Investigating Urban Heat Island effects with respect to urban Land Use Land Cover and Air Quality changes: A Case Study of Kolkata

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Sohini Sen

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Under the guidance of

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Professor

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Kolkata, West Bengal

Every challenging work needs self efforts as well as guidance of elders especially those who were very close to our heart.

My humble effort I dedicate affectionately to the following:

My Father

Late Sri. Sailesh Kumar Sen

My Mother

Mrs. Manju Sen

My Husband

Sri. Raja Ghosh

My Respected Sir.

Prof. Dr. Anupam Deb Sarkar

DETAILS OF THESIS

1. Index no. and Date of Registration	Index No. D-7/ISLM/38/17 dated 28th November 2017
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3. Name and designation of the supervisor	Dr. Debashish Das Professor Department of Architecture Jadavpur University
4. Email ID of the supervisor	ddasju@gmail.com
5. List of Publications & Conference	Attached in APPENDIX: C

STATEMENT OF ORIGINALITY

I, Sohini Sen, registered on 28th November 2017, do hereby declare that this thesis entitled "Investigating Urban Heat Island effects with respect to the urban Land Use Land Cover and Air Quality changes :A Case Study of Kolkata" contains reviews of literature and original research work carried out by the undersigned candidate for the partial fulfillment of the doctoral research.

All information in this thesis has been obtained and presented in accordance with existing academic rules and ethical conduct. I declare that as required by these rules and conduct, I have fully cited and provided reference to all materials and results that are not original to this work.

I also declare that I have checked this thesis as per the "Policy on Anti-Plagiarism, Jadavpur University, 2022", and the level of similarity as checked by the iThenticate software is less than **10%**.

Signature of candidate:

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CERTIFICATE FROM THE SUPERVISOR

This is to certify that the thesis entitled "**Investigating Urban Heat Island effects with respect to the urban Land Use Land Cover and Air Quality changes : A Case Study of Kolkata"** submitted by **Sohini Sen**, who got her name registered on **28 November 2017** for the award of **Ph. D. (Arts)** degree of **Jadavpur University** is absolutely based upon her own work under the supervision of **Prof. Debashish Das** and that neither her thesis nor any part of the thesis has been submitted for any degree/diploma or any other academic award anywhere before.

1. Debashish Das

Signature of the Supervisor

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Sohini Sen

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Abstract

This thesis starts with a brief introduction; the conversion of land from natural and agricultural uses to residential and urban uses has been under tremendous pressure from urbanization and population growth, which has had a detrimental effect on ecosystem services. Loss of vegetative cover is also exacerbated by fast population growth, urbanization, expansion, and encroachment into the limited remaining agricultural and natural areas. The land cover in rising nations has significantly changed recently, particularly in South Eastern countries like India. In this context changes of Land Use Land Cover (LULC) and deforestation that lead to the loss of agricultural land, destruction of habitats, and decline in natural greenery. These losses have a profound impact on air pollution, biodiversity, and other urban environmental variables both locally and globally.

Various literatures on Land Use and Land Cover (LULC) change and Air Temperature has been reviewed in order to develop clear ideas and concepts. Urban Heat Island impacts are found to be particularly pronounced in regions with densely populated areas and high levels of human activity. The present thesis has aimed at fulfilling the gap in systematic and collective way with suggestion, improvement and optimization. The research contributes to the current literature by adding more evidence on the correlation between urban thermal patterns (i.e., UHI), air pollution and urban land use. Remote sensing data (Landsat 7 TM and 8 OLI, Bands 4, 3, 2 for Landsat 7 TM and 5, 4, 3 for Landsat 8 OLI were determined to be the most successful at differentiating each class and were chosen for classification. Some pictures in the observation were resample using the nearest neighbor technique with a pixel size of 30m for all bands) is a primary source for analyzing environmental processes on a local or global scale. These datasets can be categorized based on their resolution, electromagnetic spectrum, energy source and imaging media. The higher the resolution of satellite data, the higher the degree of accuracy will be achieved during classification. Measurements of particulates are related mainly to individual heating systems in households, city road transport, construction, road side chulah. The Observatory is equipped with PM_{10} and $PM_{2.5}$ measuring instruments like low-cost, widely used SDS011 PM Sensor at various locations across Kolkata Metropolitan area and monitoring of particulate matter with high volume sampler (APM 460 BL) and Sampling of fine particles (Gravimetric Method) standardised by USEPA. Our research demonstrates that the outputs are consistent among devices and line up with the basic information provided by the West Bengal Pollution Control Board.

This study focuses on the development of estimated linear regression analysis which reveals a favorable link between the LST and UHI parameter and the built-up area and infilling development method (both spatial and non-spatial). The growth of urban built-up area in KMC has been a major factor in the rise in LST, as shown by the study's revelation that values produced from three years of data fluctuated throughout the study periods in order to investigate the relationship between biophysical indicators and LST. The results show the highest association between LST and land use/land cover, including biological indices, in different years in Kolkata metropolitan (NDVI, NDWI and NDBI). It has been noted that the NDVI value for the years 2010 and 2015 had high and low values of 0.422680 and -0.254902, respectively. In the latter year, the high and low values were 0.46335 and -0.05426. However, in the same context, the indices research showed that the high value was 0.39630 and the low value was -0.08893 for the year 2020.According to the NDWI analysis map of KMC, this region's water index value was 0.555556 as high and -0.471503 as low in 2010, 0.27254 as high and -0.167946 as low in 2015, and very severe cyclones "Fani" and "Bulbul" in the months of April and November 2019, respectively, severely affected this region, resulting in an index of 0.321822 as high and -0.251219 as low for the year 2020.In the context of LST, it is divided into five zones: "Very Low," "Low," "Moderate," "High," and "Very Low". The minimum and highest LST temperatures in the KMC region were 17.25°C and 28.66°C in 2010, and 19.02°C and 29.85°C, respectively, in 2015.It appears that during the course of five years, the minimum and maximum surface temperatures increased by 1.77°C and 1.19°C, respectively. However, surprisingly, the Land Surface Temperature has fallen in 2020, with a minimum of 17.40°C and a maximum of 24.10°C, a difference of 1.62°C as minimum and 5.75°C as maximum, which is a sign of improvement for Kolkata's land surface temperature. This study clarified how unplanned and rapid urbanization might affect a region's surface temperature. Understanding how LST contributes to the expansion of UHI and how it affects people's health and welfare is the aim of the study. The study also provided a practical example of how LST estimation and LU development could benefit UHI research (Land Use).It was noted from the current studies that the city has a better ecological state as a result of the COVID-19 pandemic crisis, in which people were confined to their homes, businesses were closed, and building sites were deserted.

The work described the land use land cover map of the station's immediate surroundings covering eight stations which were chosen for the investigation. All of these stations appear to be located in areas with a mix of different land use types. Near traffic junctions at all of these stations, especially Jadavpur 8B Bus Stop, Baghajatin More, Eco Aquatic Hub Ruby Crossing, Behala Chowrasta, Chittaranjan Cancer Hospital-Hazra Crossing, The Future Foundation, Peerless Hospital monitoring was done. The mixed residential, commercial, and high traffic regions displayed the highest average temperature (above 28°C to 30°C) on the day of Diwali compared to that on the days before and after Diwali, out of all the land use types evaluated. Areas with significant levels of traffic and building activity also had the maximum temperatures, $PM_{2.5}$, and PM_{10}concentrations. In areas with a disproportionately large number of water bodies, open space, greenery, and low traffic the opposite was seen on the days before, during, and after Diwali. The statistical analyses, bivariate linear regressions by least square method were performed between the year 2018 and 2020 for $PM_{2.5}$ and PM_{10} with temperature, during the day and night of Diwali, respectively. It was observed that linear regressions between the year 2018 and 2020 of $PM_{2.5}$ and temperature have normal relationship in day time R^2=0.087 and R^2=0.087 respectively and in night time R^2=0.117 and R^2=0.021respectively. This statistical analysis also confirms the assumptions explained above during the discussion on result of dispersion seen on the day.

Additionally, this observation presents the developments and summarizes the inter-relationship and co-relationship among the UHI, LULC and Air Quality pattern in Kolkata. The city experiencing one of the highest levels of Urban Heat Island Effect (UHI_e) in the world into the city during the late evening also contributed to the increased level of Air Pollution. The main conclusions of this study are that by strategically placing green spaces and using statistical models to Landsat 5 satellite remote sensing data it is possible to lower temperatures in residential and urban regions. The fast expansion of city limits in almost most of the metropolitan cities all over the world has caused an exponential rise in particulate matters PM_{10} and $PM_{2.5}$.

This study finally concludes with possible mitigation through different approaches like cool pavements, cool roofs, and urban vegetation and suggested recommendation like, Kolkata's public transport system needs to be strengthened even more to deter people from using their own cars as a form of transportation - less waste heat and air pollutants, especially aerosols would be emitted if there were fewer cars on Kolkata's roads. This study also open ups with future scope of research to incorporate Model analysis for relevant studies as well as planning, controlling assessment of vehicular emission. Quantification of environmental impact of reduced heat gain, mitigation of urban heat island, air quality management, urban bio-diversity etc.

Chapter 1: Introduction

1.1 Background of the study

The most significant sort of Land Use and Land Cover change in human history is urbanization, which involves converting other types of land to purposes related to population and economic expansion. At local, regional, and international levels, urban expansion has had an increasing impact on socioeconomic conditions and the environment. In Kolkata, the unchecked urban sprawl, loss of agricultural land and natural vegetation, increasing traffic congestion, flooding, and deterioration of air and water quality have all been caused by the rapid growth of urban centers and their peripheries. This has led to both Air Pollution and Urban Heat Island Effects. The rapid urbanization that arises from the extensive growth of transportation, manufacturing, and commercial hubs is what gives rise to the Urban Heat Island (UHI) Effect.

The process of urbanization results in the permanent loss of forests, productive agricultural fields, and surface water bodies (Pathan, 1991).India's proportion of citizens residing in cities and urban areas nearly doubled to 27.78 percent in 2001, a low figure when compared to developed nations. While living in 27 metro areas, 396 cities, and 4738 towns, the 28.53 crore urban populations outnumber both the populations of developing and developed nations combined. Urban sprawl results from low density, unplanned communities of this type. According to Shekhar (2005), urban sprawl is the growth of new construction on isolated parcels that are isolated from one another by undeveloped territory. Migration and population growths both contribute to the urbanization process. Infrastructure projects cause a large-scale movement from rural to urban areas, leading in the development of small communities into towns, cities, and metropolises. According to some, sprawl refers to the uncontrolled growth of urban areas at the borders of cities, along highways, and along routes linking cities (Sudhira, *et al*., 2003). The current rapid high level of urbanization, that change land use and land cover, rapid constructions of buildings, high label of traffic congestion in urban areas leads to the change of surface and air temperature which impacts the urban microclimate. In this study first analyzed the land use land cover change pattern map and some generic models have been first developed for understanding the microclimatic changes due to the modifications and changes urban Land Use and Land Cover.

The Municipal Kolkata area is a part of Metropolitan Kolkata which occupies 12th (Census2011) position in the world by the size of its population. It is the biggest urban area in India with a population of 44486679 (Census 2011). The city is located at 22°30' North latitude and 88°30' East longitude is the primary port of entry for North Eastern India. It is situated on the banks of the River Hooghly and approximately 120 kilometres from the Bay of Bengal with an area of 187.33 km^2 and has an average population density of 24000 persons per km^2 (Census2011). In addition, about 2 million floating population comes to the city.

1.2 Urbanization and Urban Climate

Urbanization is the process by which a region loses its rural character and way of life and the increase in the proportion of a population living in urban areas. It primarily results from rural-urban migration(Source: Oxford Reference).

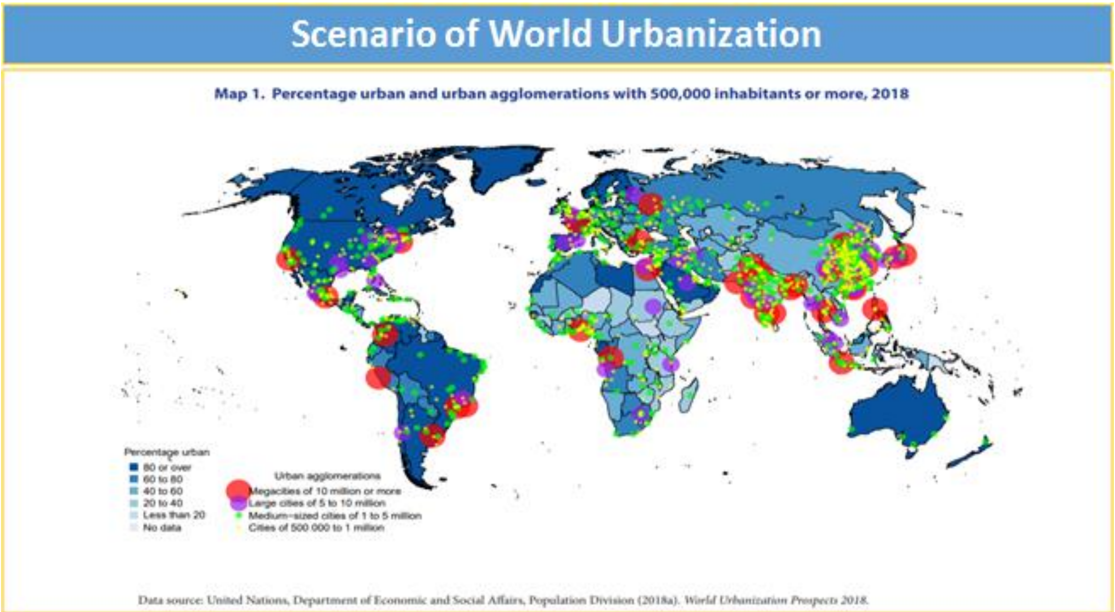


Figure 1.2.1: Scenario of World urbanization

Source: United Nations, Department of Economic and social Affairs, Population Division(2018a)

In the past century, urbanization has caused a rise in the daily mean air temperature at ground level of between 0.1 and 0.4 degrees Celsius. Urban heat islands are created as a result of this. When a significant portion of a region's natural land cover is replaced by man-made structures, heat islands are created. These structures re-radiate solar rays at night after absorbing it throughout the day (Quattrochi *et al*., 2000; Oke 1982).An "urban heat island" is nothing more than an increase in surface temperature in some areas of a city, brought on by a microclimate that is always changing and is in turn influenced by human activities like industrialization and vehicle emissions, which worsen the quality of the city's air. In densely populated places like Kolkata metropolitan, the urban heat island effect is a significant role in managing air quality and promoting public health.

1.3 Urbanization and its effects on Air Quality

Urbanization is a dynamic process that contributes significantly to human-caused climate change. Urban heat island (UHI) is a result of a variety of natural and artificial factors (Memon *et al.*, 2008a, b*;* Unger *et al.*, 2001) and hasn't been thoroughly examined (Hafner and Kidder, 1999*;* Poreh, 1995). Urban Heat Islands not only raise the temperature above that of the surrounding areas' averages, but they may also worsen the environment by reducing rainfall, which in turn raises pollution and airborne suspended solid particle matter levels. During the 100 years that ended in 2005, the earth's surface temperature rose by 0.74° C to 0.18°C. According to the current IPCC report's summary of climate model predictions, which is in the 21st century, there would be little doubt that the average global surface temperature will rise by 1.1 to 6.4 degrees Celsius.

Despite being hindered urban environments complexity in both space and spectral terms, remote sensing (Herold *et al.*, Jensen and Cowen 1999; 2004) appears to be a suitable urban data source for these researches (Donnay *et al.*, 2001). Conditions favoring the rise in temperatures over urban areas compared to neighboring rural areas include a decreased sky-view factor, the removal of soil cover and replacement with concrete or asphalt surfaces, and the large release of waste heat from the industrial, commercial, residential, and transportation sectors. (P. Pandey *et al.*, / Science of the Total Environment 414 (2012) 494-507).

In Kolkata, the brisk growth of urban centers and their outskirts has frequently resulted in a number of intricate environmental issues. Because of the increased heat in metropolitan areas, more energy must be used to cool buildings, which worsens the air quality and has detrimental health effects. For instance, greater temperatures contribute to more Ozone (O_3) pollution being produced (Lo and Quattrochi, 2003; Cardelino and Chameides, 2000). The UHI signal indicates a variety of significant land surface changes that may have an impact on climate, local weather, ecosystem function, and human health (Imhoff, Zhang, Wolfe, Bounoua, *et al.*, 2010). There is growing interest in the mapping of urban thermal conditions and their relationship to Land Use and Land Cover (LULC) and air pollution. The degradation of vegetation cover is caused by urbanization, expansion, and encroachment into the few remaining agricultural and green regions, together with rapid population increase (Amiri, Weng, Alimohammadi, Alavipana *et al.*, 2009).

Urbanization inevitably has an impact on the environment, as seen by increased land surface temperatures (LST), urban heat islands (UHI), and air pollution. Numerous studies have demonstrated that various regional elements as well as urban and street layout influence the air temperature in urban canyons (Bärring, Mattsson, and Lindqvist 1985). According to LST research, the conversion of surface soil, water content, and vegetation can affect the balance of land surface energy (Li and Zhou, 2011).Based on this concept, the primary goal of this study is to understand the relationship between urban land use classification and the UHI pattern of the city Kolkata and identify the impact of land use changes over air pollution and urban heat island effect in different year (i.e. 1996 and 2016) using remote sensing satellite imageries and locally collected pollution data.

1.3.1 Effects of Urbanization

- Small villages, towns, and cities of all sizes are impacted by urbanization, which also contributes to the emergence of megacities with populations of more than 10 million.
- Globally, over 50% of the population lives in urban areas today.
- According to the 1901 Census, 11.4% of Indians lived in urban areas. By 2001, that number had risen to 28.53%, and as of 2017, 34% of Indians live in urban areas, according to The World Bank. A UN poll estimates that 40.76% of the country's population would live in urban areas by 2030.

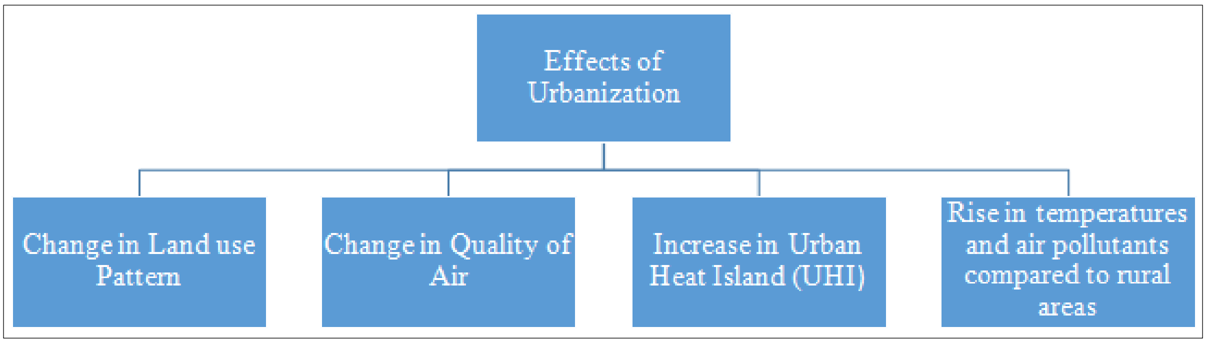
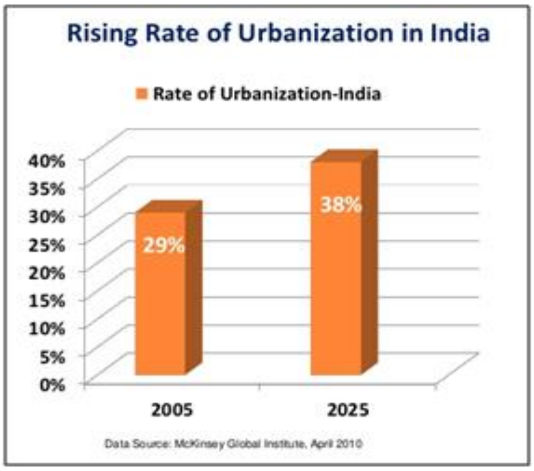


Figure 1.3.1.1: Effected areas due to urbanization



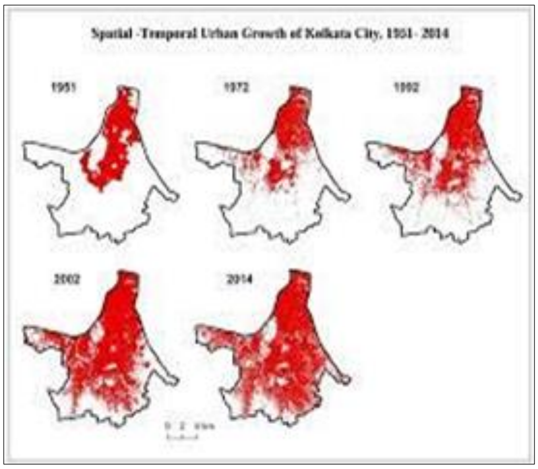


Figure 1.3.1.2: Rising rate of urbanization in India

Source: researchgate.net

Figure 1.3.1.3: Spatial-temporal urban growth

Source: sciencedirect.com

1.4 Urban Population pattern in Kolkata and its impact

Eastern India's largest urban agglomeration is called the Kolkata Metropolitan Area (KMA). According to the 2001 Census, there are 14.72 million people living in KMA, compared to 22.5 million people living in West Bengal's metropolitan areas as a whole. The city of Kolkata's infrastructure and municipal upkeep are handled by the Kolkata Municipal Corporation (KMC), formerly known as the Calcutta Municipal Corporation and founded in 1876. A 187.33 sq. km. area is serviced by the KMC. The city is organized into 15 boroughs, which are comprised of 141 administrative wards.

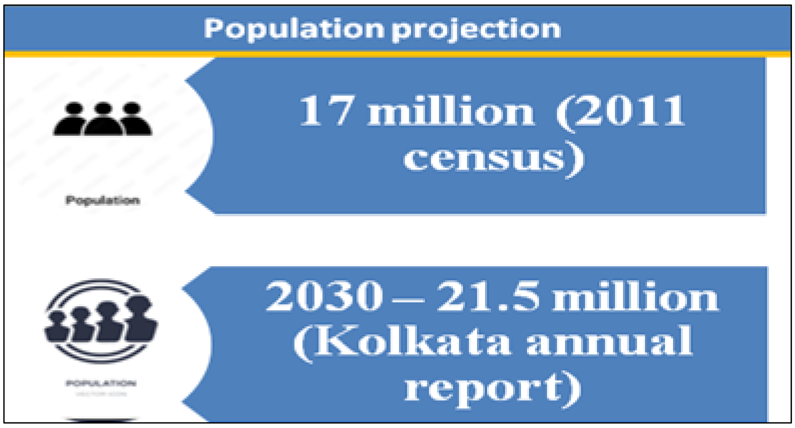


Figure 1.4.1: Population projection of Kolkata. **Source: Kolkata annual report**

Urbanization and population increase have put enormous pressure on the conversion of land from natural and agricultural uses to residential and urban uses, which has had a severe negative impact on ecosystem services (Justice *et al.*, 2015). The destruction of vegetation cover is caused by urbanization, rapid population increase, and encroachment into the few remaining agricultural and green spaces (Bakhtiar Feizizadeh and Thomas Blaschke, 2013) as well.

In developing nations like Asian nations, rapid urbanization is highly concerning. Forests, productive agricultural fields, and surface water bodies are lost forever as a result of urbanization (Pathan, 1991).In India, the proportion of citizens residing in urban areas and cities nearly doubled to 27.78 percent in 2001.

The present era's accelerating urbanization makes it extremely challenging to monitor population trends using outdated classical survey and census methods. Censuses are typically conducted every 10 years; therefore their usefulness for population monitoring is rather restricted.

1.5 Urban Heat Island (UHI)

Urban Heat Island, a concept that dates back to the 1940s (e.g., Balchin and Pye, 1947), describes how human activity causes a city's atmosphere to be warmer than its surrounding countryside. When winds are light, the UHI's interpose temperature difference is greater at night than it is during the day. UHI is most apparent in the summer and winter seasons. Due to heat pockets known as "Urban Heat Islands," which are caused by human heat produced by equipment and vehicles as well as incident solar radiation being stored by the built environment, urban regions experience higher temperatures than rural ones (UHI) (Landsberg HE, 1981).Additionally, the temperature differential between urban and rural areas affects how intense a heat island is. The size, population, and density of a city, as well as the morphology of cities, all affect the intensity of heat islands (Ferrar TA John Wiley & Sons, 1976, Oke TR., 1982).

Table 1.5.1: classification of urban heat island types (a simple scheme, after Oke,2006a).

UHI type	Location
Air temperature UHI: Heat island urban border layer, urban canopy layer	Found at or below tree or roof peaks Located above the roof line and can be seen downwind of the urban plume.
Surface temperature UHI	Different heat islands depending on the definition of surface utilized, (e.g. bird's eye view 2D vs. true 3Dsurface vs. ground)
Sub surface UHI	Found in the ground beneath the surface

The Canyon Layer Urban Heat Island is the urban heat island that is determined by the variations in ambient air temperature between buildings at street level. The capacity of urban fabric to absorb heat and urban geometry determine the intensity of UHI primarily (Arnfield A J, 1990).

