quantification, monitoring, and forecasting of UHI at the ward level.

Studies to assess the extent of the impact of UHI on the environment, energy use, economics, and health in the Indian context needs to be taken up, covering the key climate zones and large, medium, and small cities. The perspectives of the impact of UHI on comfort, health and energy consumption for thermal comfort would each require data in a particular form. It would be necessary to establish the linkages and use appropriate metrics for a quantitative understanding of each impact. The data from different city contexts in each of the climatic zones of the country obtained through a uniform methodology would enable an appreciation of the scale and quantum of the impacts of the UHI effect. This will help in prioritization of various mitigation strategies.

Climate change-induced high temperatures and humidity is likely to increase the energy demand in cities, particularly in UHI localities. An Increase in residential and commercial air conditioning will further increase the number and intensity of the UHIs. The government of India is promoting Energy Conservation Building Code (ECBC) guidelines for increasing energy efficiency in buildings and currently 16 Urban Local bodies have incorporated the guidelines for building approvals. This will help in providing passive cooling solutions and reduce air conditioning requirements for buildings.

The government policy on pushing the adoption of electric vehicles will also reduce the aerosol load, heat exhausts, and the intensity of UHIs.
Green buildings can reduce energy requirement of buildings by 25%-30%. Indian Green Building Council is promoting these buildings. Integrating renewable energy resources like solar in building design will further help in achieving Net Zero buildings and help accomplish the COP 26 commitments.

Cool roofs have the potential to combat heat waves because of their efficiency in reducing the induction of heat onto the roofs. Cool roofs can reduce Urban Heat Island effect, Indirect footprint Reduction through improvements in peak summer energy consumption rates and help long-term adaptation to heat stress. NDMA has launched the guidelines for alternate cooling solutions for the residential areas and there is adoption of cool roof programmes. UHI mitigation and adaptation will require active participation and collaboration of Ministry of Housing & Urban Affairs (Urban development Plans, Building guidelines), Ministry of Environment and Forest and Climate Change (Environment, Air Pollution), Ministry of Power, Ministry of New & Renewable Energy (Low Carbon Energy), Ministry of Earth Sciences (UHI Observations, Simulation and Forecasting), State Governments and Municipal Corporations. A national level plan needs to be prepared for UHI inclusion at the policy level for harmonizing of UHI related measures taken by various agencies.

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