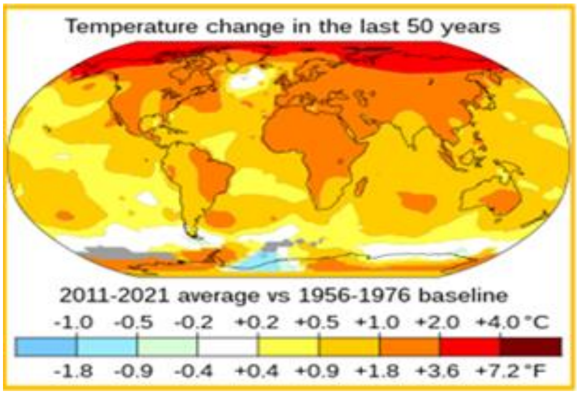


Figure 1.5.1: Average surface air temperatures from 2011 to 2021 compare to the average of 1956-1976 and the typical Urban Heat Island profile Source: researchgate.net

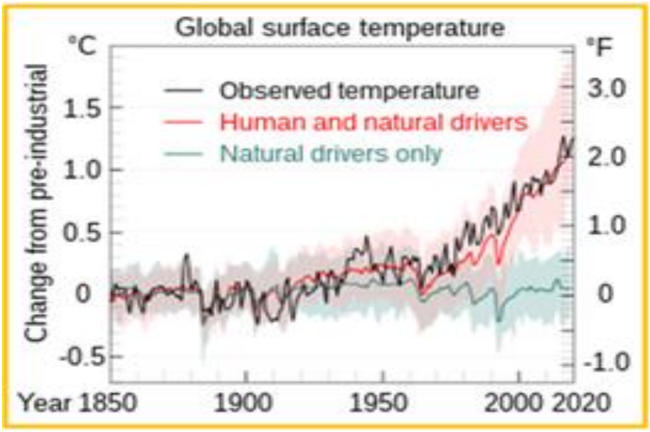


Figure 1.5.2: Change in average surface temperature since the industrial revolution

Source: researchgate.net

Because of the increased heat in metropolitan areas, more energy must be used to cool buildings, which worsens the air quality and has detrimental impacts on health. For instance, greater temperatures cause more ozone (O_3) pollution to be produced (Lo and Quattrochi, 2003; Cardelino and Chameides, 2000).

Urban heat island in tropical Area

Tropical trees with greater leaf surface area and extensive root zone transfer significant amount of water vapour from surface to the atmosphere in terms of evapotranspiration and thus facilitates surface to atmosphere heat transfer in from of latent heat. The latent heat transfer constitutes a significant component of surface energy balance (SEB) in tropical cities. Therefore, the replacement of green cover by impervious surface upsets SEB in tropical climate.

UHI has become a growing concern to the quality of densely built urban environments, particularly in tropical cities. In tropical climate, urban geometry modifications could be helpful through installation of radiant cooling strategies, building ventilations, and evaporative cooling surfaces.

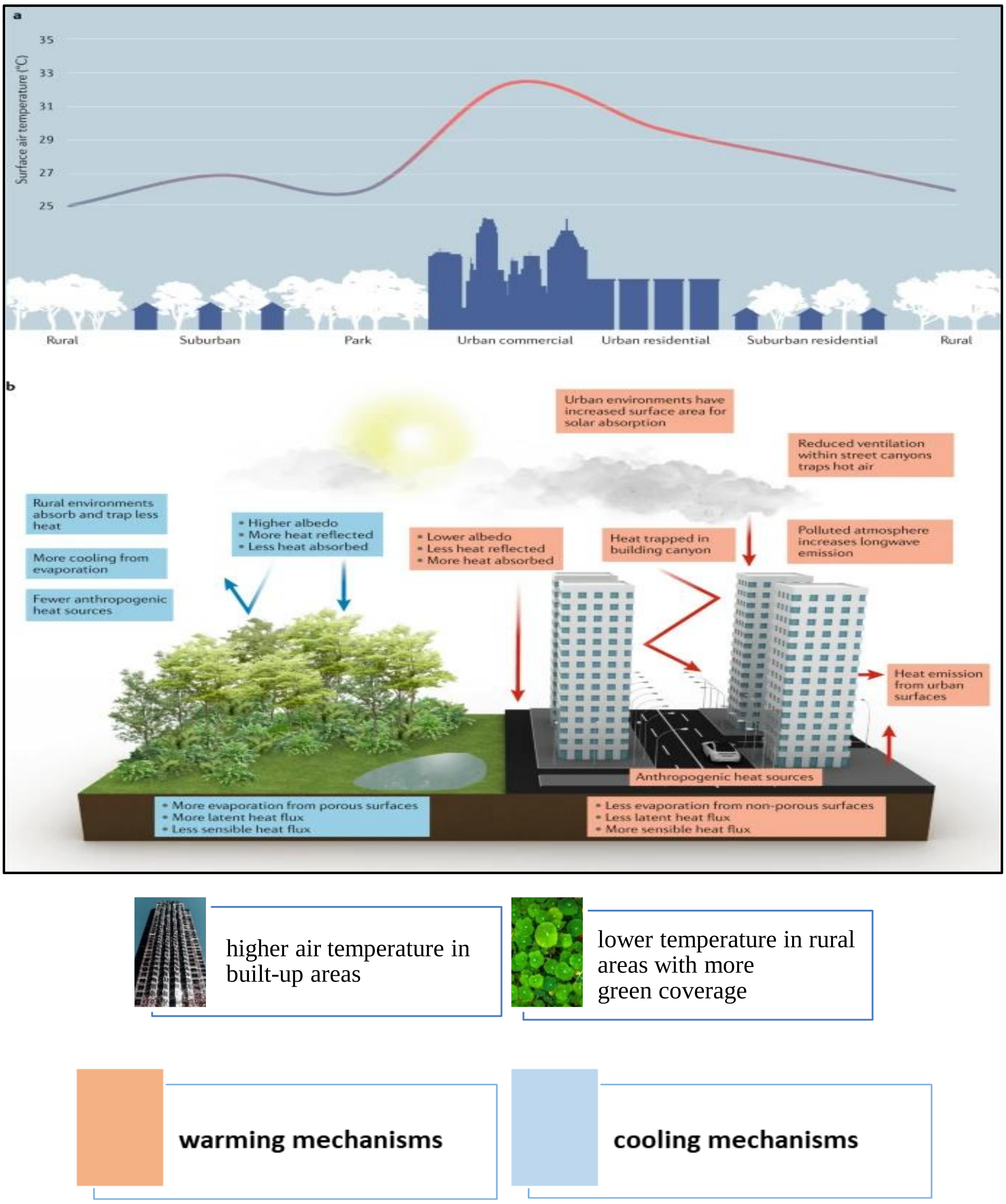


Figure 1.5.3: Typical Urban Heat Island profile

Source: nature.com/researchgate.net

1.6 Land Surface Temperature

The resultant radiative skin temperature of the land brought on by solar radiation is known as the Land Surface Temperature (LST).The zone of land where the sun's incoming energy interacts with and warms the ground or the canopy's surface in vegetated areas is where LST detects the emission of thermal radiation (Urban Heat Island Modeling for Tropical Climates, Ansar Khan and Yupeng Weng, 2021). Temperatures of bare soil and vegetation combine to form LST. Consequently, the air temperature that is given in the daily weather report and the Land Surface Temperature are not the same.

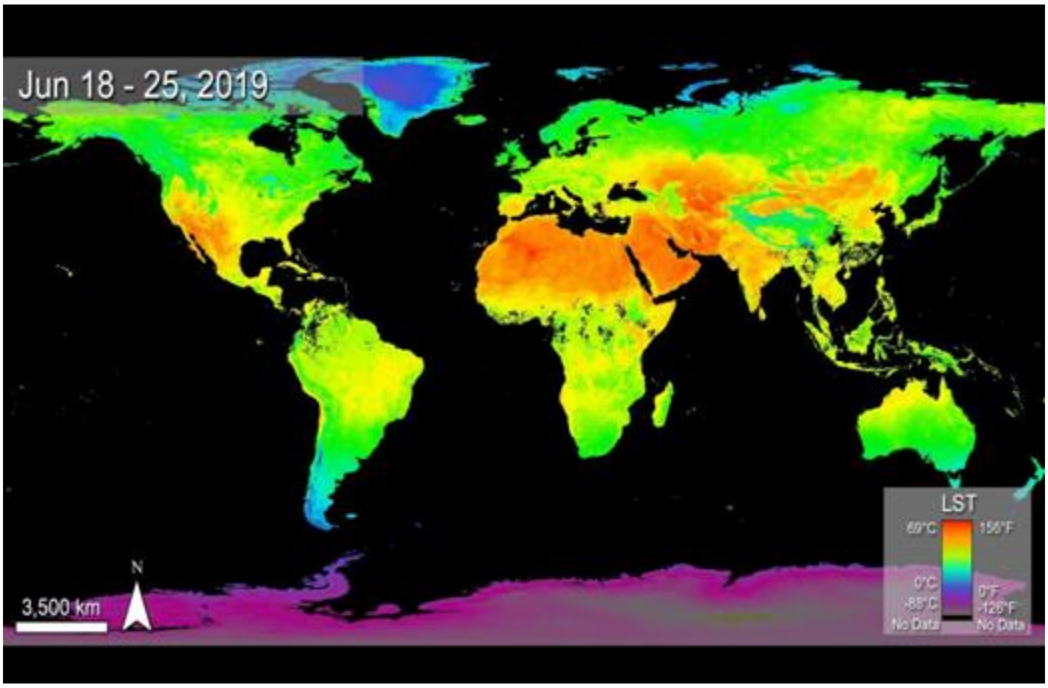


Plate 1.6.1: Global Land Surface Temperature (by Terra MODIS, NASA)

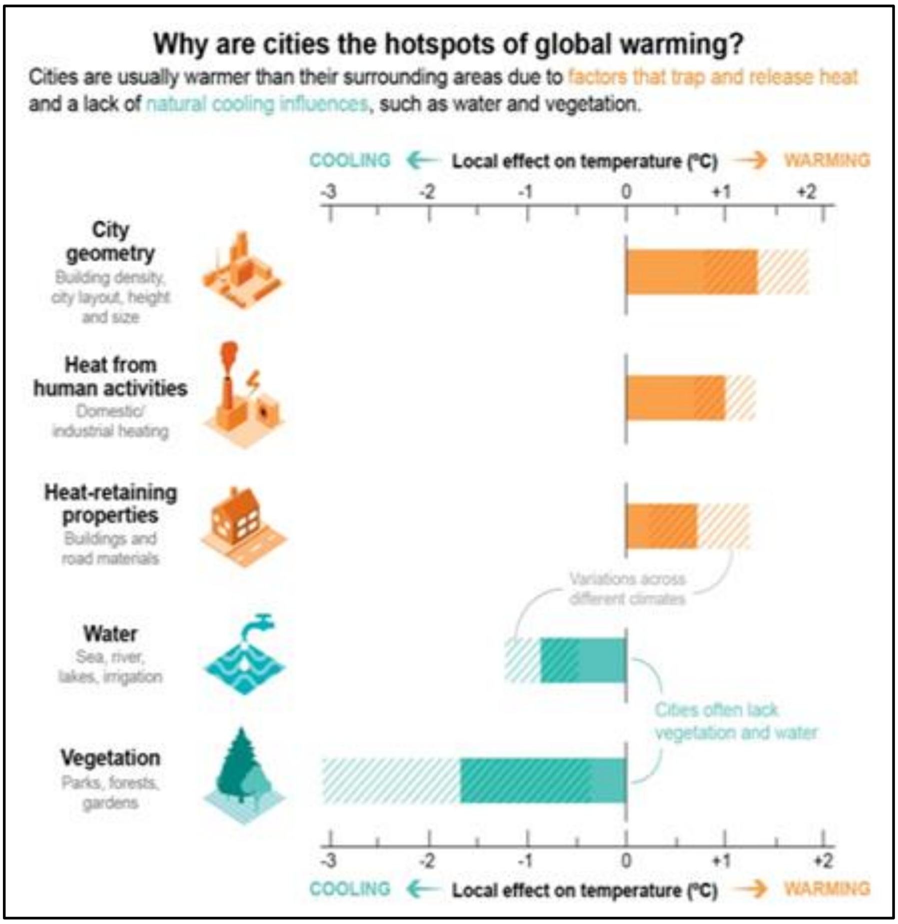


Figure 1.6.2: Hotspots of Global Warming **Source: IPCC Report 2021**

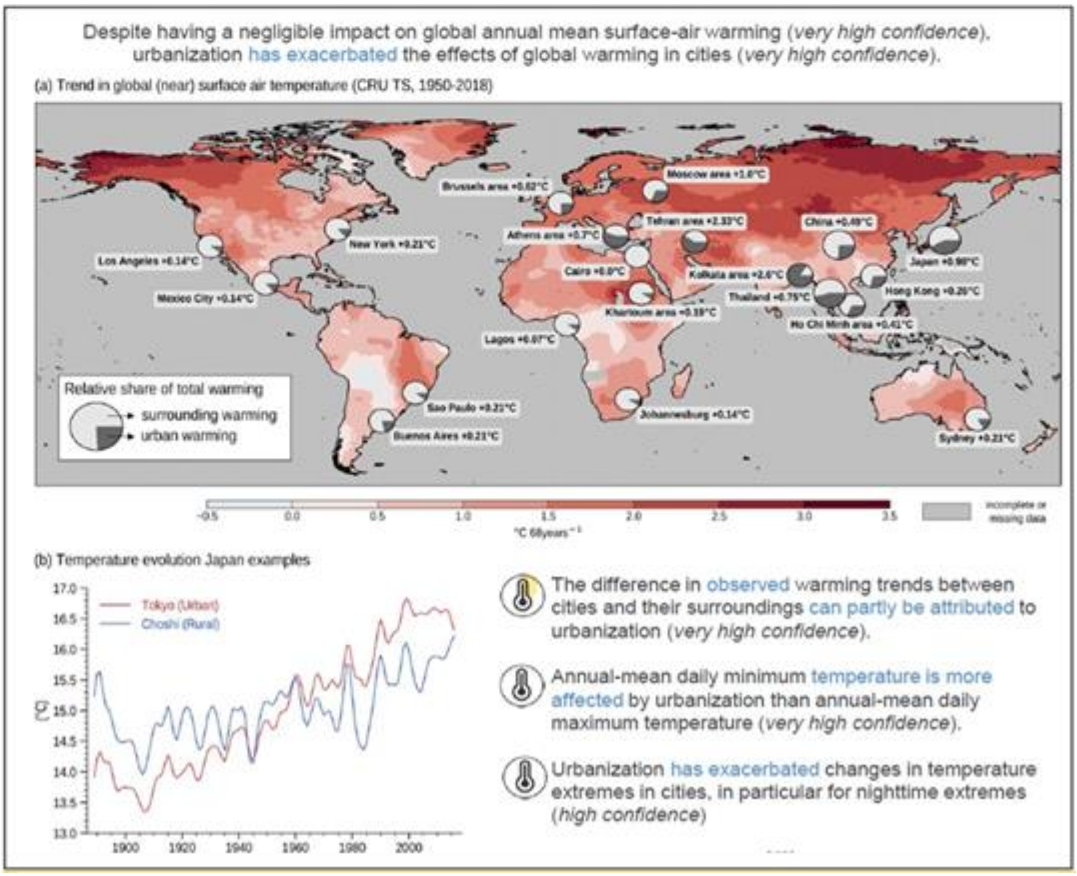


Figure 1.6.3: Temperature ImpactSource: IPCC Report 2021

1.7 Air Temperature and its impact in Kolkata

The hotness or coolness of the air is measured by its air temperature. In meteorology, it is also known as surface temperature. The temperature recorded by a thermometer that is placed in the open but shielded from the sun is known as the air temperature. Surface or Air Temperature measurements can be used to locate urban heat islands. Air temperatures are significantly yet indirectly influenced by Surface Temperatures. For instance, parks and other vegetated places, which frequently have cooler Surface Temperatures, help to chill the air. On the other hand, densely populated places often result in warmer air temperatures. However, the relationship between surface and Air Temperatures is not constant since air mixes inside the atmosphere (U.S. EPA, 2015. Measuring Heat Islands).

CLIMATE CHANGE

IPCC report warning: 4.5°C rise in Kolkata by century-end, rise in cyclones, sea level

Sea level close to Sundarbans at the southern fringe of Kolkata expected to rise 60 cm by century-end

NEXT NEWS ›

By Jayanta Basu
Published: Tuesday 24 August 2021

The recently released climate change report has set off alarm bells across the world. A drastic future may be in store for India and south Asia as well.

Kolkata and its surroundings have warmed up especially and worse is in store, the Intergovernmental Panel on Climate Change (IPCC) report has warned.

Kolkata may experience a 4.5 degree Celsius rise in annual mean temperature in 2081-2100 compared to the pre-industrial period (1850-1900) under the worst possible greenhouse gas emission scenario, according to the report released August 8, 2021.

Kolkata recorded the highest rise in surface air temperature within the studied cities and regions across the world in 1950-2018, according to the report.

The pre-industrial period (1850-1900) is considered a benchmark; it was during this time that industrialisation was intiated and human-induced emissions started to increase.

The report predicted that while total rainfall in the city and adjoining areas may increase marginally, short-duration extreme rainfall events would increase substantially.

Plate 1.7.1: IPCC Report

Kolkata's heat islands show increased intensity

Dhruba Dasgupta

, 29.06.16

An increase in vehicular traffic, intensive land use and encroachment of the wetlands in the eastern fringes of the city are adding to the intensity of the heat island effect in Kolkata, according to a recently concluded research by Auburn University in the US done in collaboration with the India Meteorological Department.

"Every city, big or small, has its own urban heat island magnitude. It is important to know it as also identify the root causes," says climatologist Chandana Mitra, lead author of the study that is yet to be published. An urban heat island is a city or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities.

Source: www.inawe.in/kolkatas-heat-islands-show-increased-intensity/

Plate 1.7.2: Report of Dhruba Dasgupta

1.8 Land Use Land Cover (LULC) changes

Human-caused Land-Usage Change - It is evident that environmental factors including soil properties, climate, topography, and vegetation confine land use. However, it also emphasizes the value of land as a crucial and limited resource for the majority of human activities, such as farming, forestry, energy generation, settlement, leisure, and water collection and storage. A vital component of production, land has historically been closely linked to economic expansion throughout much of human history (Richards, 1990). As a result, ownership of property and its usage is frequently the subject of heated disagreements amongst people. The properties of land cover are changed or maintained by human activities, which are regarded as the closest causes of change. They include anything from the initial conversion of natural woodland into agriculture to ongoing grassland management (such as choosing the frequency and intensity of grazing) (Schimel *et al*., 1991; Hobbs *et al*., 1991; Turner, 1989). Such behaviors cannot be understood in isolation from the underlying driving forces that encourage and limit production and consumption since they are a result of a variety of social aims, such as the demand for food, fiber, living space, and recreation. Some of these factors, such private property rights and the international and local power systems, affect who has access to or authority over land resources. Other factors, such population density and the extent of economic and social advancements, have an impact on the demands that will be made on the land, while technology has an impact on the amount of exploitation that is feasible. Others, like agricultural pricing policies, influence land-use choices by establishing the incentives that influence each decision-maker. It is debatable in both scholarly and policymaking contexts how these elements combine to generate distinct uses of the land in various environmental, historical, and social circumstances. In addition, there are several theories as to what variables are the key determinants. Particular controversy appears in evaluation the relative importance of the different forces underlying land-use resolutions in specific cases. For instance, the apparent degradation of dry ground may be the result of overgrazing by ever-growing numbers of groups of nomadically herding cattle; a "development" intervention's unexpected consequences, such as the construction of bore holes that put more strain on the soil nearby the wells, or the political clout of groups that have access to public lands through their links with the government (Pearce 1992; NERC 1992). The creation of policy solutions or the rights of opposing user groups may be affected by the identification of a specific cause.

1.8.1 Scenario of Land Use and Land Cover in Kolkata

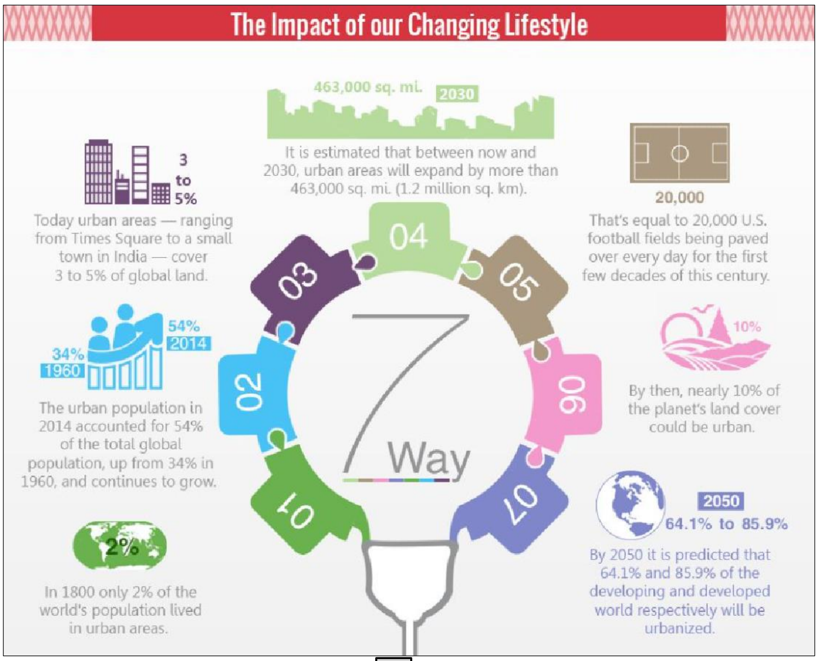
Like other third world metropolitans, Kolkata is also facing a problem of overcrowding which is the result of a mixed land use pattern with a pre-dominating residential land use. Due to a lack of available land, the metropolitan city has experienced rapid vertical growth (high rise buildings), which has increased demand for basic services (physical infrastructures, such as potable water, sewerage and drainage, electricity, etc.). This has placed a great deal of strain on the civic administration because the installed capacity would not be able to keep up with the rising demand over a specific geographic area.

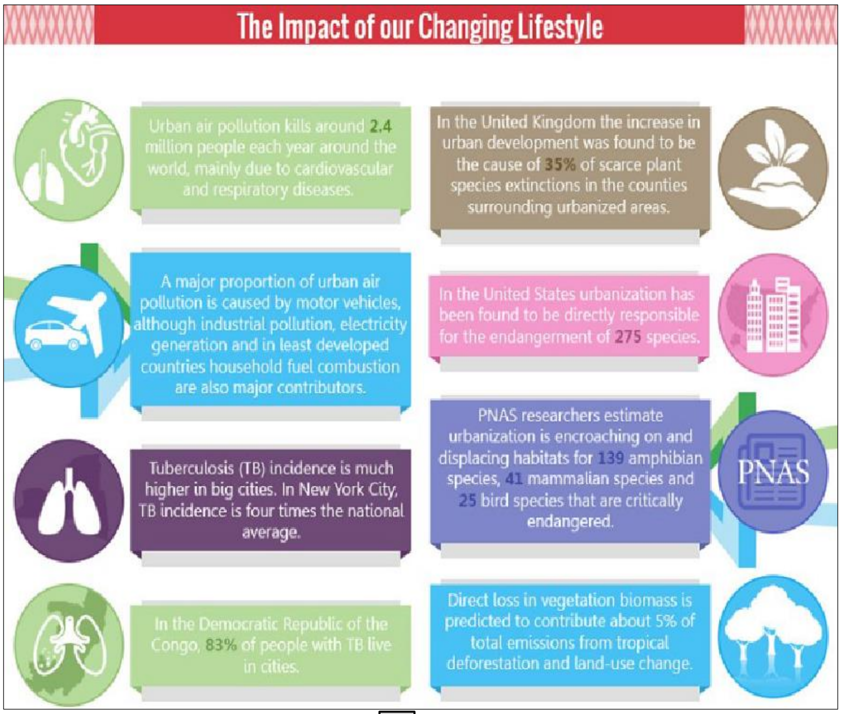
1.8.2 Impact of LULC changes on Land Surface Temperature

The strain of a growing population, expanding industry as well as technological advancement has compelled the remodelling of natural surfaces into artificial urban surfaces (Khan Ansar, Akbari *et al*.). In contrast to moist, porous, less heat-capturing, and less heat-retaining natural surfaces, manufactured surfaces are typically impermeable, less reflecting, lack moisture, and impact surface dynamics. The urban surface has a higher "Land Surface Temperature (LST)" than the natural surface as a result of these altered features, which causes the phenomenon of UHI (Khan Ansar, Akbari *et al*.). Several research studies investigate the relationship between LST and LULC changes globally and found that LULC fluctuation significantly affects LST and therefore Air Temperature (Coseo and Larsen, 2014; Estoque *et al.,* 2017; Sultana and Satyanarayana, 2018, 2019, 2020).

1.9 Air Pollution

In the majority of developing nations, air pollution is one of the biggest and most serious environmental and public health concerns. The purpose of this paper was to provide insight information about the current state of Air Quality in different Indian towns, as well as the numerous causes and effects of Air Pollution. People are being educated about the numerous gases and particulate matter found in the air, as well as the consequences these substances has on the ecosystem and possible solutions. Methods: The National Air Quality Index (NAQI) enables comparisons across different cities so that fresh approaches to reducing the amount of airborne particulates can be developed. Based on historical NAQI data, the concentration of various pollutants and dangerous gases for several Indian cities is evaluated in this article, indicating the locations that are most at risk from pollution.


The Impact of our Changing Lifestyle
463,000 sq. mi.
2030
It is estimated that between now and 2030, urban areas will expand by more than 463,000 sq. mi. (1.2 million sq. km).
3 to 5%
Today urban areas — ranging from Times Square to a small town in India — cover 3 to 5% of global land.
20,000
That's equal to 20,000 U.S. football fields being paved over every day for the first few decades of this century.
54%
2014
34%
1960
The urban population in 2014 accounted for 54% of the total global population, up from 34% in 1960, and continues to grow.
10%
By then, nearly 10% of the planet's land cover could be urban.
01
02
03
04
05
06
07
7 Way
2050
64.1% to 85.9%
By 2050 it is predicted that 64.1% and 85.9% of the developing and developed world respectively will be urbanized.
2%
In 1800 only 2% of the world's population lived in urban areas.


The Impact of our Changing Lifestyle
Urban air pollution kills around 2.4 million people each year around the world, mainly due to cardiovascular and respiratory diseases.
In the United Kingdom the increase in urban development was found to be the cause of 35% of scarce plant species extinctions in the counties surrounding urbanized areas.
A major proportion of urban air pollution is caused by motor vehicles, although industrial pollution, electricity generation and in least developed countries household fuel combustion are also major contributors.
In the United States urbanization has been found to be directly responsible for the endangerment of 275 species.
PNAS researchers estimate urbanization is encroaching on and displacing habitats for 139 amphibian species, 41 mammalian species and 25 bird species that are critically endangered.
PNAS
Tuberculosis (TB) incidence is much higher in big cities. In New York City, TB incidence is four times the national average.
In the Democratic Republic of the Congo, 83% of people with TB live in cities.
Direct loss in vegetation biomass is predicted to contribute about 5% of total emissions from tropical deforestation and land-use change.

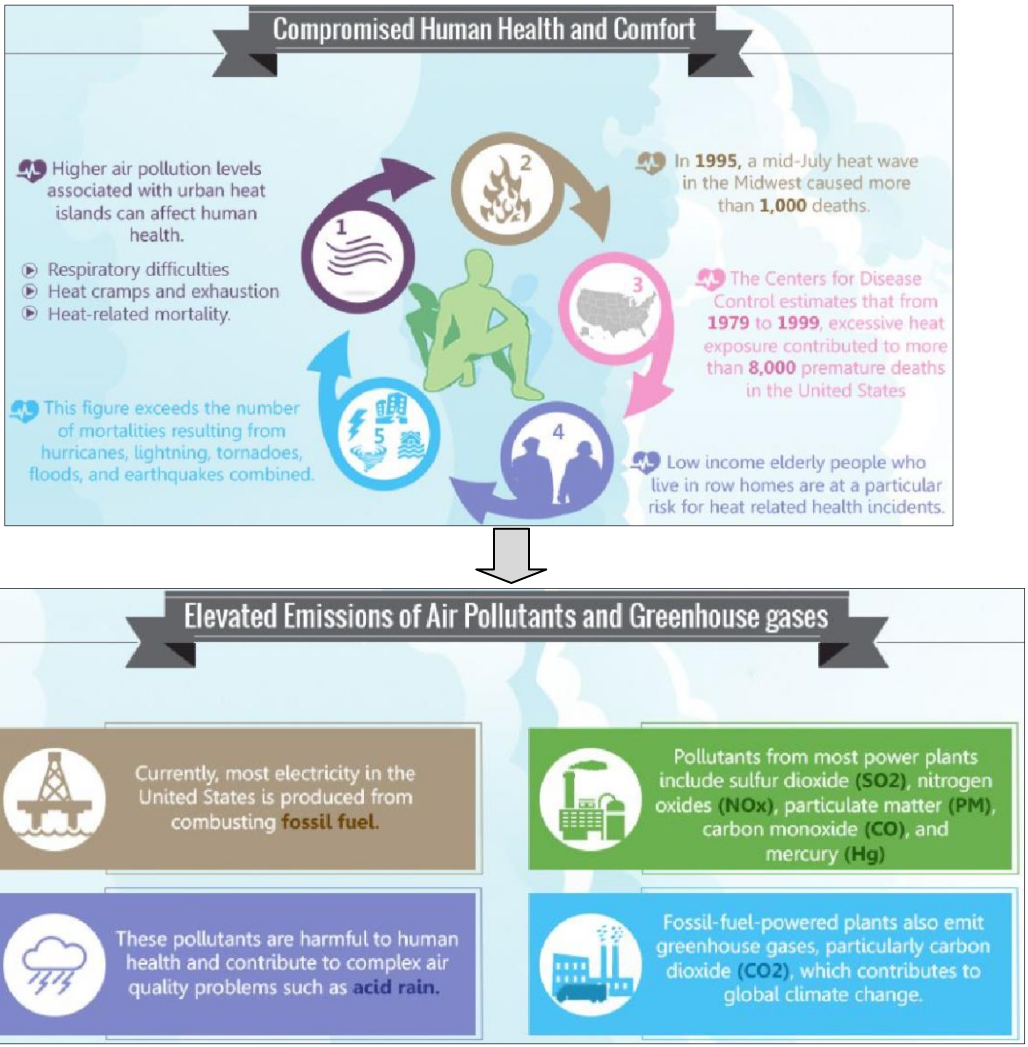


Figure 1.9.1: Impact on human life style

Source: openaccessgovernment.org

Findings: Due to the significant dangerous web of particulate matter (PM) and toxic chemicals present in the air that living organisms breathe, it has been recognized over the past few years that the rate at which urban air pollution has increased throughout India is worrying. All Indian cities have incredibly higher levels of particle pollution. Only a small number of cities can be singled out as having initiated Air Quality Monitoring (AQM), and as a result, have seen some improvement in the quality of the air. However, the majority of afflicted places are small and medium sized towns, which experience an alarming increase in pollution. Air pollution has become a national emergency in numerous cities around the nation as a result of an enormous growth in the number of automobiles, industries, and manufacturing facilities.

- ❖ Total life lost due to ambient Air Pollution by regions, 2012.
- ❖ According to a recent OECD analysis titled "The Economic Consequences of Air Pollution," by the year 2060, outdoor air pollution might result in 6 to 9 million more fatalities per year.

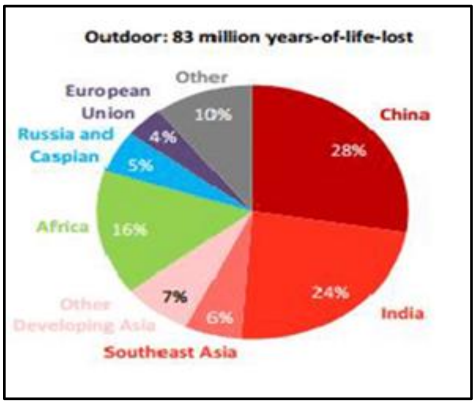


Figure1.9.2: Total life lost due to Ambient Air Pollution by regions, 2012.
Source: Air Quality Monitoring in Dehradun City and its Impacts on Health by Sagarmoy Phukan

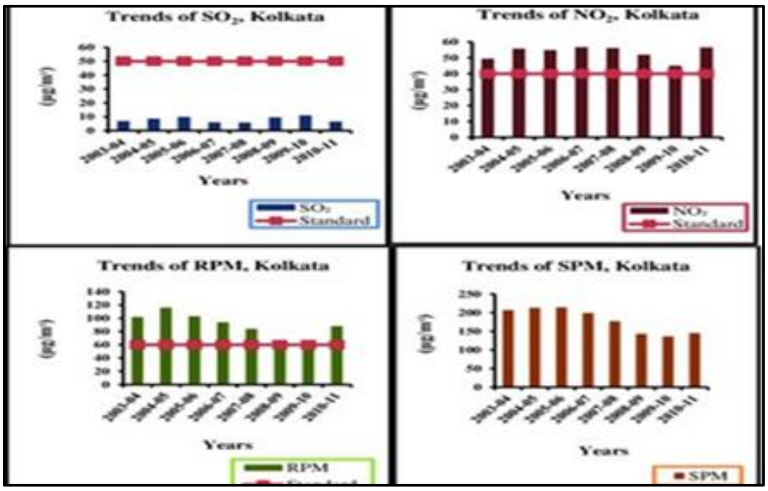


Figure 1.9.3: Trend of pollutants like SO_2, NO_2, $PM_{2.5}$, Respirable particulate matter (PM_{10}) over the years.
Source: "Air Pollution and Human Health in Kolkata, India: A Case Study" by M.S. Haque & R.B. Singh.

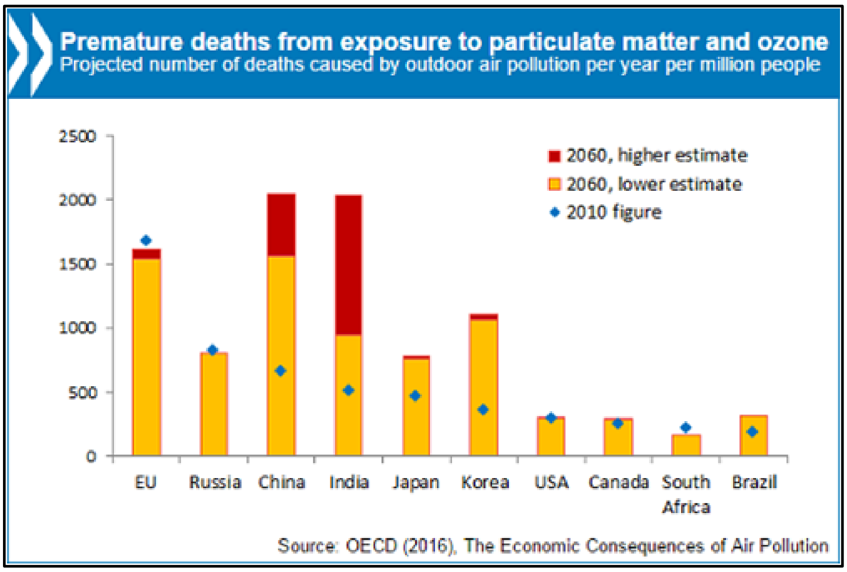


Figure 1.9.4: Premature deaths from exposure to PM and Ozone.

Source: researchgate.net

1.10 Air Quality and Vehicular Emissions

When a vehicle is in motion, harmful pollutants that are byproducts of the fuel combustion process, rise to the surface and mix with air molecules in the surrounding area. Two categories exhaust emission and evaporative emission, can be used to categories automotive emissions in cities. Running losses and hot soak emissions, which are created when fuel evaporates while an engine is still hot at the end of a journey, are examples of evaporative emissions. Evaporative emissions can also result in diurnal emissions. Therefore exhaust emission again can be categorized into two types, one is start up emission (can be highlighted once the car has started, Initially) and another is running emission (Because the engine's temperature has increased and may be the cause of more burning fuel pollutants, the vehicle is in a hot stabilised state and produces a lot of car pollutants).

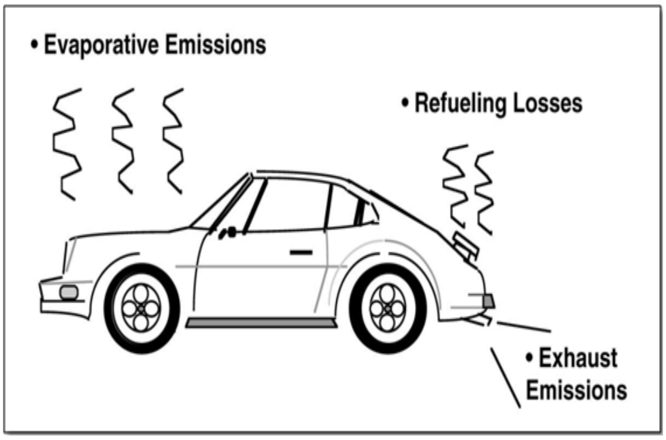


Plate 1.10.1: Car pollutants

Source: US Environmental and Protection Agency (2012)

According to official database from West Bengal Pollution Control Board (2012), it has been measured that Kolkata city has maximum exhaust emission concentration of RSPM which is approximately more than 150µg/m^3 compared to other megacities because of maximum congestion and older fleet vehicles which are plying on the city road. In term of another toxic pollutant like NO_x, Kolkata recorded highest concentration which is approximately more than 65µg/m^3 compared to the other metro cities and Kolkata is remarkable in this context where the concentration is more than the threshold limit which is 40µg/m^3. As per the official estimates in the year 2010, there are 43 critically polluted cities, among which Kolkata ranked third after Delhi (1strank), and Mumbai (2ndrank). 25 emission checking stations have been established by the West Bengal Pollution Control Board around the state of West Bengal. Durgapur and Barrack pore are the other two stations designated to detect particulate matter ($PM_{2.5}$), while three stations in Kolkata have started to test PM_{10}.However, the WBPCB has launched a few mobile vans with emission measuring equipment in collaboration with the Department of Environment, Government of West Bengal, through which various toxic and carcinogenic pollutants, including SO_2, NO_2, $PM_{2.5}$, PM_{10}, NH_3, CO, Benzene, Ozone, and Pb are measured at different intersection points in the city of Kolkata. Dunlop Bridge, Ultadanga, Salt Lake, Moulali, Minto Park, Behala, Chowrasta, Tollygunge, Victoria Memorial, Rabindra Sadan, Science city Connector are some of the important emission monitoring station throughout KMC area.

1.10.1 Vehicular emission issues in the context of Kolkata

According to the West Bengal Pollution Control Board, the main causes of the highest vehicular emissions are the high average age of the vehicles, the extremely small amount of road surface area, the condition of the road surface, such as speed breakers, the high population density using the same amount of road space, mixed vehicular modes, as well as slow moving vehicles, which are to blame for the congested traffic conditions in Kolkata. Further, it has been identified some of the reasons which are communicate for the city of Kolkata's vehicular pollution. It mostly consists of:

a) High emissions from gasoline-powered two- and three-wheelers.
b) Using fuel of low quality, such as benzene, olefin, and high sulphur fuel
c) Fuel adulteration, particularly the use of "katatel" (Kerosene and exhaust lubricated fuel), is a common occurrence in Kolkata's inner-city automobiles, particularly in a few three-wheeled vehicles.
d) Poor vehicle maintenance and even the prevalence of many heavy, ancient, petrol-powered automobiles contribute to significant emissions.
e) Unpredictable traffic patterns that cause congestion and release significant amounts of car emissions.
f) The majority of Kolkata's main traffic intersection locations have been invaded by pavement dwellers, street vendors, and illegal parking; as a result, the width of the road has shrunk, which has led to severe traffic congestion in the city.

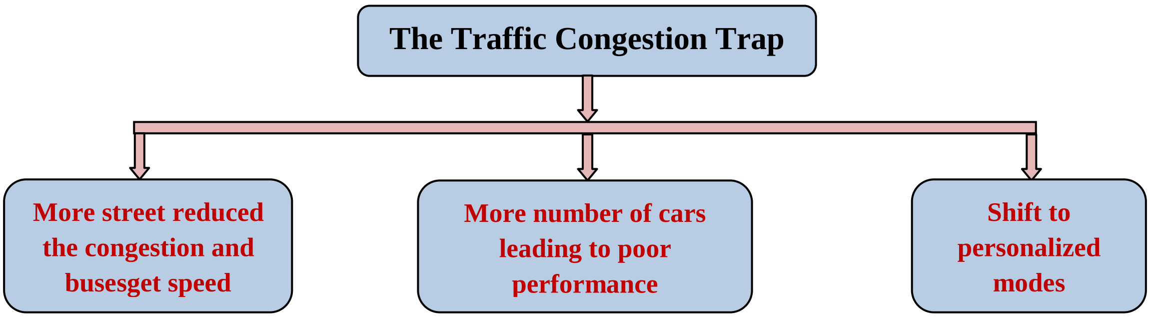


Figure 1.10.1.1: The Traffic Congestion Trap

Source: Traffic Congestion Scenario of Third World by William Vickrey (2004)

(g) Inadequate road space created by improperly constructed road dividers between two lanes of traffic limits greater traffic mobility, and even poorly constructed speed bumps slow down traffic in Kolkata.

(h) Even poor traffic management by the traffic police in Kolkata and issues with the traffic signalling system can cause congestion and pollution.

(i) A significant number of vehicular pollutants are released into the air in Kolkata due to unscientific overpass construction, car size and weight, and poor traffic management.

1.10.2 Kolkata and its Air Pollution aspect

According to the West Bengal Pollution Control Board, the primary causes of air pollution, in addition to vehicle emissions, include: a relatively high vehicle age, a relatively limited amount of road surface area, situations like speed breakers on the road surface, a large number of people using the same amount of road space, a combination of vehicle types including slow moving vehicles, and other considerations. It has been determined that a number of factors contribute to Kolkata's traffic congestion, including high emissions from two and three wheeled petrol vehicles, the use of low-quality fuel, the use of "katatel" (kerosene and exhaust lubricated fuel), poor vehicle maintenance, and even the prevalence of many heavy, old, petrol-powered vehicles.

Road dust, soil dust, building activity, traffic, and industrial emissions in industrial zones are all to blame for the source of high level of SPM. Along with human causes, other factors at play include the roughness of the sources and the weather. The SPM concentration in Kolkata is impacted by the city's high relative humidity as it accepts gas-to-particle conversion processes (Gupta *et al.*, 2008). Transport sectors in Kolkata also emit huge amount of particulate matter in the atmosphere, however including the unpaved road is major contributor for the concentration of particulate matter.

The Telegraph

Poor air quality behind more than half of lung cancer cases in Kolkata, say experts

Krishnendu.Bandyopadhyay
@timesgroup.com

Kolkata: Pollution could be responsible for more than half of Kolkata's lung cancer cases, warned experts at a symposium on the occasion of World Cancer Day on Friday. While cancer patients with squamous cell carcinoma — which is usually linked with smoking — were more common till recently.

Experts said they are now coming across more and more patients with adenocarcinoma, which is evidently linked with declining air quality. "We are seeing an alarming rise in lung cancer patients, and majority of them do not have any history of smoking," said Woodlands Hospital pulmonologist Arup Halder.

Health experts from the city urged for a collective effort to clean up the ambient air to save lives. Suman Mallik, chief of radiation oncology and MV Chandrakantha, a consultant medical oncologist of Narayana Superspeciality Hospital said air pollution was behind more than 50% of lung cancer cases. "I have not found any history of smoking in more than half my patients," they added.

Chandrakantha called for a collective effort from all sectors to clean up the air to reduce the burden of diseases. "Air pollution is considered to be the single largest threat to human health globally. By polluting the air, we are exposing the children to a greater risk," said senior paediatric and neonatal medicine expert Abhijit Sarkar.

"The rise of child patients with sinusitis, pneumonia, and childhood asthma is very very sharp." Sarkar said that exposure of young adults to an increase of every 10 microgram finer particulate matter (PM2.5) per cubic meter of air increases the risk of cancer by 22%, upper digestive tract cancer by 42% and lower GI tract cancer by 35%.

"In the absence of data on the prevalence of cancer affliction, we can only assume what we are seeing and discussing is only a tip of an iceberg and solutions are not as obvious as we think. But the cleaning up of ambient air should be the top priority as it is playing havoc with our lives, be it respiratory diseases, cardiac ailments or various types of cancer," said Bishan Basu, head of radiotherapy, Calcutta National Medical College.

The SwitchOn Foundation, which organised the symposium, also launched Clean Air Medical Students Ambassador programme. Medical students chosen for the programme will get a stipend and undergo training on air pollution and its impact.

LET KOLKATA BREATHE

ALARMING SIGNS

Cancer cases in Bengal
1,08,394 new cases in 2020
1,21,639 projected cases in 2025
13,000 new cases every year

Leading cancer cases
- Lung (20% of men and 6.6% of women among new cancer patients)
- Prostate
- Mouth and tongue
- Larynx

Greater proportion of lung cancer cases
- 2020 - 20%
- 2016 - 16%
- 2006 - 14.9%

* Source: National Centre for Disease Informatics and Research Institute, ICMR, Bengaluru

'Pollution cuts life expectancy by 9 yrs in N India, 7 yrs in Kol'

2.5-2.9 Yrs Of Life Lost In MP & Maha: Study

'Late' cry against police, PCB

OUR BUREAU

Calcutta: Calcuttans were often prompt in reporting noise violations in their neighbourhoods but the response from police or the pollution control board was often slow.

The allegations have emerged from across the city over the past three days. Loudspeakers blared till late into the night and crackers went off in frequent intervals.

"Dekhchhi (we are looking into it)," was the standard response of many police stations. Some sent teams to seize banned firecrackers too late, while a few did nothing.

A resident of Alipore said it took her multiple calls to Lalbazar and Alipore police station on Monday to get cops moving against a roadside programme that had a woman dancing to loud music and men throwing money at her around midnight.

Residents of Shyampukur said they had reported continuous bursting of banned firecrackers in their locality and wondered why the police were deaf to the deafening noise that had kept the entire neighbourhood awake.

When cops finally reached the locality, no banned crackers could be found.

A resident of Kasba had complained to the state pollution control board (PCB) about blaring microphones but no help arrived.

Police commissioner Anuj Sharma had on Sunday asked in the official WhatsApp group of Calcutta police why crackers were still bursting after 10pm. He also said he had received complaints, which he would take up with the officers in charge of the respective police stations.

The top cop's posts in the WhatsApp group suggest that at least some police stations had not done enough to carry out Sharma's order to enforce rules.

The Supreme Court had last year ordered that permissible firecrackers could be burst only between 8pm and 10pm. In Bengal, permissible crackers are those that produce 90 decibels of noise at five metres from the source.

Outdoor events where disc jockeys perform and music is played at a high volume are also banned.

Calcutta police arrested 400 people on Monday for bursting banned crackers and around another 375 for gambling and disorderly conduct.

Despite the arrests, residents of places across the city complained that noise rules were hardly followed.

"We have not been able to sleep for three nights. Almost everyone in the building has complained to the police but there has been no action," said a resident of a high-rise building on Burdwan Road, in the heart of Alipore.

She said a woman was dancing on a stage in an open-air programme close to midnight and people were throwing money at her.

"It was obscene and unsafe for a woman to dance in the middle of a road with people

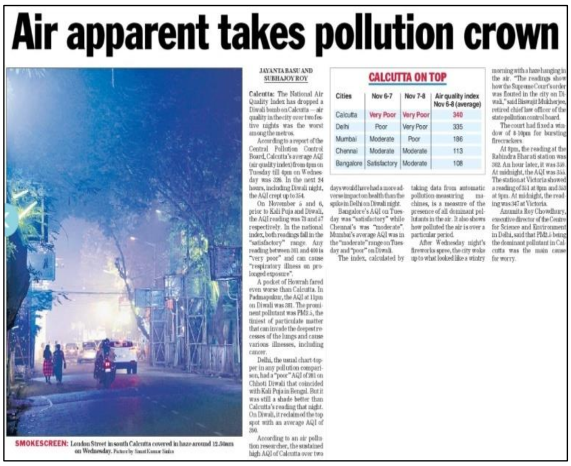
Post-Diwali city air 'severe'

CALCUTTA: Many parts of Calcutta reported a noisy Diwali night and the air quality index was "severe" across the city for most of Monday morning. Over 1,100 people were arrested for possessing or bursting banned crackers, gambling or disorderly conduct.

METRO

CALCUTTA TUESDAY 29 OCTOBER 2019

Plate 1.10.2.1: Newspaper clippings(continued)



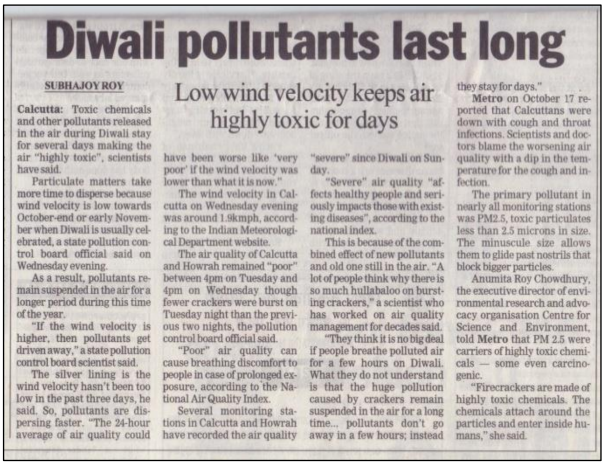
Air apparent takes pollution crown

JAYANTA BASU AND SUBHAJOY ROY

CALCUTTA ON TOP

Cities	Nov 6-7	Nov 7-8	Air quality index Nov 6-8 (average)
Calcutta	Very Poor	Very Poor	340
Delhi	Poor	Very Poor	335
Mumbai	Moderate	Poor	186
Chennai	Moderate	Moderate	113
Bangalore	Satisfactory	Moderate	108

SMOKESCREEN: London Street in south Calcutta covered in haze around 12.50am on Wednesday.



Diwali pollutants last long

SUBHAJOY ROY

Low wind velocity keeps air highly toxic for days

Calcutta: Toxic chemicals and other pollutants released in the air during Diwali stay for several days making the air "highly toxic", scientists have said.

Particulate matters take more time to disperse because wind velocity is low towards October-end or early November when Diwali is usually celebrated, a state pollution control board official said on Wednesday evening.

As a result, pollutants remain suspended in the air for a longer period during this time of the year.

"If the wind velocity is higher, then pollutants get driven away," a state pollution control board scientist said.

The silver lining is the wind velocity hasn't been too low in the past three days, he said. So, pollutants are dispersing faster. "The 24-hour average of air quality could have been worse like 'very poor' if the wind velocity was lower than what it is now."

The wind velocity in Calcutta on Wednesday evening was around 1.9kmph, according to the Indian Meteorological Department website.

The air quality of Calcutta and Howrah remained "poor" between 4pm on Tuesday and 4pm on Wednesday though fewer crackers were burst on Tuesday night than the previous two nights, the pollution control board official said.

"Poor" air quality can cause breathing discomfort to people in case of prolonged exposure, according to the National Air Quality Index.

Several monitoring stations in Calcutta and Howrah have recorded the air quality "severe" since Diwali on Sunday.

"Severe" air quality "affects healthy people and seriously impacts those with existing diseases", according to the national index.

This is because of the combined effect of new pollutants and old one still in the air. "A lot of people think why there is so much hullabaloo on bursting crackers," a scientist who has worked on air quality management for decades said.

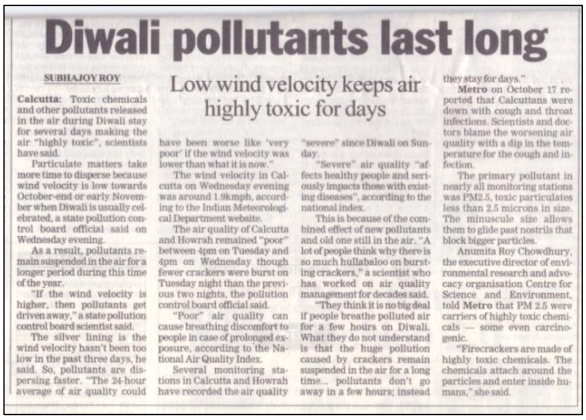
"They think it is no big deal if people breathe polluted air for a few hours on Diwali. What they do not understand is that the huge pollution caused by crackers remain suspended in the air for a long time... pollutants don't go away in a few hours; instead they stay for days."

Metro on October 17 reported that Calcuttans were down with cough and throat infections. Scientists and doctors blame the worsening air quality with a dip in the temperature for the cough and infection.

The primary pollutant in nearly all monitoring stations was PM2.5, toxic particulates less than 2.5 microns in size. The minuscule size allows them to glide past nostrils that block bigger particles.

Anumita Roy Chowdhury, the executive director of environmental research and advocacy organisation Centre for Science and Environment, told Metro that PM 2.5 were carriers of highly toxic chemicals — some even carcinogenic.

"Firecrackers are made of highly toxic chemicals. The chemicals attach around the particles and enter inside humans," she said.



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This is because of the combined effect of new pollutants and old one still in the air. "A lot of people think why there is so much hullabaloo on bursting crackers," a scientist who has worked on air quality management for decades said.

"They think it is no big deal if people breathe polluted air for a few hours on Diwali. What they do not understand is that the huge pollution caused by crackers remain suspended in the air for a long time... pollutants don't go away in a few hours; instead they stay for days."

Metro on October 17 reported that Calcuttans were down with cough and throat infections. Scientists and doctors blame the worsening air quality with a dip in the temperature for the cough and infection.

The primary pollutant in nearly all monitoring stations was PM2.5, toxic particulates less than 2.5 microns in size. The minuscule size allows them to glide past nostrils that block bigger particles.

Anumita Roy Chowdhury, the executive director of environmental research and advocacy organisation Centre for Science and Environment, told Metro that PM 2.5 were carriers of highly toxic chemicals — some even carcinogenic.

"Firecrackers are made of highly toxic chemicals. The chemicals attach around the particles and enter inside humans," she said.

THE TELEGRAPH CALCUTTA THURSDAY 8 NOVEMBER 2018

Sky casts Diwali dampener

OUR SPECIAL CORRESPONDENT

An overcast sky over the city on Wednesday morning.

Plate 1.10.2.1: Newspaper clippings(continued)

Night after, as noisy

RULE BREAK

Poor air quality behind more than half of lung cancer cases in Kolkata, say experts

THE TELEGRAPH CALCUTTA THURSDAY 8 NOVEMBER 2018

Sky casts Diwali dampener

OUR SPECIAL CORRESPONDENT

Alipore: A trough of low pressure over south Bengal led to an overcast sky on Diwali and a few spells of rain in the morning.

Met department officials said the rain might dry up on Thursday but the sky could remain partly cloudy over the next one or two days.

With the sun blocked out, the Alipore Met department recorded a temperature of 25.6 degrees Celsius at 2.30pm on Wednesday, almost eight degrees lower than what had been recorded around the same time 24 hours before.

"The temperature is expected to climb up to 30 degrees on Thursday as the cloud cover will thin," an official in the department said.

The nip in the air that was being felt in the morning in the last week of October would take a while to come back but a dip in the minimum temperature, which read 24.5 degrees on Wednesday, three degrees above normal, is likely over the weekend.

Drizzles started a little after 8.30am and continued in phases till noon. The Calcutta Municipal Corporation's drainage pumping station in Mominpur recorded 9.4mm of rain, the highest. The ones in Patuli, Joka, Ultadanga and Behala Flying Club recorded 8.6mm, 8.4mm, 0.3mm and 5.6mm, respectively.

"Moisture was flowing into the city's skies under the impact of a north-south trough of low pressure that stretched from east Bihar to Gangetic Bengal. The trough has started weakening, which is why there was no rainfall post-noon," said Sanjib Bandyopadhyay, deputy director general, India Meteorological Department, Calcutta. "The sky will remain partly cloudy on Thursday but rain is not expected."

Weather watchers expect a change in the wind flow after Friday, when a low-pressure area is likely to form over the Bay of Bengal, triggering a fall in the mercury.

"The minimum temperature is expected to drop to 20 or 21 degrees over the weekend. The dip could have come about earlier but did not happen because a well-marked, low-pressure area that was supposed to stay over the Bay of Bengal had entered Tamil Nadu. So, it did not pull the north-westerly wind that ferry cold to Calcutta and its surroundings as expected," a Met official said.

"We expect a cyclonic circulation that is hovering near Thailand to develop into a low-pressure area and move close to the Andamans by Friday. That should draw the cold north-westerly wind from Kashmir towards Bengal and its neighbouring states," the official said.

How much the minimum temperature dips will depend on the path the low-pressure area, which may intensify further, takes.

An overcast sky over the city on Wednesday morning. Picture by Pradip Sanyal

Plate 1.10.2.1: Newspaper clippings

1.11 Summary

- Air quality in mega cities and other developed urban centres is a serious problem due to their high pollutant concentrations and health related issues.
- Aerosol concentrations have grown along with Air Pollution over the Indian subcontinent; they serve as a barrier and lessen the temperature difference between the sea surface and land (*IPCC Report & IIT Mumbai, 2020*).
- In India, extensive burning of firecrackers during Diwali festival is considered as a short term anthropogenic pollution causing serious health issues (Kulshestha *et al.*, 2004, Mandal *et al.*, 2011).

- Under the worst case scenario for greenhouse gas emissions, Kolkata's annual mean temperature might climb by 4.5 degrees Celsius by 2100 compared to the pre-industrial era (1850–1900). Teheran and Moscow also experienced warming over this time span of 2.6°C and 2.3°C, respectively *(IPCC Report August 8, 2021).*
- Past studies show that due to change in LULC and increase more built up caused air deterioration and Urban Heat Island effects.
- Literature reviewed after doing scientific observation as stated previously.

1.12 Statement of Problem

In the past century, urbanization has caused a rise in the daily mean Air Temperature at ground level of between 0.1 and 0.4 degrees Celsius. Urban Heat Islands are created as a result of this. When a significant portion of a region's natural land cover artificial surfaces that collect solar energy during the day and then reradiate it at night are used as a replacement, heat islands are created (Quattrochi *et al*., 2000; Oke 1982). An "Urban Heat Island" is nothing more than an increase in surface temperature in some areas of a city, brought on by a microclimate that is always changing and is in turn influenced by human activities like industrialization and vehicle emissions, which worsen the quality of the city's air. For the management of Air Quality and public health in urbanized areas like Kolkata metropolitan, the Urban Heat Island effect is essential. As a result of the rising Air Temperatures, more electricity is needed to counteract the heat island effect, which raises emissions of greenhouse gases and Air Pollutants. The primary pollutants are Sulphur dioxide (SO_2), Nitrogen oxides (NOx), particulate matter (PM), Carbon Monoxide (CO), and mercury (Hg). In addition to being dangerous to human health, these pollutants have a role in complicated concerns with the quality of the air, such as the creation of smog at ground level, fine particulates, and acid rain. Urban heat islands can impact general discomfort, respiratory problems, heat exhaustion and cramps, non-fatal heat stroke, and heat-related deaths having a negative impact on human health. They may harm as well nighttime cooling and increase air pollution levels.

1.13 Conclusion

Structure of the Study Report

This thesis consists of eight chapters starting from background of study to avenues for future research. The thesis begins with an overview and introduction of the landscape conditions to establish the rationale of the present work at the very inception in the study is categorized into several chapters. The **Chapter I** is devoted to the back drop of the study with introducing the study area along with its problem.

Chapter II starts with literature study on investigating theUrban Heat Island effects with respect to the changes of urban Land Use Land Cover and Air Quality. This chapter also discusses various case studies where the Urban Heat Island has been studied with reference to Air Quality and Land Use Land Cover Changes. From these studies the Heat Island aspects and its research techniques are finalised to be used for analysing the land use types and classification, built forms, air quality pattern in Kolkata. This chapter is the foundation for the next chapter where the heat island form is categorized as generic types based on various biophysical indices changes of urban area.

Chapter III addresses the ideas of scope for the current study, the research problem and gap, the hypothesis and research question, and the objectives and methodology of work.

Chapter IV elaborates the output of the Satellite Imageries, Field Survey Data and Air Quality Monitoring Instruments.

Chapter V examines the scenario of Urban Heat Island effect with respect to LST and Land Use Land Cover change**.** In this chapter investigation of the connection between the biophysical indicators and LST done, this study found the alteration of values obtained from three years data throughout the study periods which is obvious that the growth of urban built-up area in KMC has been greatly influencing the rise in LST.It is also found that there is some low vegetation cover- and built-up area which infers Urban Heat Island zone.

Chapter VI presents the case study areas at the core areaof the city.The meteorological data such as the air temperature, surface temperature and pollution data were measured and analysed for understanding the concentration of Particulate Matter and Air Temperature which are significantly related to the various land use land cover types (like built up, water bodies, open spaces and vegetation cover) in different season.The final part of the chapter discusses the differences in the day and night time temperature and PM_{10}/$PM_{2.5}$ among the different land use categories during the Diwali period through different statistical analysis.

Chapter VII deals withthe aspect of Urban Heat Island effect depending on Air Quality in the special occasion of Diwali, LST and LULC change. In this chapter exploration of thepositive correlation among Air Temperature, Land Use pattern and Air Quality (PM_{10} and $PM_{2.5}$) and also the Correlation and Linear Regression studies were performed between PM_{10} / $PM_{2.5}$ and temperature, during Diwali day and night done. High correlation coefficient was obtained between PM_{10} / $PM_{2.5}$ and temperature.

Lastly **Chapter VIII** has incorporated the concluding observation along with the coverage of chapter summary. Conclusion and future suggestions are included in this chapter with some important suggestions for Quantification of environmental impact of reduced heat gain. Mitigation of Urban Heat Island, Air Quality management, urban bio-diversity,ecological planning of Kolkata urban metropolitan area were also suggested.Given the limitations of the current investigation, several markers could not be assessed. Each signal that could not be measured signifies a knowledge and opportunity gap. This is an important aspect which can suggest to urban planners how to increase the vegetative cover and how to moderate the temperatures by increasing vegetative cover, at the same time reduce Air Pollution.

Appendix A presents the analytical formulation of important parameters to make use of in the present work, List of different tables and necessary data are enumerate in **Appendix B**, while the publications are listed in **Appendix C.**

Chapter 2: Literature Review

2.1 Introduction

Before one starts exploration on particular concept its emergence and development should be considered. If there is knowledge of any papers or journals, it would be easier to compare the opinions and ideas presented in the researcher's findings in the context of earlier work. The last ten years have seen a real increase in UHI research in India. In the last five years, research has focused more and more on mitigating the complex urban microclimate. Various literatures related to Land Use Land Cover (LULC) change and Air Temperature, Land Surface Temperature, Urban Heat Island (UHI) pattern and also the changing issues have been assessed for building clear intention and concepts of them. In this chapter existing literatures related to major issues of the study have been classified into five types, namely-

- Literatures on Air Quality, Air Pollution Pattern and its monitoring Instrument Related.

RELEVANT LITERATURE REVIEW

URBANIZATIN, POPULATION, METEOROLOGICAL STATUS
Pathan (1991), Poreh (1995).Nichol, J. E. (1996),(Hafnerand Kidder, (1999), Jensen and Cowen (1999), Wilson, J. S, Clay, M, Martin, E.(2003),Herold *et al*., (2004),Bagan, H., Yamagata, Y. (2012), Jafrin, M., Beza, B.B.(2018),Mr. Ershad Ali (March 2020).

LAND USE LAND COVER (LULC)
Definition, Classification & types of LULC, Anderson J., R E E Hardy *et al*., (1976),Akbari, H. (2005), Ashror M Dewan *et al*., (2008),Wu *et al*.,(2008); B. Bhatta (2009), Rinner, C. and Hussain, M. (2011), Mohan, M.(2011), Reveshty, (2011),Pradnya Nesarikar – Patki (2012) Biswajit Nath (2013), Buyadi, S. N. A. (2013), B. Feizizadeh and T. Blaschke (2013), Zeng *et al*., (2014), Liu *et. al*., (2014), Güneralp *et al*., (2015), Sun a,n, J (2016),Mukhopadhaya, S.(2016), Mukherjee (2018), Yu, Z., Yao, Y., Yang, G (2019). Shah Fahad (2021)

URBAN HEAT ISLAND (UHI), AIR TEMPERATURE, LAND SURFACE TEMPERATURE
Bah l, H. D. and B. Padmanabhamurty (1979), Oke T R (1981), Oke T R (1982), Ojo (1982), Zhao, Z. C., Luo (1990), Wei-Chyung Wang1(1990),Solecki W., Rosenzweig, R, (2004), Brian Stone Jr. (2005), Rahman, A. (2007), Lilly Rose A. (2008), Jun-Pill Kim, (2009), P. Shahmohamadi (2010), Uwadiegwu I, (2011),Menglin S. Jin (2011), Kibassa Deusdedit (2012), Y. Roth (2013), Vennapu Lakshmana Rao (2014), Jun Pill (2014),M M T D Kasthuri(2016),L. Sun a, n, J. Wei *et al*. (2016),Ansar Khan (2016),Pradnya Nesarikar – Patki (2016), Santanu Bajani, Debashish Das (2020), Janata Mondal, Priyank Patel(2022).

AIR QUALITY, AIR POLLUTION PATTERN
Coakley, J. (1983), Coakley, J. A. (1985), Pope C. (2002), Kulshrestha U. (2004), Singh, A. & Adak, (2006), WHO (2006) Air quality guidelines, Vijay Bhaskar (2008), Pope C. A. (2009), The Gazette of India (2009), Stephen D. Superczynski (2011),GPCB (2013), A. Chatterjee(2013), Annual Report 2012-13, Rosario Lanzafamea (2013), Chirag Verma1 and Dhananjay K (2014), Abhinav Pandey(2016), Velasco, A(2016), Goel, A. (2017), Nisha Vaghmaria (2018).

INSTRUMENT RELATED
Vijay Bhaskar, B.(2008), Maricq, M. M. (2013), Wang, Y (2015), Marć , M. (2015), Velasco, A.(2016), Deville Cavellin (2016), Esposito, E (2016), Cross, E. S. (2017), Alice Cavaliere (2018), Konstantinos N. Genikomsak (2018),Nikolaos-Fivos Galatoulas (2018),Hai-Ying Liu (2019), Konstantinos N. (2019), Hai-Ying Liu (2019), Sohini Sen, Debashish Das (2019), Sohini Sen, Debashish Das (2021).

Figure 2.1.1: Details of category of major relevant journals reviewed

- Scenario of National and International literature review aspect.
- Bibliometric Analysis.
- Literatures on Urbanization, information about KMC and its meteorological status, Land Use Land Cover (LULC)definition, classification & types or changing pattern of LULC in tropical region including Kolkata Municipal Corporation area.

- Literatures on Urban Heat Island (UHI), Air Temperature, Land Surface Temperature changing issues and a variety of metrics, including the Normalized Difference Vegetation

Index (NDVI), the Normalized Difference Water Index (NDWI), and the Normalized Difference Building Index (NDBI).

2.2 National Scenario

- **Monsingh D. Devadas and Lilly Rose A. (2008),** *"Assessing the Urban Heat Island Effect's Intensity in Chennai, a Hot and Humid City"*, Studying the various land uses in Chennai and analyzing them to comprehend the effects of urban built-up and other urban parameters on the intensity of UHI are vital to defining the relationship between urban factors and UHI intensity. They employed the technique of employing HOBO Data loggers to capture data on air temperature once every three minutes. In the city, stationary measurements were made at 30 different points.

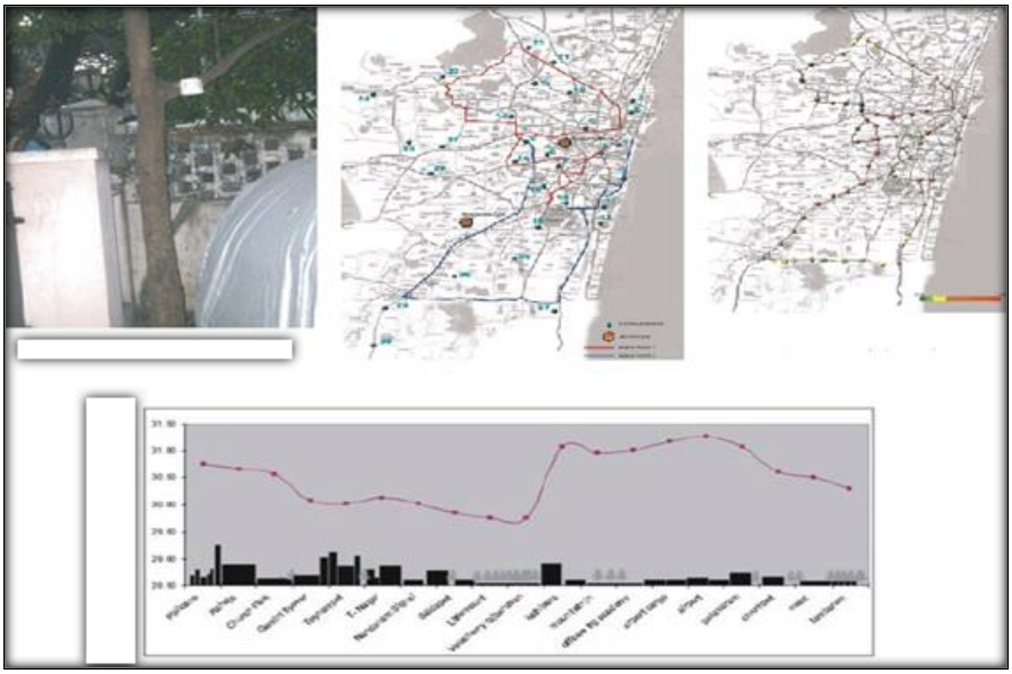


Plate 2.2.1: Sketch of Urban Heat Island profile in Chennai city

Plate 2.2.2: Typical instrument set up for measurements (HBO) (Lilly Rose A., Monsingh D, 2012)

- **Pradnya Nesarikar – Patki and Pratima Raykar – Alange (2012),** *"Study of Influence of Land Cover on Urban Heat Islands in Pune using Remote Sensing"*, In order to comprehend the function and impact of different land covers to create a better microclimate in urban areas, it was determined in this article if change in land cover in Pune leads to change in Land Surface Temperature or not. To anticipate temperature fluctuation associated with various forms of land cover, this experiment used the remote sensing application IDRISI - Andes.

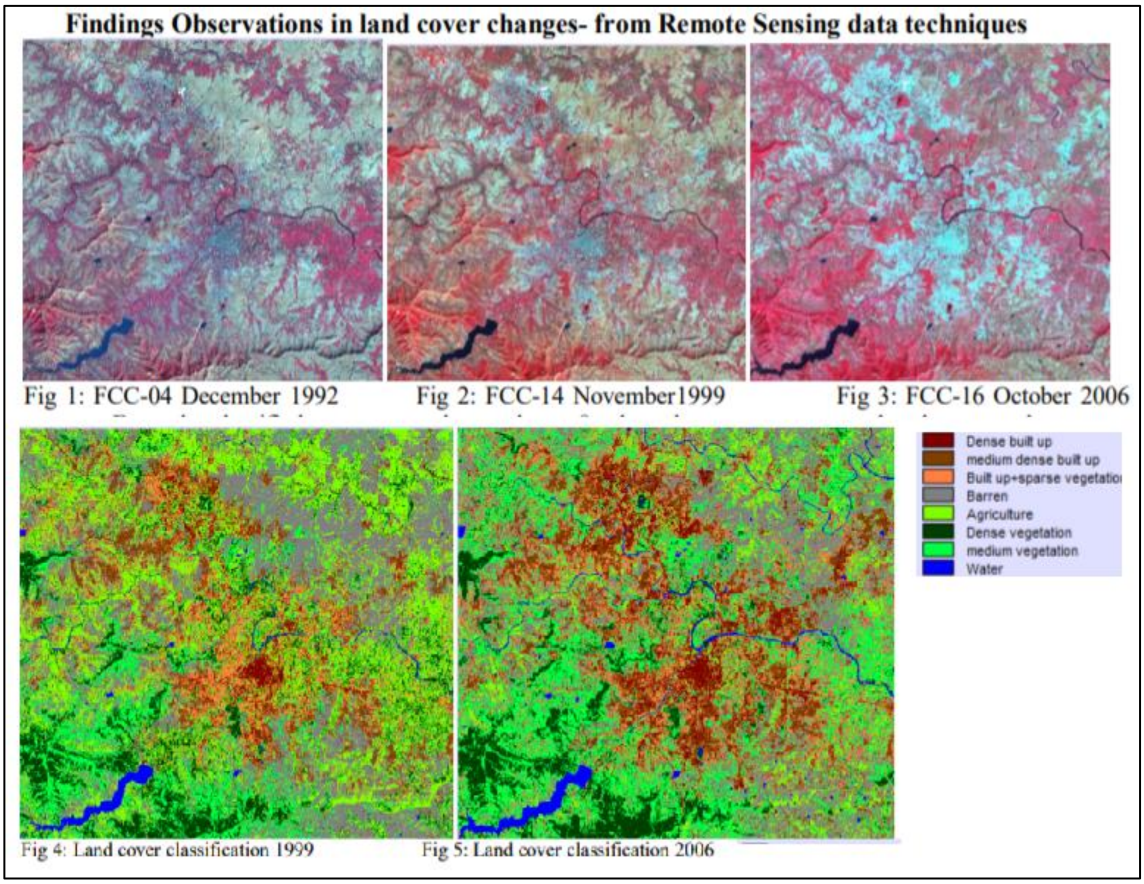


Figure 2.2.4: LULC classification in Pune 1999, 2006.

Source:Study of Influence of Land Cover on Urban Heat Islands in Pune using Remote Sensing (PradnyaNesarikar-Patki 2016)

- **Biswajit Nath and Shukla Acharjee (2013),** *"Urban Municipal Growth and Land use Change Monitoring using High Resolution Satellite Imageries and Secondary Data - A Geospatial Study on the Indian city of Kolkata Municipal Corporation"*,The study observed the growth scenario of Kolkata Urban Municipal Area (before 1793- 2008) and the Land uses status of Kolkata Municipal Corporation (from 1990-2008) using the Land use mapping of KMC and carried out using NASA-GLCF provided free Landsat TM (Geo TIFF) imageries from 1990-2004.

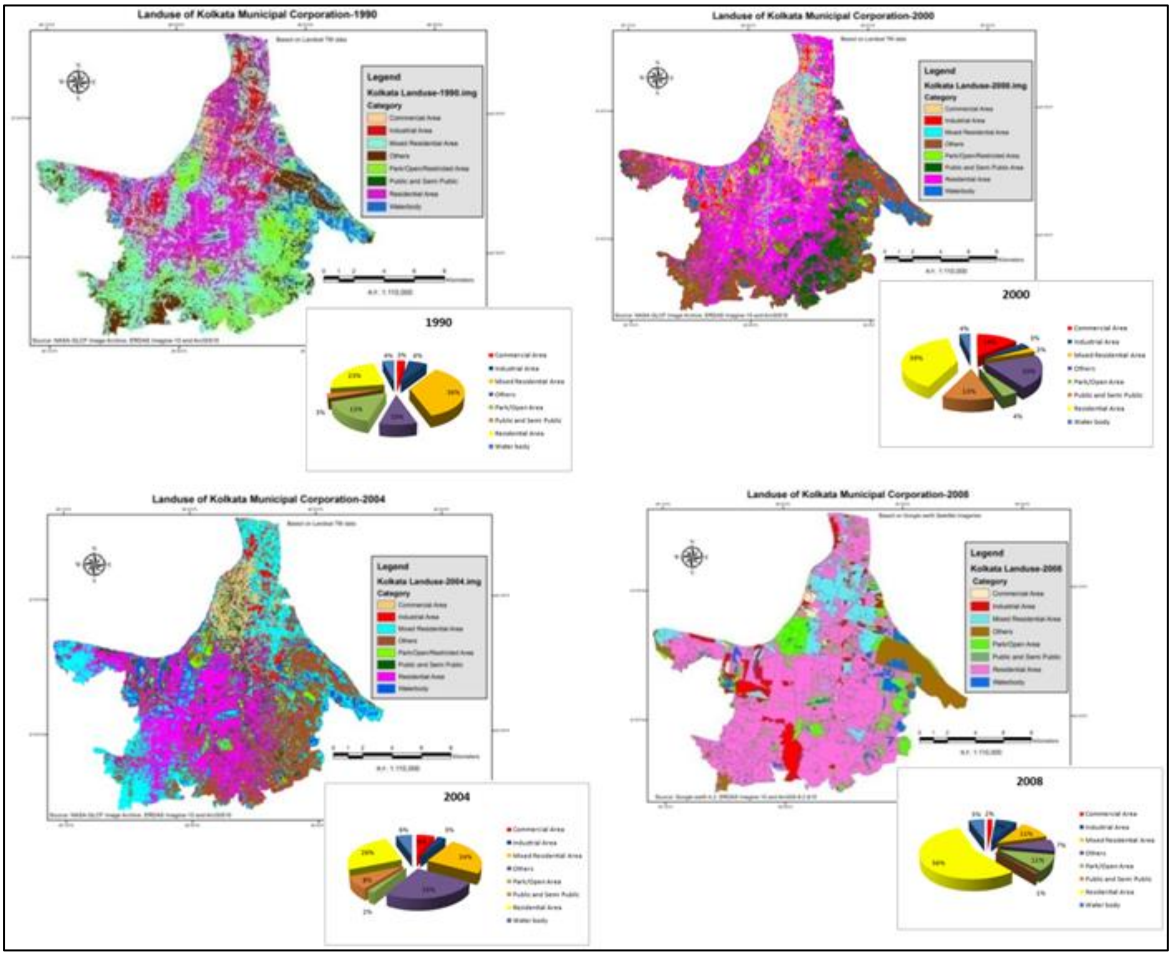


Figure 2.2.1: A Geospatial Study on Kolkata Municipal Corporation, India

Source: Urban Municipal Growth and Land Use Change Monitoring using High Resolution Satellite Imageries and Secondary Data (Biswajit Nath, Shukla Acharjee, Sept, 2013).

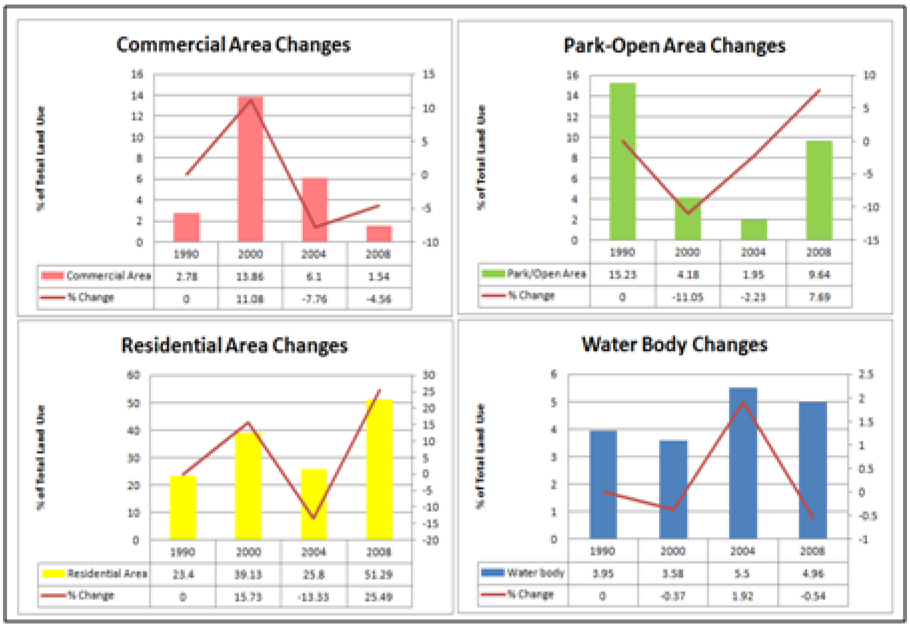


Figure 2.2.2: Area wise changes in LULC types

Source: Biswajit Nath, Shukla Acharjee, Sept, 2013

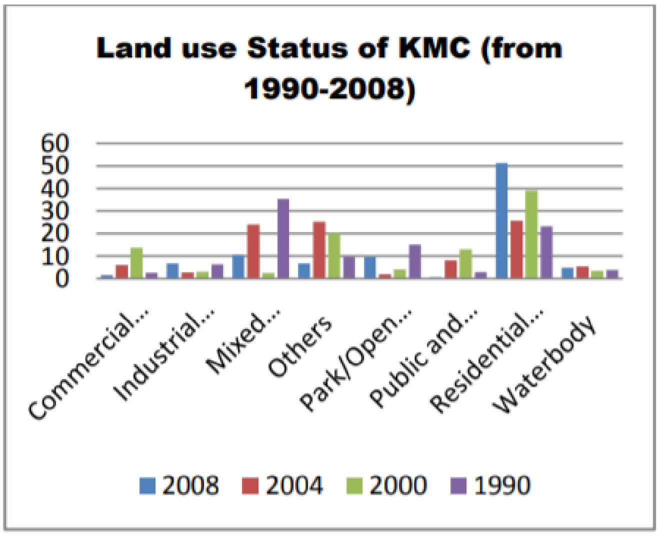


FIG. LANDUSE STATUS OF OF KMC (FROM 1990-2008)

Figure 2.2.3: Land Use status of KMC (1990 – 2008)

Source: Biswajit Nath, Shukla Acharjee, Sept, 2013

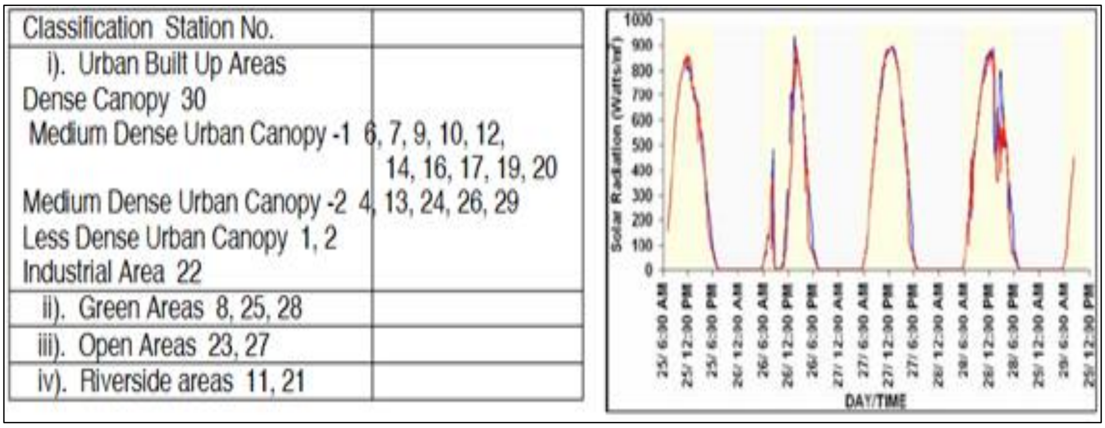
Table 2.2.1: Year wise land use of KMC

Year wise Landuse of Kolkata Municipal Corporation (Category wise Area shows in Hectares and its share of percentage)									
SL.No	Land use Category	Area (Hecatres)	%	Area (Hecatres)	%	Area (Hecatres)	%	Area (Hecatres)	%
		2008		2004		2000		1990	
1	Commercial Area	298.93	1.54	1180.53	6.10	2670.89	13.86	537.38	2.78
2	Industrial Area	1314.83	6.77	558.90	2.90	624.30	3.24	1244.04	6.43
3	Mixed Residential Area	2035.98	10.49	4672.80	24.16	518.50	2.69	6851.41	35.43
4	Others	1319.95	6.80	4914.18	25.40	3892.49	20.21	1887.18	9.76
5	Park/Open Area	1871.53	9.64	377.01	1.95	805.37	4.18	2945.22	15.23
6	Public and Semi Public	98.36	0.51	1583.73	8.19	2525.60	13.11	583.20	3.02
7	Residential Area	11509.46	51.29	4991.76	25.80	7537.86	39.13	4524.07	23.40
8	Water body	962.03	4.96	1064.97	5.50	689.22	3.58	764.73	3.95
	TOTAL	19411.08	100	19343.88	100	19264.22	100	19337.24	100
Note: Area computed by Author						Source: Landsat TM Imagery and ERDAS Imagine-10v			

Temporal Landuse Change Detection of Kolkata Municipal Corporation (Showing Category wise share of Percentage Change)									
SL.No	Land use Category	% of Landuse (A)	% of Landuse (B)	% of Landuse Change (B-A)	% of Landuse (C)	% of Landuse Change (C-B)	% of Landuse (D)	% of Landuse Change (D-C)	% of Overall Landuse Change (D-A)
		2008	2004	2004-2008	2000	2000-2004	1990	1990-2000	(1990-2008)
1	Commercial Area	1.54	6.10	(-) 4.56	13.86	(-) 7.76	2.78	(+) 11.08	(-) 1.24
2	Industrial Area	6.77	2.90	(+) 3.87	3.24	(-) 0.34	6.43	(-) 3.19	(+) 0.34
3	Mixed Residential Area	10.49	24.16	(-) 13.67	2.69	(+) 21.47	35.43	(-) 32.74	(-) 24.94
4	Others	6.80	25.40	(-) 18.60	20.21	(+) 5.19	9.76	(+) 10.45	(-) 2.96
5	Park/Open Area	9.64	1.95	(+) 7.69	4.18	(-) 2.23	15.23	(-) 11.05	(-) 5.59
6	Public and Semi Public	0.51	8.19	(-) 7.68	13.11	(-) 4.92	3.02	(+) 10.09	(-) 2.51
7	Residential Area	51.29	25.80	(+) 25.49	39.13	(-) 13.33	23.40	(+) 15.73	(+) 27.89
8	Water body	4.96	5.50	(-) 0.54	3.58	(+) 1.92	3.95	(-) 0.37	(+) 1.01
	TOTAL	100	100		100		100		
Where plus (+) sign indicate Positive Change and Minus (-) sign denotes Negative Land use change									

Source: Urban Municipal Growth and Land Use Change Monitoring using High Resolution Satellite Imageries and Secondary Data. A Geospatial Study on Kolkata Municipal Corporation, India (Biswajit Nath, Shukla Acharjee, Sept, 2013)

- **M. Mohan *et al.* (2009)**, "*The impact of urbanization during half a century on surface meteorology based on WRF model simulations over National Capital Region, India*", carried out a summertime field operation in 2008 May called DELHI - I (Heat Island Intensity Experiments in Delhi - I) to comprehend the most recent dynamics and intensity of Delhi's heat island phenomenon. It was discovered that the heat island's intensity ranged from 4.1°C to 5.2°C. Urban heat island impacts were found to be particularly pronounced in regions with densely populated areas and high levels of human activity.



Classification Station No.	
i). Urban Built Up Areas Dense Canopy 30 Medium Dense Urban Canopy -1	6, 7, 9, 10, 12, 14, 16, 17, 19, 20
Medium Dense Urban Canopy -2	4, 13, 24, 26, 29
Less Dense Urban Canopy 1, 2 Industrial Area 22	
ii). Green Areas 8, 25, 28	
iii). Open Areas 23, 27	
iv). Riverside areas 11, 21	

Figure 2.2.5: Assessment of Urban Heat Island Intensities over Delhi, 2009

Source: Manju Kikegawa Yukihiro, Ogawa Koichi, Kandya Anurag

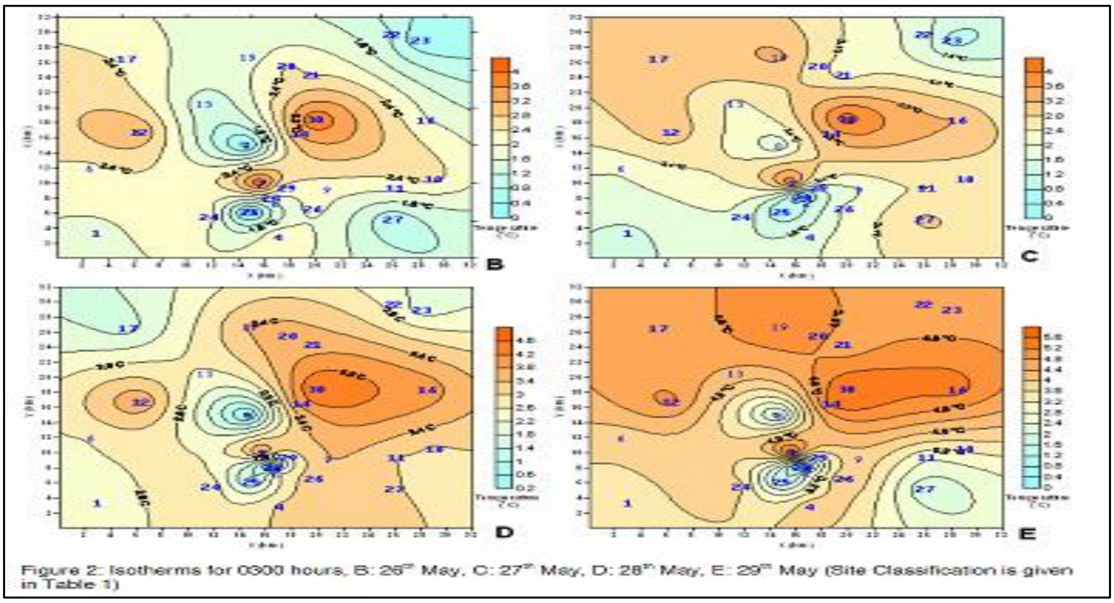


Figure 2.2.6: The UHI intensity in Delhi

Source: Assessment of Urban Heat Island Intensities over Delhi, 2009 (Manju Kikegawa Yukihiro, Ogawa Koichi, Kandya Anurag)

- **Vennapu Lakshmana Rao (2014)**, *"Effects of Urban Heat Island on Air pollution concentrations"*. This paper explored the heat island magnitudes, which essentially depend on the surface wind speeds, through the process of The daily pressure and temperature of the morning ascent taken at 05:30 IST at the surface level ant the same parameters at 950hpa level are considered for a period of five years (2009 - 2013).
- **Deborah Balk and Mark R. Montgomery (2018)**, *"Urbanization in India: Population*

*and Urban Classification Grids for 2011".*The idea of gridded population estimates two spatial representations of metropolitan regions at a resolution of 1 km, based on official population and settlement types tabulations - were established by researchers (i.e., statutory towns, outgrowths, and census towns). One is based on census data, the other on remotely sensed measurements of built-up terrain produced from the Global Human Settlement Layer.

- **Ramesh Kesavan *et al.*, 2021**, **"***ARIMA modeling for forecasting Land Surface Temperature and determination of urban heat island using remote sensing techniques for Chennai city, India"*, This analysis of the images and model outputs demonstrates that LST in built-up areas is growing with time. For Chennai city and the surrounding area, The model study's LST values revealed a negative correlation between Land Use and Land Cover (LULC).The LST maps created from the model analysis showed expanding UHI hotspots in the city's southeast and west, where development is occurring quickly. The current study will aid in predicting a city's LST and locating UHI hotspots for effective urban design.
- **Shah Fahad, 2021**,*"Urban Heat Island Dynamics in Response to Land-Use/Land-Cover Change in the Coastal City of Mumbai"*, This work was carried out to estimate and quantify the UHI dynamics the city of Mumbai in response to the LULC fluctuation over 1991-2018 using temporal Landsat datasets. In the Mumbai city between 1991 and 2018, the built-up areas nearly doubled, from 173.09 to 346.02 km2, while the vegetation cover significantly decreased from 215.8 to 129.27 km2. As a result, both urban heat island (UHI) and non-UHI zones have seen a large increase in the LST.
- **Janata Mondal, Priyank Patel *et al.*, 2022**,"*Examining the expansion of Urban Heat Island effect in the Kolkata Metropolitan Area and its vicinity using multi-temporal MODIS satellite data"*. This study looked at high-rise structures and population density, which increased quickly over the study period along with a loss in greenery. The Normalized Difference Vegetation Index (NDVI) readings are lower within the KMA, while they are higher in the nearby rural regions but more enhanced in the surrounding rural areas using multi-temporal MODIS satellite data.

2.3 International Scenario

- **Oke (1982) and Quattrochi *et al.*, 2000**, have defined urban heat island in their work "*The energetic basis of urban heat island*" and "*A decision support information system for urban landscape management using thermal infrared data"* as heat islands that arise when manmade surfaces that capture solar radiation during the day and reradiate it at night replace a significant portion of a region's natural land cover. The term "heat island effect" is also used to describe this rise in air temperature in metropolitan areas relative to suburban and rural areas.

- **Willium D. Solecki, *et al.*, 2004**, in their paper "*Urban Heat Island and climate change - An Assessment of Interacting and Possible Adaptations in the Camden, New Jersey Region"*, in the cited paper. In urbanized areas, the Urban Heat Effect is a crucial element in managing air quality and promoting public health.
- **Brian Stone Jr. *et al.*, 2005**,in his *paper 'Urban Heat and Air Pollution'*presents empirical evidence that links recent regional temperature fluctuations to increased ozone formation within the 50 largest metropoliton regions of the country. He also analyses regional climate and ozone formation during the 1990s and finds that regional temperatures were more strongly linked to annual violations of the national ozone standard than were emissions of regulated ozone precursors from mobile and stationary sources.
- **Qihao Weng and Shihong Yang, 2006**, in their paper *"Urban air pollution pattern,land use,and thermal landscape: An examination of the linkage using GIS"*to look into local air pollution trends in Guangzhou from 1980 to 2000, and to look into how these patterns relate to changes in land use, land cover, and urban thermal landscape. The geographical patterns of air pollutants investigated were favorably connected with urban builtup density and values of Land Surface Temperature determined from satellites, especially with measurements made during the summer.
- **Menglin S. Jin, 2011**, in his paper *"Satellite observed Urbanization characters in Shanghai, China: Aerosols, Urban Heat Island Effect and land atmosphere Interactions introduced urban heat island effect (UHI)"*is the key component of the urban system's land surface. UHI denotes a difference in surface temperature between urban and rural areas.
- **Uwadiegwu I,Egbu, A. U andKalu, A. O., 2011**, in his paper "*A study of Urban Heat Island areas in Lagos Metropolis using satellite imagery from 1984 to 2011*". The main finding is a negative correlation was found to exist between LST (Land Surface Temperature) and NDVI (Normalized Difference Vegetation Index) value.
- **Stephen D. Superczynski and Sundar A. Christopher, 2011**, *"Exploring Land Use and Land Cover Effects on Air Quality in Central Alabama Using GIS and Remote Sensing*". The cause and effect of LULC and Air Quality are quantified in this research using a Triangulated Irregular Network (TIN) model based on air pollution monitor observations.

- **Jun Pill, 2014**, "*Land Use Planning and The Urban Heat Island Effect"*, The primary conclusions of this study are that by strategically placing green spaces and using statistical models to Landsat 5 satellite remote sensing data, it is possible to lower temperatures in residential and urban regions.
- **Nikolaos-Fivos Galatoulas, Panagiotis I. Dallas, Luis, 2018**, "*Development and On-Field Testing of Low-Cost Portable System for Monitoring $PM_{2.5}$ Concentrations*". The current work develops the idea of creating a portable, low-cost Air Pollution monitoring system (APMS) to measure particulate matter (PM) concentrations, specifically tiny particles ($PM_{2.5}$) with a diameter of 2.5 m or less.

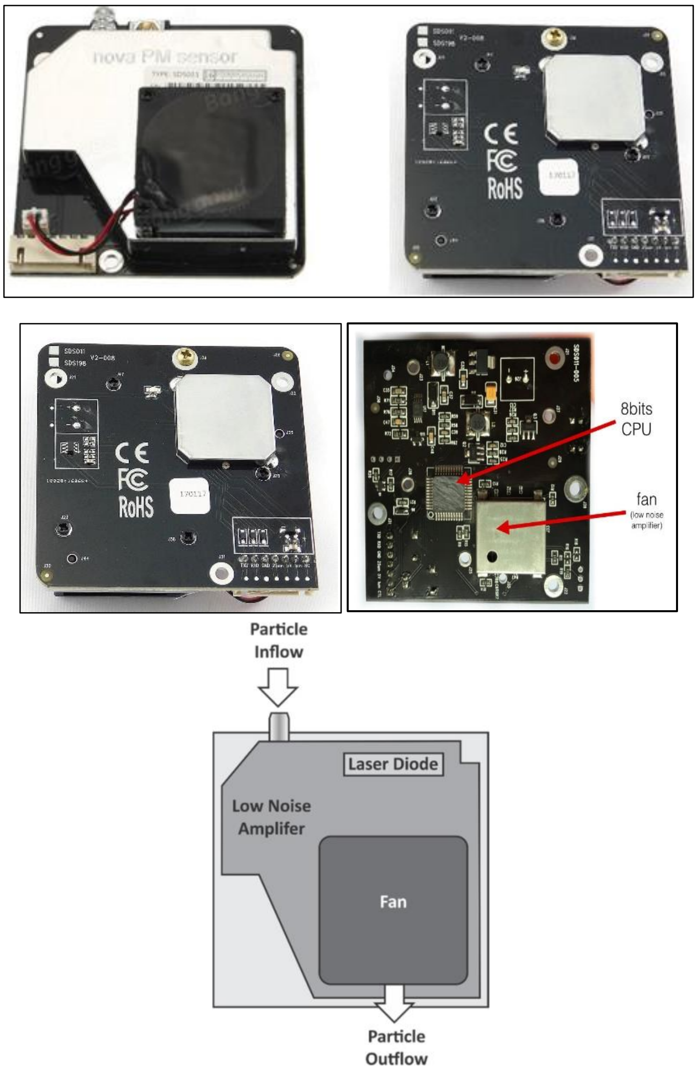


Plate 2.3.1: Nova PM Sensor SDS011: (a) Sensor front (b) Sensor back(c) Sensor inside

Source: Nikolaos – Fivos Galatoulas, Panagiotis I. Dallas, Luis 2018, "Development and On-Field Testing of Low-Cost Portable System for Monitoring $PM_{2.5}$ Concentrations".

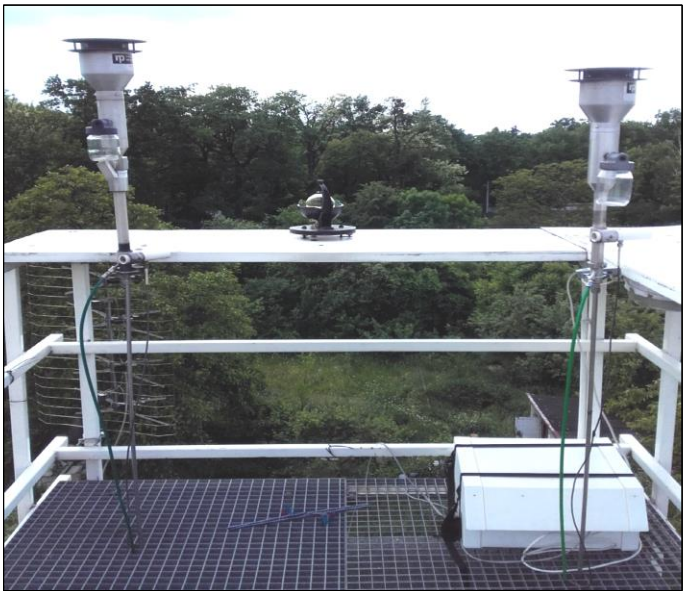


Plate 2.3.2: The placement of the PM sensor measurement box and TEOM inlet.

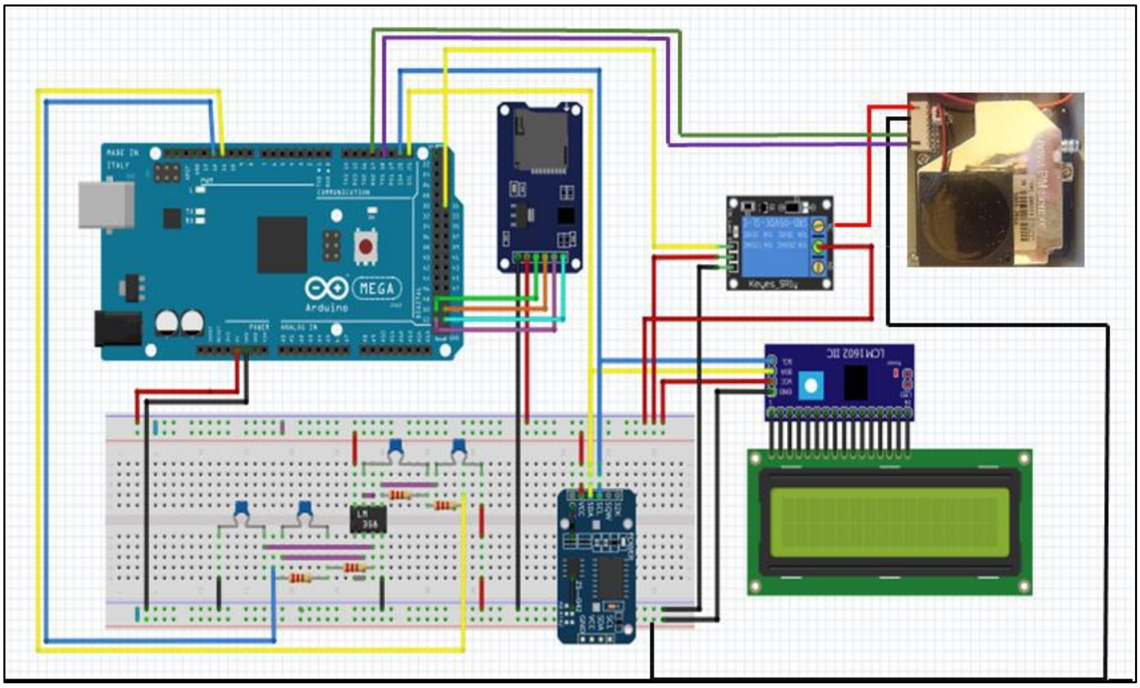


Plate 2.3.3: Circuit Design

Source: Nikolaos – Fivos Galatoulas, Panagiotis I. Dallas, Luis 2018

“Development and On-Field Testing of Low-Cost Portable System for Monitoring $PM_{2.5}$ Concentrations”

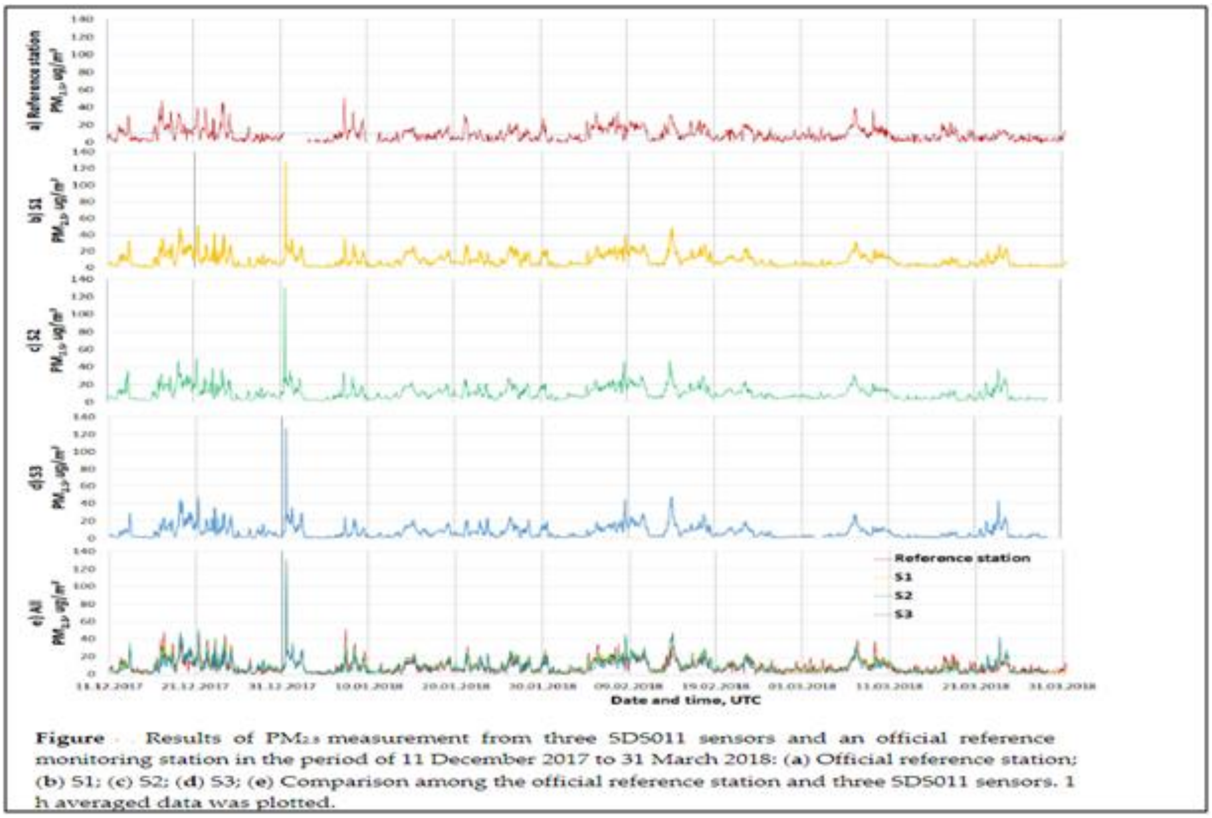


Figure 2.3.1: Results of $PM_{2.5}$ measurements

Source: Nikolaos – Fivos Galatoulas, Panagiotis I. Dallas, Luis 2018

"Development and On-Field Testing of Low-Cost Portable System for Monitoring $PM_{2.5}$ Concentrations"

- **Hai-Ying Liu, Philipp Schneider, January 2019,** "*Performance Assessment of a Low-Cost $PM_{2.5}$ Sensor for a near Four-Month Period in Oslo, Norway*". The main finding of this study is that all three sensors produce results that are remarkably similar to one another, with inter sensor correlations showing R values higher than 0.97 and all three sensors showing very high linearity against formally measured $PM_{2.5}$accumulation with R^2 values fluctuate from 0.55 to 0.71. The sensor response was impacted severely by high RH (above 80%). The findings show that employing these affordable SDS011 sensors for suggestive $PM_{2.5}$ monitoring under specific environmental circumstances is often feasible.

- Hai-Ying Liu, Philipp Schneider, Rolf Haugen, Matthias Vogt January 2019 "Performance Assessment of a Low-Cost $PM_{2.5}$ Sensor for a near Four-Month Period in Oslo, Norway". The authors used three sensors, and all three showed very high linearity when compared to officially recorded amounts of $PM_{2.5}$, with R^2 values ranging from 0.55 to 0.71. Inter sensory correlations showed R values greater than 0.97. The sensor response was impacted severely by high RH (above 80%). The outcomes showed that employing these affordable SDS011 sensors for suggestive $PM_{2.5}$ monitoring under specific environmental circumstances is generally feasible.

2.4 Bibliometric Analysis (Such as Annual Publication, Reports, Key Words, Cited Documents…)

A branch of study called bibliometrics looks at knowledge bases both inside and between fields. One aspect of bibliometrics is citation analysis, which is concerned with quantifying the evaluation of citation patterns in a corpus of literature. A tried-and-true method for measuring scholarly productivity quantitatively is bibliometric analysis. This study's objective was to examine the output of research worldwide using original journal articles. A unique and original perspective to the issue is developed through literature reviews, which help to avoid duplicating information already written by other academics in the field. Reviews of the literature provide familiarity with the field's knowledge and the opportunity to assess the importance of further research. Annual reports are thorough publications created to tell readers about the performance of a subject or object of study in the year prior.

A bibliometric analysis tool called the Three-Field Plot shows how collaboration patterns, publication impact, and publication productivity are distributed within a certain field of study. A Three-Field Plot was made using the cited references' country, keyword, and year of publication, and to illustrate the percentage of research subjects for every nation and the recentness of the publications they referenced.

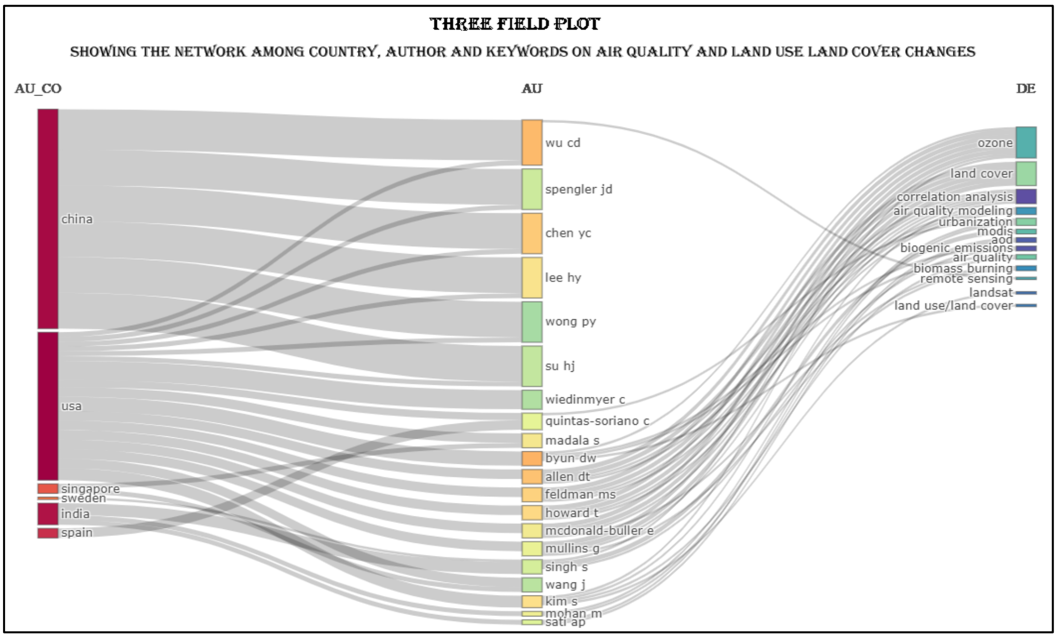


Figure : 2.4.1 Three Field Plot showing the network among country (left), author (middle),and keywords (right) on Air Quality and Land Use Land Cover Changes

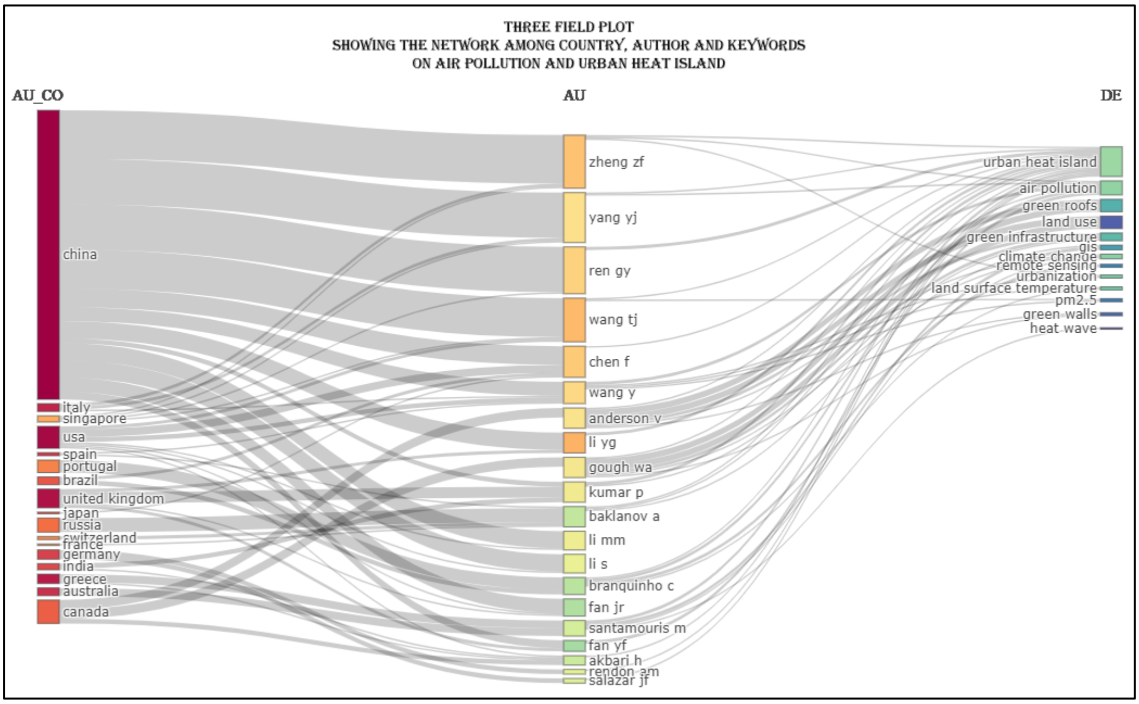
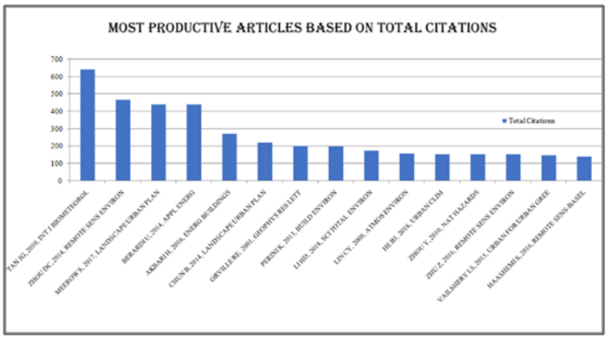


Figure 2.4.2: Three Field Plot showing the network among country (left), author (middle) and keywords (right) on Air Pollution and Urban Heat Island

The height of the rectangular nodes in the collaboration network reflects how frequently a given nation, organization, or publication appears. The lines' widths between the nodes are proportionate. A three-field map showing the relationships between nations, institutions, and journals based on a Sankey diagram (An illustration of a flow from one set of values to another is a Sankey diagram. Nodes are the objects that are connected, and links are the connections between them).

Local Citation is the amount of citations a document received from other documents in the particular search that was conducted, whereas Global Citation is the total number of citations a document received from all publications indexed in a source (Scopus, WOS, Google Scholar, etc.). It makes it possible for readers to find your sources and read more about the concepts you present in your paper.



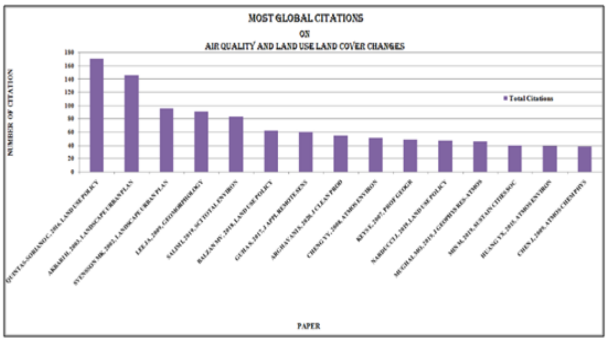


Figure 2.4.3: Most Global citations **Figure 2.4.4: Most Productive Articles based on total citations**

This study can be used to determine the significance of the most fruitful papers and globally cited materials on the subject. Researchers discovered that the landscape layout (e.g., Patch area, degree of urban cluster, etc.) can also greatly effect PM 2.5 concentration in addition to the types of land cover and environmental greenness. This was not addressed here due to the paucity of available data.

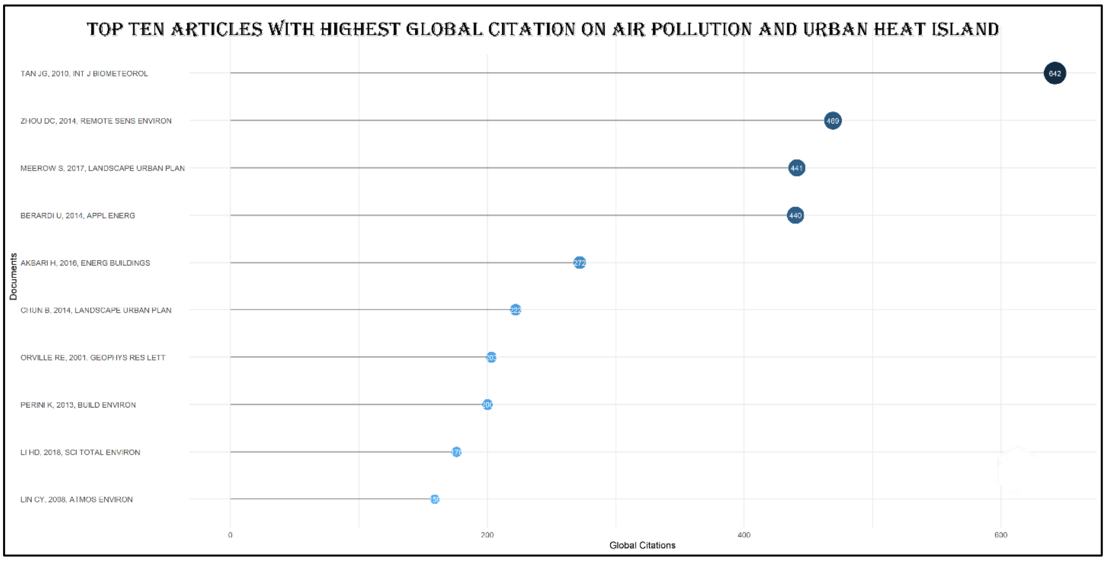


Figure 2.4.5 : Top 10 articles with highest global citation

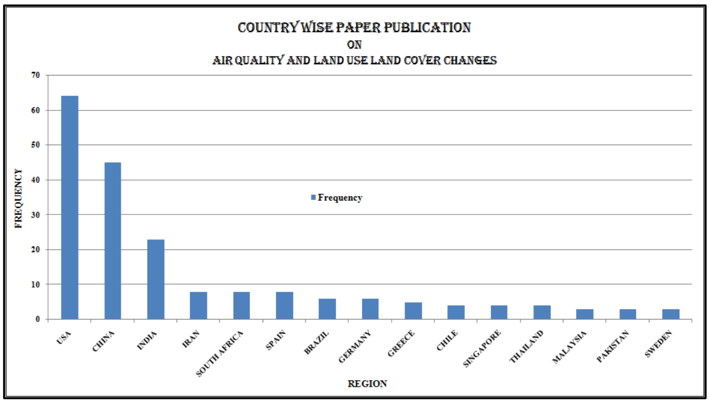


Figure 2.4.6 : Country wise paper publication

This study's goal was to evaluate previous research on the relationship between air quality and LULC change. The "Web of Science (WoS) Science Citation Expanded Database" was searched, utilizing papers published in various years and nations.

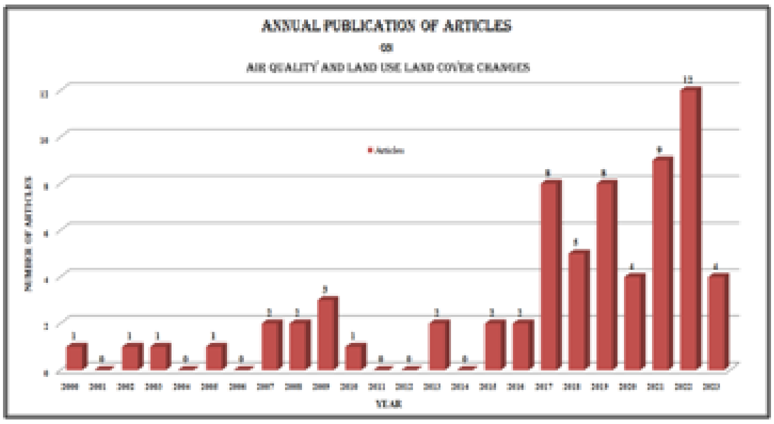


Figure 2.4.7: Annual Publication of Articles on Air Quality and Land Use Land Cover Changes

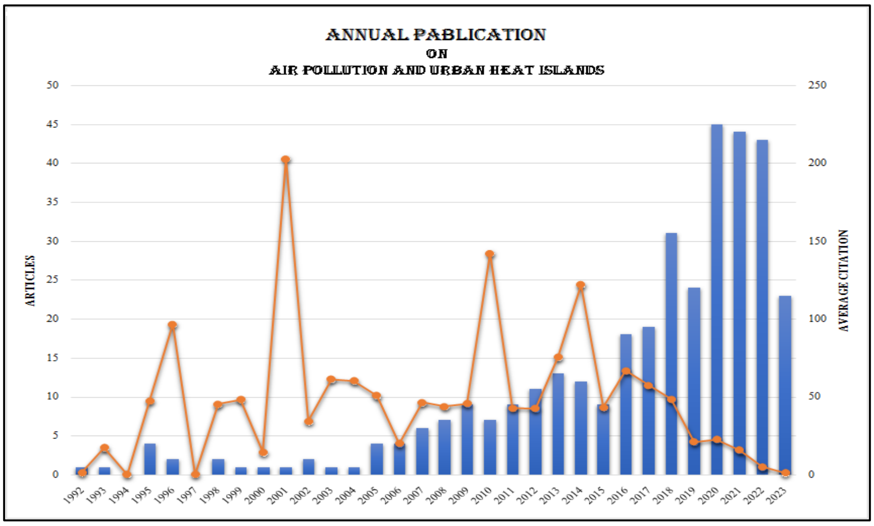


Figure 2.4.8: Annual Publication on Air Pollution and Urban Heat Island

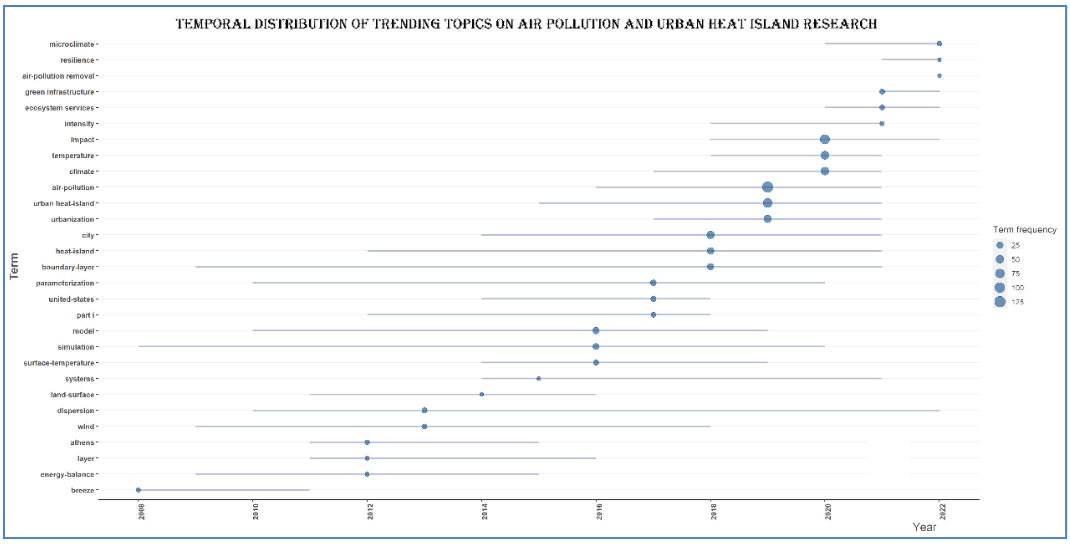


Figure 2.4.9 : Temporal distribution of trending topics in Air pollution and Urban heat island research

The primary aim of the current study was to conduct a systematic assessment of the literature, with a focus on sustainable urban planning. The review updated and analyzed the current state of scientific production in the field using the most reputable worldwide bibliographic databases, Web of Science and Scopus.

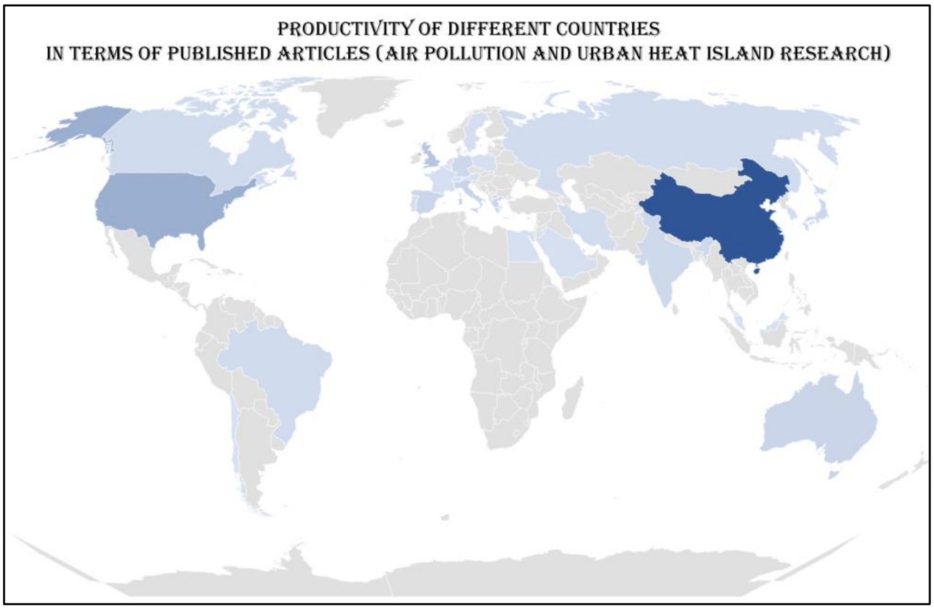


Figure 2.4.10 : Productivity of different countries in terms of published articles

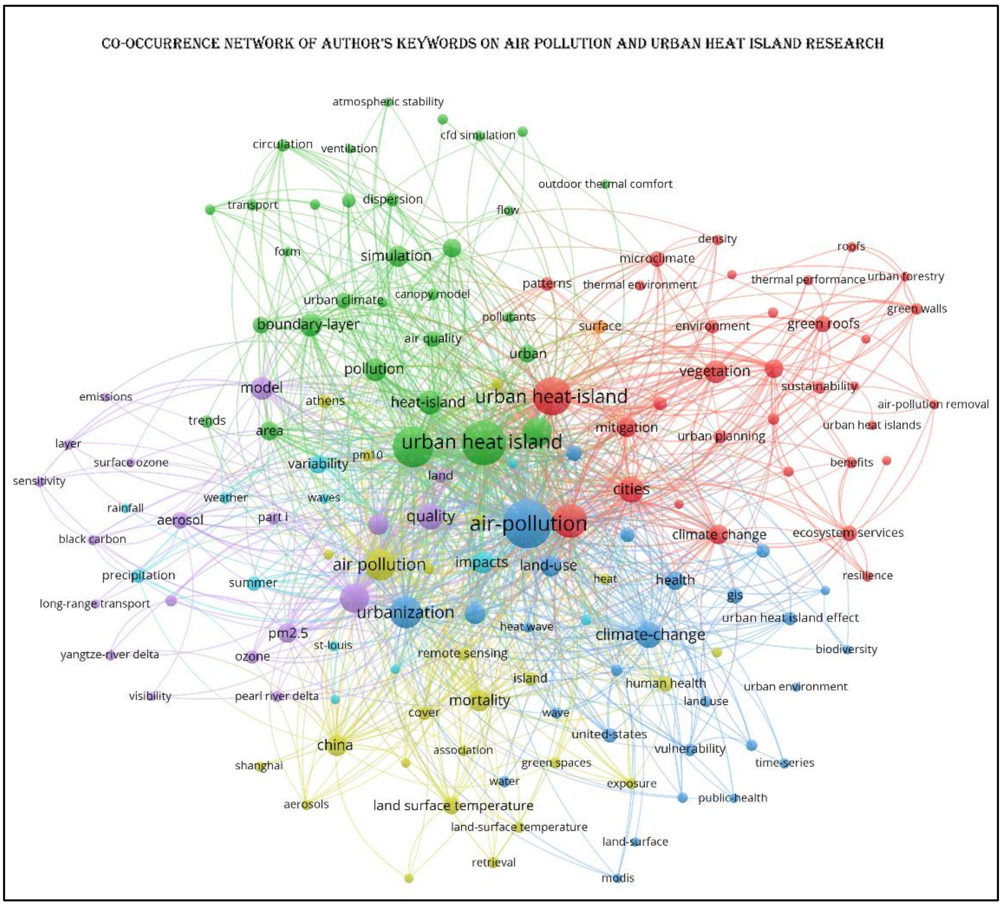


Figure 2.4.11: Co- occurrence network of author's keywords on air pollution and urban heat island research

The findings of the examination of the information from the Cite Seer digital library are presented in this research work . Initially, looked at the data from the perspective of the top-level source Internet domains that provided the data. Secondly, the calculated national proportions in Cite Seer-indexed papers and contrasted them with conventional bibliography-based estimates.

2.5 Kolkata and its over view from Meteorological aspect

The city of Calcutta (now Kolkata) was founded in 1698 on the site of three villages, and it was legally expanded in 1717 when the English bought 38 villages. By 1793, there were 55 villages located directly outside of Calcutta's municipal limits. In 1710, there were just 12,000 inhabitants and by 1752, there were 409000. With the exception of London, Calcutta was the largest British city by the eighteenth century and was known as the "Second City of the Empire". With a population of 4.5 million in 1960, Calcutta was the tenth-largest "urban agglomeration" in the world. By 1995, however, it had grown to 11.7 million, making it the ninth-largest metropolis in the world (WRI, 1996) (Akbari and others, 2001).

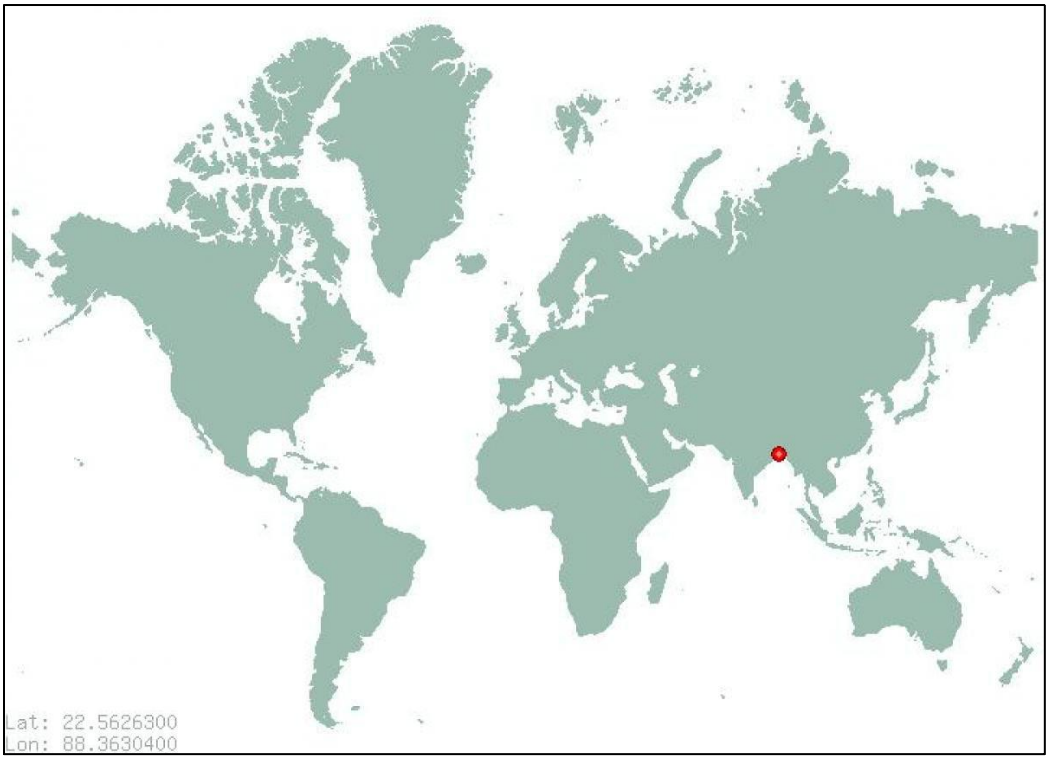


Figure 2.5.1: Kolkata- The "City of Joy" **Source: mapsofkolkata.com**

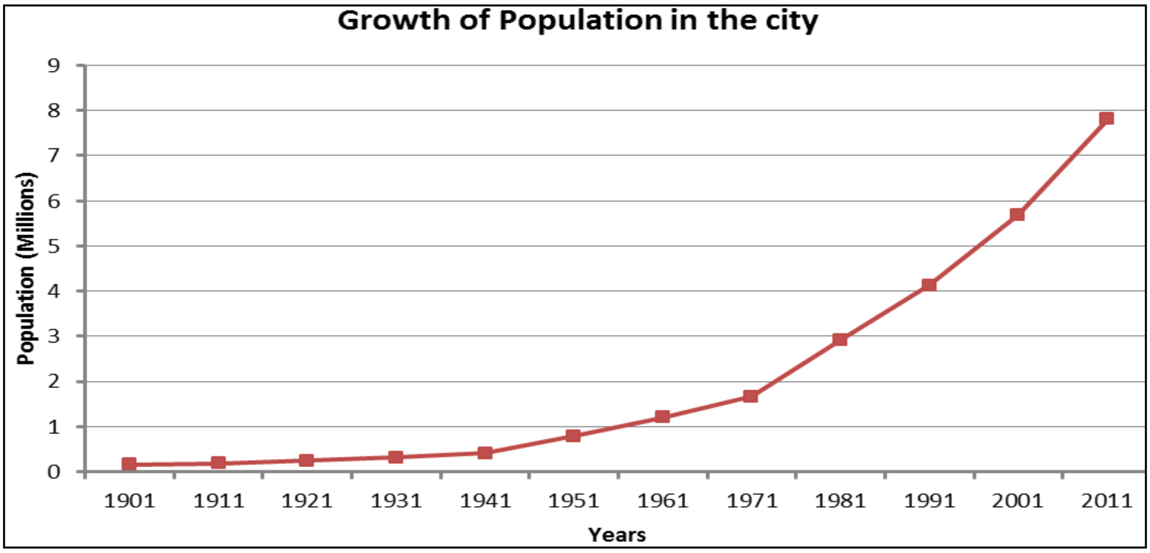


Figure 2.5.2: Growth of urban population in the city **Source: census of India**

The third most populated metropolitan region in India is Kolkata Metropolitan, the capital of West Bengal. It is situated in the country's east along the Hooghly River's banks. The Kolkata metropolitan area spans 1,886.67km^2 (728.45sq. mi.) and is made up of 39 local municipalities and 3 municipal corporations, including Kolkata Municipal Corporation. The city's average elevation is 17 feet, which is not far above sea level as it is a contemporary city with a long history, a mixture of different land uses and land coverings, and a susceptibility to air turbulence, it has been chosen as the research location.

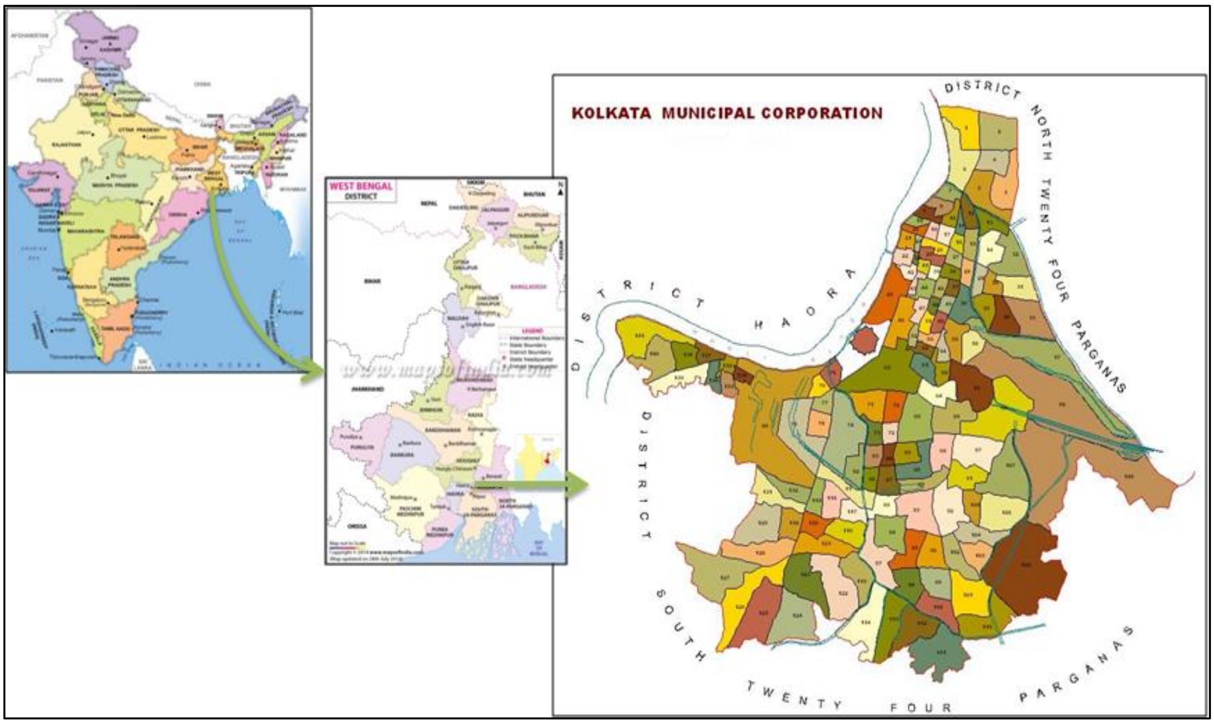


Figure 2.5.3: Location of Kolkata (Latitude and Longitude are 22.5667° N and 88.3667° E)

Source: http://en.wikipedia.org/wiki/Kolkata **Source: NATMO, Kolkata**

2.5.1 Meteorological Status in Kolkata

- The climate in Kolkata is tropical, moist and dry (Koppen climatic classification Aw).

- The yearly mean temperature is 24.8°C (80°F), while the monthly mean temperature ranges from 15°C to 30°C (59°F to 86°F).

- During dry spells, the maximum temperatures frequently approach 40°C (104°F) in May and June. Summers are hot and muggy with temperatures in the low 30s.

- Winter typically lasts only two and a half months, with seasonal lows between December and January varying from 48.2°F to 51.8°F (9°C to 11°C). Around 96 percent of the air is humid in the mornings and 67 percent in the afternoons.

- 1,582 mm of rain fall each year (62.3 inches).

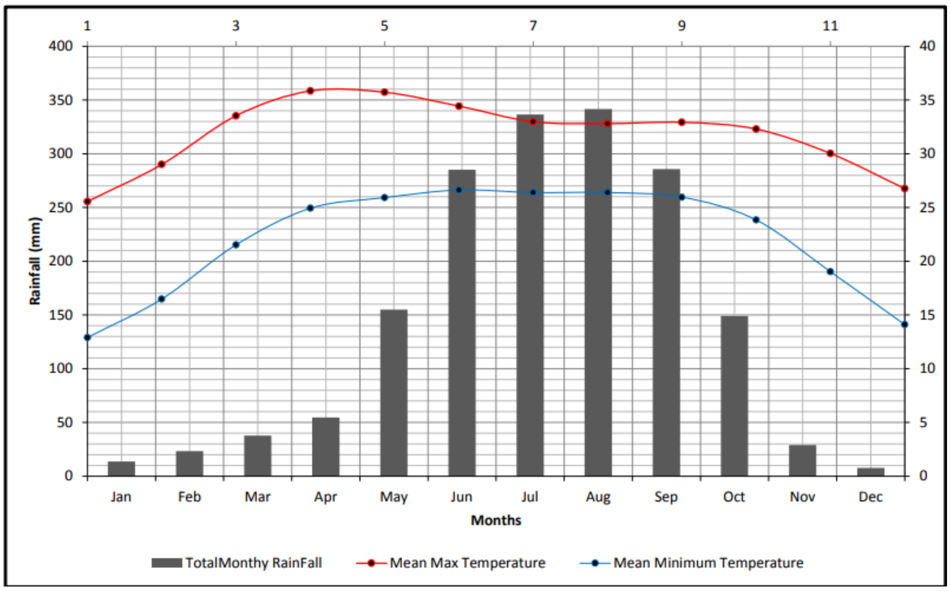


Figure 2.5.1.1: Meteorological conditions of Kolkata 1980 -2013

Source: National Centre for Sustainable Coastal Management Ministry of Environment & Forests, Anna University Campus (Chennai) case study kolkata 25th August, 2015

2.6 Macro and Micro climate in Kolkata

The climate of a sizable geographic area, such as a country or a region, is known as the macroclimate. Microclimate consists of very small patterns, whereas macroclimate comprises of patterns at the local, regional, and landscape levels. A tiny area's microclimate is its unique climate in relation to its surroundings. It could be more or less likely to frost, warmer or colder, wetter or drier. The influence of macro and microclimate elements to outdoor comfort is similar. (Jian Zhang, Fan Zhang *et al*.).

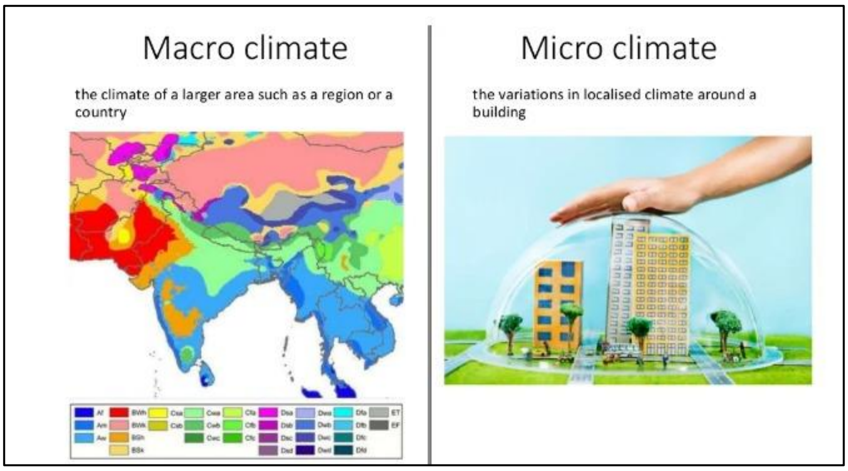


Plate 2.6.1: Macro and Micro Climate

Source: Avani Gajbhiye (Institute of Design Education and Architectural Studies (IDEAS), Using Koppen's classification of climate

By analyzing its numerous components and effects on the microclimate in Kolkata, it is possible to analyze the geometry of the urban built form. Urban climatology has generally accepted the urban canyon, a simplified rectangular vertical profile of indefinite length, as the fundamental structural unit for characterizing a typical urban open space, i.e. filtered from extraneous non climatic characteristics. These studies (e.g., Nunez, M. - Oke, T. 1977, Oke, T. 1988, Todhunter, P. E. 1990, Yoshida, A. et al. 1990-1991, Santamouris, M. et al. 1999, Asimakopoulos, D. N. et al. 2001, Arnfield, J. 2003) provided fundamental information on street microclimate. In general, it was discovered that street orientation and the height-to-width ratio (H/W) were the two factors that had the biggest effects on the microclimate of the urban street canyon. Many part in Kolkata fall under this category.

2.7 Information about urbanization in Kolkata

Urbanization in Kolkata, particularly during the post-colonial era, was a quick but chaotic process. Eastern India's largest urban agglomeration is called the Kolkata Metropolitan Area (KMA). According to the 2001 Census, there are 14.72 million people living in KMA, compared to 22.5 million people living in West Bengal's metropolitan areas as a whole. Even though KMA's share of the State's urban population has decreased over the past 25 years or so due to a number of initiatives the State Government has taken to improve urban facilities in other West Bengal cities and towns, KMA still makes up close to 59 percent of the State's urban population, down from 69 percent in 1981 and 64 percent in 1991.Another significant demographic feature of KMA is that, at almost 8000 people per square kilometer, it has the greatest average residential density among Indian metropolises (Kolkata Annual Report, 2006).

Urbanization and population increase have put enormous pressure on the conversion of land from natural and agricultural uses to residential and urban uses, which has had a severe negative impact on ecosystem services (Justice *et al.*, 2015). The destruction of vegetative cover is caused by urbanization, encroachment into the few remaining agricultural and natural regions, and rapid population growth (Bakhtiar Feizizadeh and Thomas Blaschke 2013).

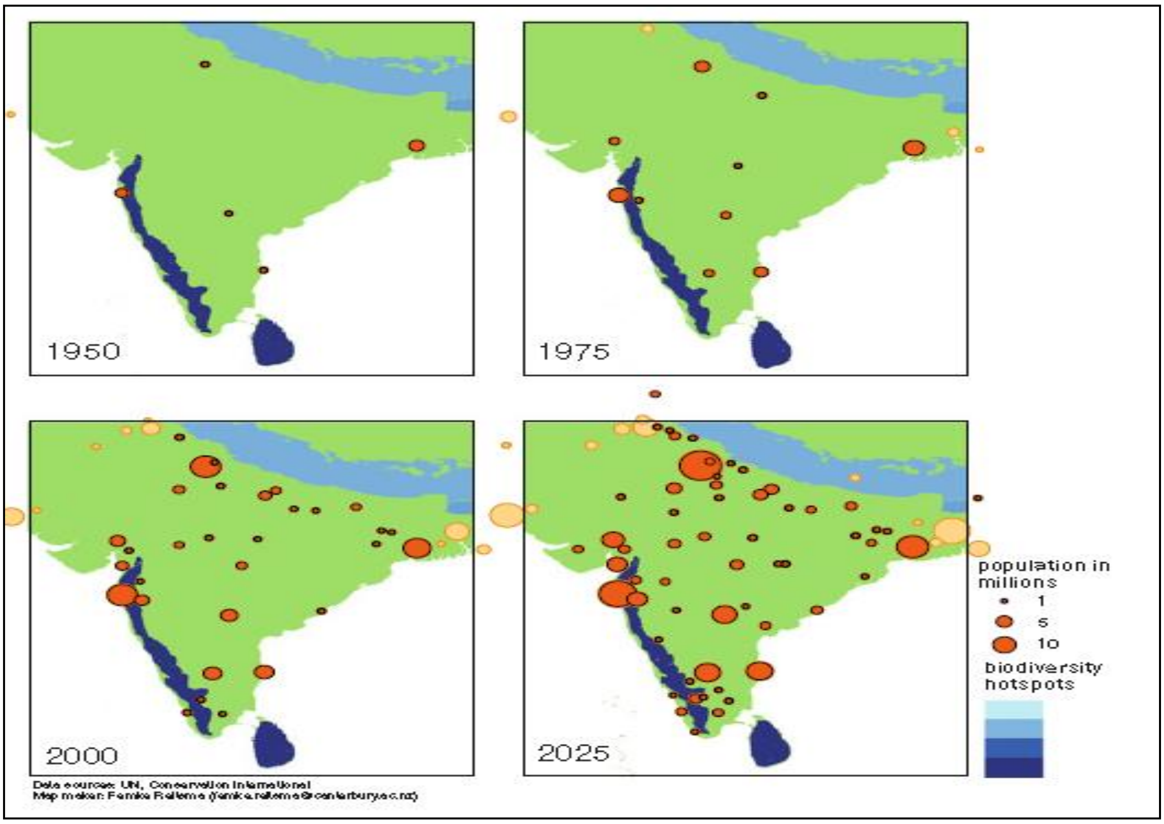


Figure 2.7.1: Patterns of Urban Expansion in different decades(INDIA)

Number of HH	Number of Wards 2001	Number of Wards 2011
1000-4999	38	41
5000-8999	83	63
9000-12999	17	29
13000-16999	3	6
17000-21000		2

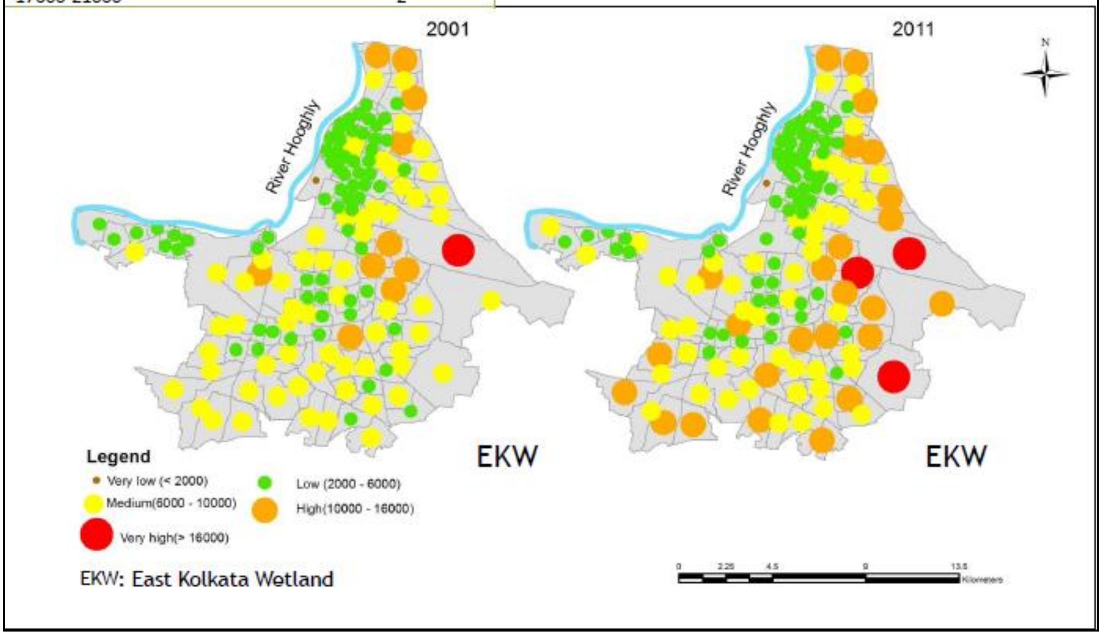


Figure 2.7.2: Growth of Housing

Source: National Centre for Sustainable Coastal Management Ministry of Environment & Forests Anna University Campus (Chennai), Case study Kolkata, 25th August 2014

2.8 Land Use Land Cover (LULC) Change in Kolkata

Land use records how people use the land, whereas land cover describes the actual form of land, such as a forest or open water. The term "land cover" refers to the physical and biological covering of land, including plants, water, bare soil and/or man-made buildings (Ellis, 2007). On the other hand, land use, it is outlined as the social and economic goals, circumstances, and frameworks for managing lands, has a more difficult component because it involves social sciences and management concepts. Although they are frequently used interchangeably, Land Use and Land Cover have distinct differences. Even though the land cover may appear to be the same, land cover represents the spatial distribution of the various land cover classes on the earth's surface and can be directly estimated qualitatively as well as quantitatively by remote sensing. Land use and its changes require the integration of natural and social scientific methods to identify which human activities are taking place in different parts of the landscape, even when the land cover appears to be the same (Lambin *et al*., 2001).

One of the most significant changes noticed in environment is the change in Land Usage and Land Cover. Although noticeable, the size, diversity, and regional unpredictability of the changes have made it difficult for scientists to quantify and evaluate changes in land use and land cover. Furthermore, because human activities directly influence the majority of changes in land use and land cover, these changes rarely adhere to accepted ecological theories. According to an article P. S. Roy and Arijit Roy, published in the Journal of the Indian Institute of Science in January 2010, the Remote Sensing and Geographic Information System has shown to be crucial in evaluating and analyzing changes in LULC.

2.9 Air Pollution, Ambient Air Quality (PM_{10} and $PM_{2.5}$) and its Heath Effect

Any substance that alters the natural properties of the atmosphere, whether it be chemical, physical, or biological, is considered an air pollutant. Air pollution can occur indoors or outdoors. Common causes of Air Pollution include motor vehicles, industrial operations, household combustion appliances, and forest fires (Plate.2.8.4, Fig. 2.8.3).Based on the synthesis of scientific studies, when dangerous gases and dust are discharged into the atmosphere, Air Pollution results. Forest fires, human activity, and volcanic eruptions are just a few of the many factors that contribute to Air Pollution. The biggest contributors are cars and electricity plants. Biological and human diseases are brought on by Air Pollution.

It is well known that Air Pollution has a negative impact on human health. In addition to having a negative influence on human health (Plate.2.8.1,2.8.2), Air Pollution also has an obvious effect on plants, animals, and materials. Numerous epidemiological studies have suggested that air pollution from traffic is a factor in the negative health effects of repeated exposure to air pollution. The impact of Air Pollution on health is currently estimated to be significant in Europe (Brunekreef and Holgate, 2002).Recent epidemiological studies highlighted the significance of taking into account within-city heterogeneity in air pollution concentration estimates (Jerrett *et al.,* 2005; Hoek *et al.,* 2008; Beelen *et al*., 2008; Brauer *et al.*, 2003). The health of the exposed city population in Kolkata is beginning to suffer as a result of the high levels of particle matter and other hazardous air pollutants present in the city's air. Other significant towns and cities in the state would have more or less comparable circumstances (WBPCB Report 2004).

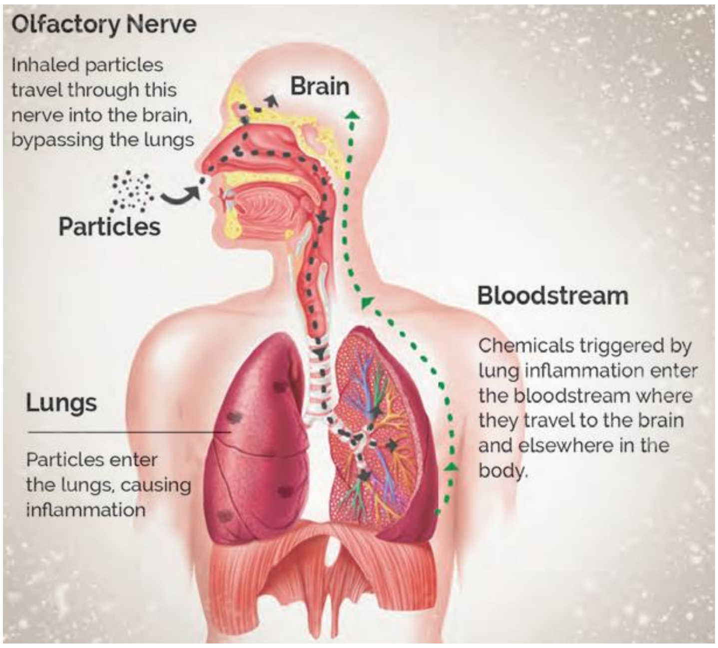


Plate 2.9.1: Health Impact of Particulate Matter

Source: A Guide Book of WBPCB Department of Environment, Government of West Bengal

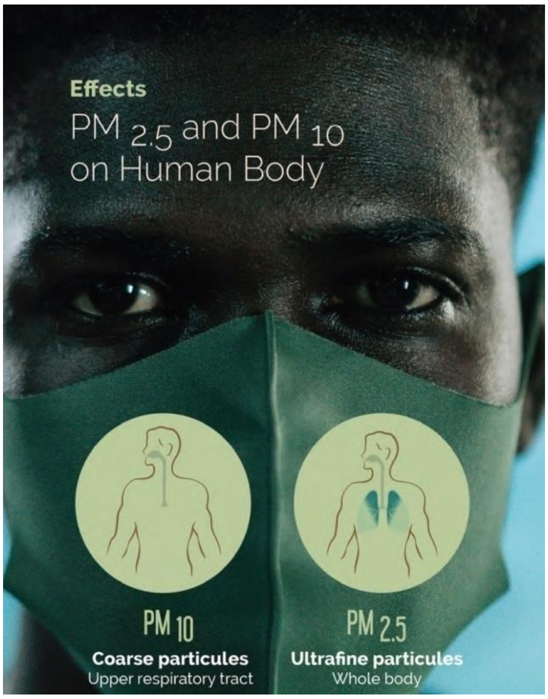


Plate 2.9.2: Effect of PM $_{10}$ and PM$_{2.5}$on Human Body

Source: A Guide Book of WBPCB Department of Environment, Government of West Bengal

Pollutant concentrations in the air are referred to as ambient air quality criteria or standards and usually apply to outdoor air. The standards are set forth for a number of goals, including planning and other objectives as well as the preservation of human health, structures, crops, plants, and ecosystems. Other causes of pollution include wind-borne dust, vegetation-related biogenic emissions, and smoke from bushfires (pollen and mould spores). The following are the most typical air contaminants found in ambient air: Particulate matter (PM_{10} and $PM_{2.5}$).

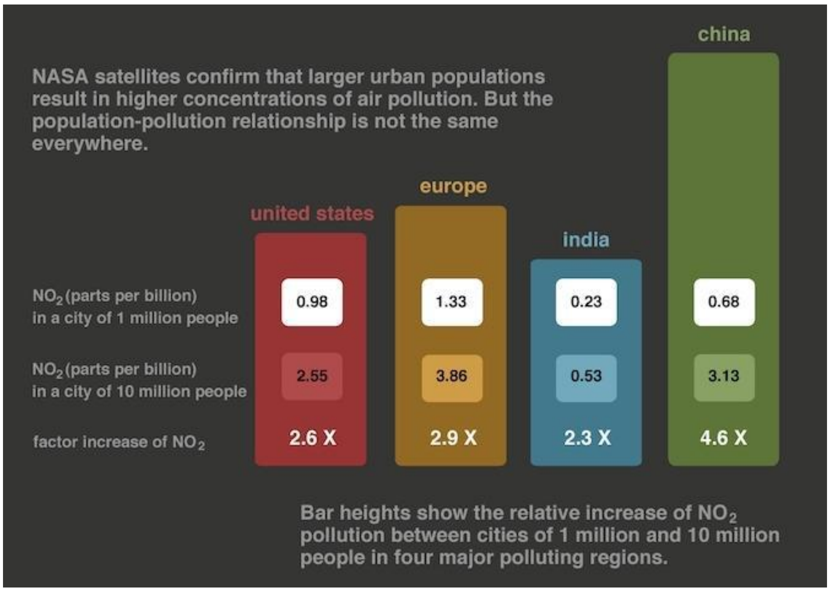


Plate 2.9.3: Impact of urbanization - Urban population & air pollution

Source: World Health Organization, 2019

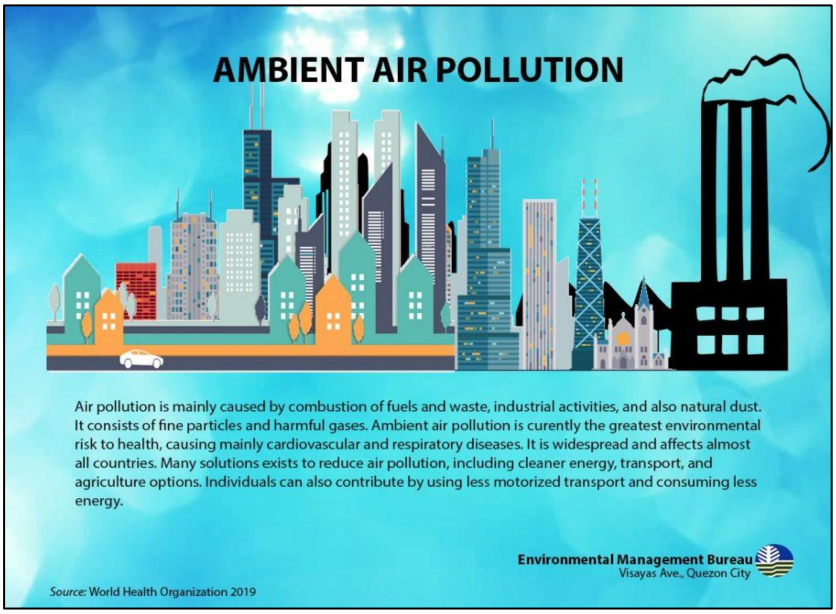


Plate 2.9.4: Ambient Air Pollution

Source: World Health Organization, 2019

There are major differences in the atmospheric movement and destiny of airborne particles (Godish, 1997). Fine particle dry deposition occurs slowly. Fine primary and secondary particles can travel great distances and have long atmospheric lives (days to weeks). They can't be easily linked to their origins as a result. The lifetime of coarse particles is 24 hours or less, and their maximum range is 100 kilometres. In contrast to coarse particles, which are more likely to be irregularly dispersed even over relatively short distances, fine particles typically spread out equally over a vast region.

During their deposition in the respiratory system, human inhaled particles are segregated according to size. A smaller particulate penetrates deeper into the lungs and retains longer in the lungs.

Mucous, which particles might enter the stomach through when it is ingested, is a second pathway for poisoning. This method allows atmospheric lead to enter the body and cause poisoning. Synergistic effects are caused by the way air pollutants interact with one another. The interaction between PM_{10} and sulphur dioxide is one illustration of this. Normal sulphide removal occurs in the upper respiratory system, but adsorption-absorption of sulphide onto particles enables sulphide to penetrate deeply into the pulmonary system, where sulphide poisoning may occur (Godish, 1997). The main effect of exposure to coarse particles is the exacerbation of respiratory diseases like asthma. The health effects of fine particles are most directly linked to premature death, increased respiratory symptoms and disease, more hospital admissions, and ER visits as a result of heart and lung disease (Shprentz, 1996).

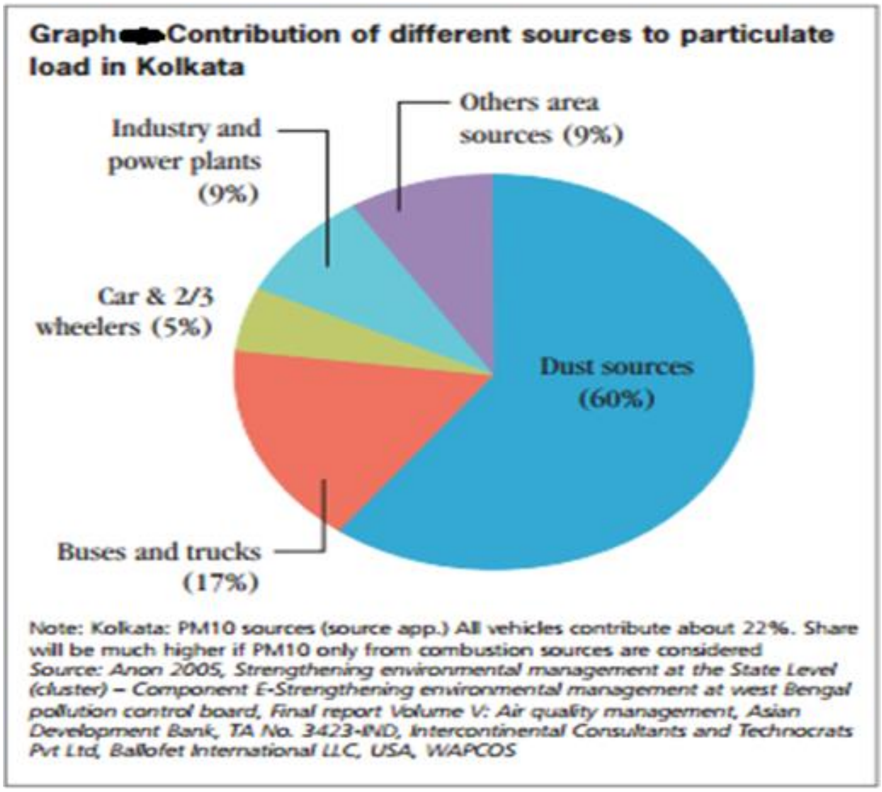


Figure 2.9.1: Graphical contribution of different sources to particulate load in Kolkata

Source: WPCB Annual Report 2004

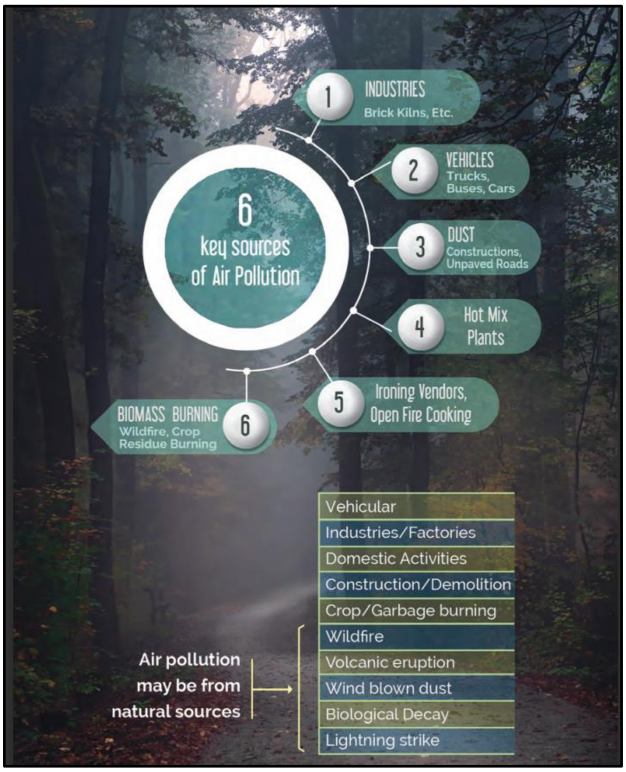


Plate 2.9.5: Sources of Air Pollution

Source: A Guide Book of WBPCB Department of Environment, Government of West Bengal

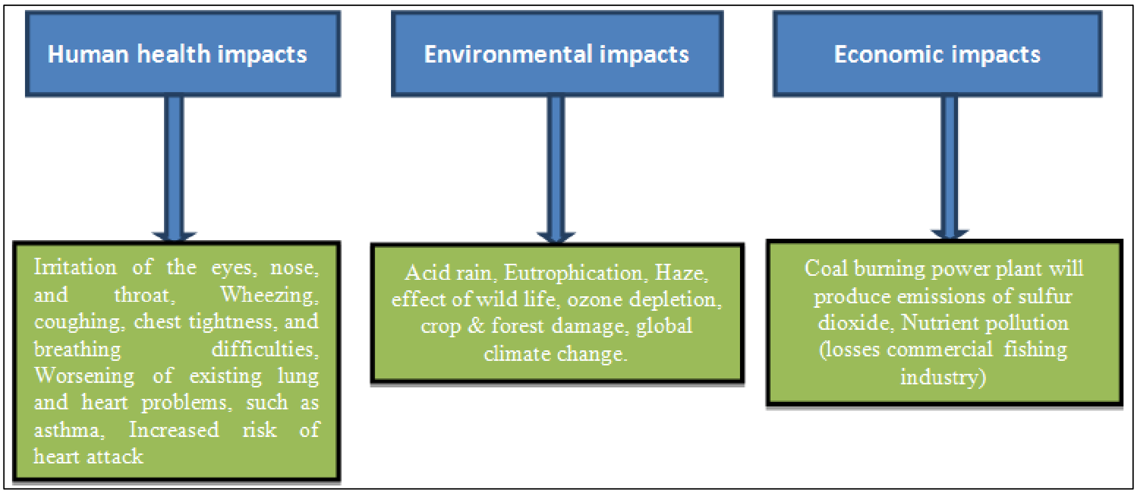


Figure 2.9.2: Impact of Air Pollution

Source: Department of Environmental Protection

In semi-equilibrium with the surrounding gases, particulate matter is a complicated mixture of suspended solid and liquid particles. Respirable Particulate Matter (RPM or PM_{10}) is a term for particles smaller than 10µm in diameter. These tiny particles are small enough to enter a person's lungs and respiratory system. Particles with a diameter of less than 2.5µm, or the finer fraction, are referred to as $PM_{2.5,}$ are mainly aerosols. These aerosols, which are secondary pollutants that can even reach the lungs' alveoli, are created when vapors condense through photochemical processes (Air Quality Status of West Bengal – A State of Environment Report, 2004).

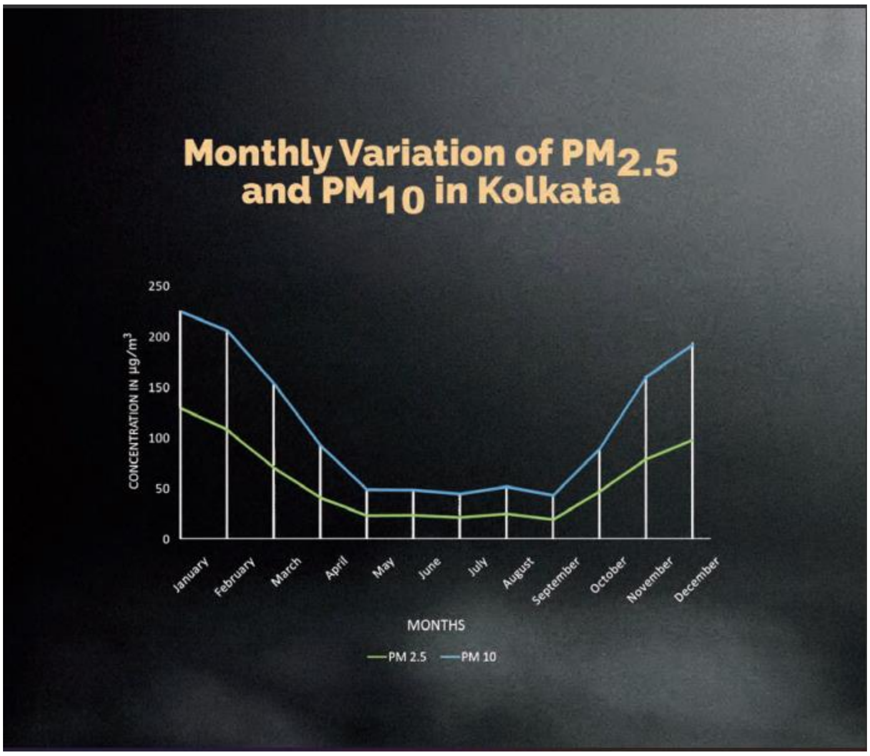


Plate 2.9.6: Monthly Variation of $PM_{2.5}$ and PM_{10} in Kolkata

Source: A Guide Book of WBPCB Department of Environment, Government of West Bengal

It is categorized in several ways:

a. Emission based classification: PM that is classified as primary is that which is released into the atmosphere using the same chemical name. Road dust, fly ash, soot, and other types of wind-borne dust are among the main particulate matter.

b. Secondary PM: If airborne particles are created by chemical processes, they are referred to as secondary particles. Sulfates, nitrates, and other particles classified as secondary particulate matter. b. Classification based on size: Table and Figure display the particulate matter classification and size (National Ambient Air Quality Monitoring Status NAAQMS/45/2019-20).

Table 2.9.1: Classification of particulate matter

Fraction	Size range
Respirable Suspended Particulate Matter (RSPM) or PM_{10} (thoracic fraction)	• ≤ 10 μm diameter • produced by mechanical attrition of dusts • lung deposition principally by impaction • 2.5 μm – 10 μm is called coarse fraction
Accumulation mode or Fine particles or $PM_{2.5}$ (respirable fraction)	• ≤ 2.5 μm in diameter • composed mainly of carbonaceous materials (organic and elemental), inorganic compounds (sulfate, nitrate, and ammonium), and trace metal compounds (iron, aluminium, nickel, copper, zinc, and lead) • penetrates deeper into the lungs • increases respiratory symptoms, causes irritation of the airways, coughing, or difficulty breathing, decreases lung function; aggravates asthma, chronic bronchitis, irregular heartbeat, nonfatal heart attacks, premature death in people with heart or lung disease
Ultrafine Particles (UFP)	• ≤ 0.1 μm large surface area to mass ratio • making them potential carriers of harmful gaseous compounds • cause severe pulmonary inflammation and hemorrhage, high degree of alveolar and interstitial edema, disruption of epithelial and endothelial cell layers and even death

Assessment of ambient air quality of the country for 2019

Source: Status of PM_{10} in 2019 CPCB

In semi-equilibrium with the surrounding gases, particulate matter is a complicated combination of suspended solid and liquid particles. Size of PM_{10} is 10 m. Organic and inorganic carbon, metals/elements including silicon, magnesium, and iron, as well as ions like sulphates, nitrates, and ammonium, are the main ingredients. It can create health issues by settling in the lungs and bronchi. Comparatively speaking, the center, north-east, and south zones have lower levels of PM_{10} than the east, north, and west zones. 44 of the 73 coastal cities covered by NAMP are over the NAAQS. The national average is exceeded by 62 industrial cities and 44 million plus cities. 111 of the 122 non-attainment cities are above the national average.

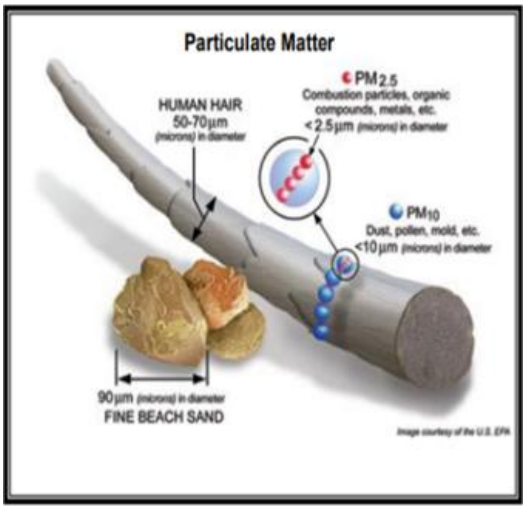


Figure2.9.3: Size of Particulate Matter

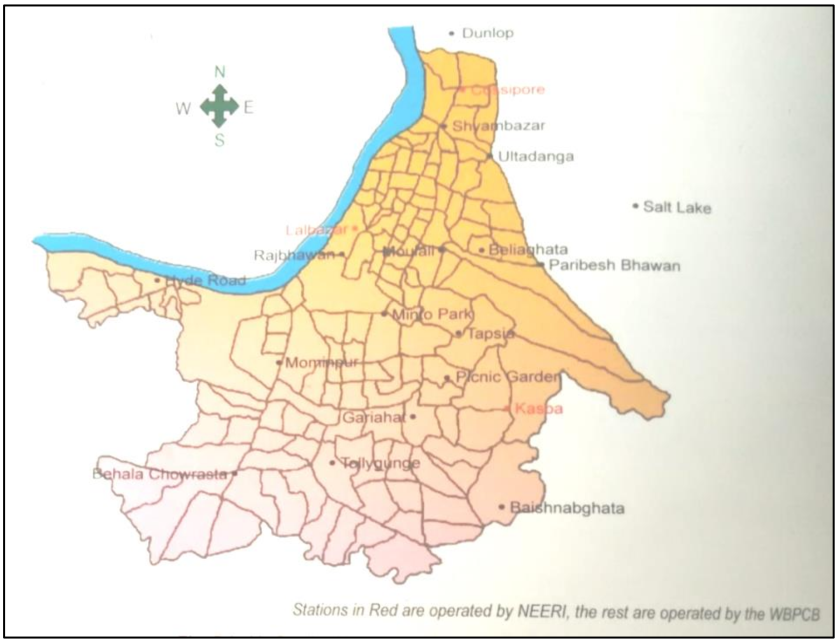
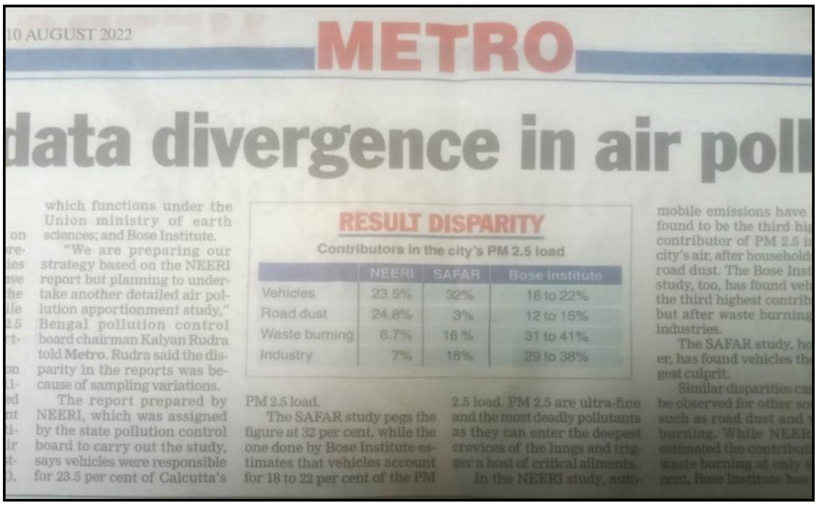


Figure 2.9.4: Air Quality monitoring centres in Kolkata (Red are operated by NEERI)



10 AUGUST 2022

METRO

data divergence in air poll

which functions under the Union ministry of earth sciences; and Bose Institute.

"We are preparing our strategy based on the NEERI report but planning to undertake another detailed air pollution apportionment study," Bengal pollution control board chairman Kalyan Rudra told Metro. Rudra said the disparity in the reports was because of sampling variations.

The report prepared by NEERI, which was assigned by the state pollution control board to carry out the study, says vehicles were responsible for 23.5 per cent of Calcutta's PM 2.5 load.

The SAFAR study pegs the figure at 32 per cent, while the one done by Bose Institute estimates that vehicles account for 18 to 22 per cent of the PM 2.5 load. PM 2.5 are ultra-fine and the most deadly pollutants as they can enter the deepest crevices of the lungs and trigger a host of critical ailments.

In the NEERI study, automobile emissions have found to be the third hi contributor of PM 2.5 i city's air, after household road dust. The Bose Inst study, too, has found veh the third highest contrib but after waste burning industries.

The SAFAR study, ho er, has found vehicles th gest culprit.

Similar disparities ca be observed for other so such as road dust and burning. While NEER estimated the contribut waste burning at only cent, Bose Institute has

RESULT DISPARITY

Contributors in the city's PM 2.5 load

	NEERI	SAFAR	Bose Institute
Vehicles	23.5%	32%	18 to 22%
Road dust	24.8%	3%	12 to 15%
Waste burning	6.7%	16 %	31 to 41%
Industry	7%	18%	29 to 38%

Plate 2.9.7: NEERI Report from Newspaper

Source: NEERI Report "Contribution in the city's $PM_{2.5}$load (10^{th}August 2022)

2.9.1.1 Air Pollution, Ambient Air Quality (PM_{10} and $PM_{2.5}$) and its Heath Effect (in COVID and Pre COVID period)

Demonstrate that daily worldwide CO2 emissions fell by 17% by early April during the COVID-19 forced confinement period relative to mean 2019 levels, and that the overall effect on the 2020 yearly emissions level depended on the length of the confinement or lockdowns. Based on the synthesis of scientific studies, for all pollutant AQIs, an average decrease of greater than 24% has been seen across all cities; $PM_{2.5}$ decreased by 45%, PM_{10} declined by 48%, and CO decreased by 41%. When considering $PM_{2.5}$ (g/m^3), the average concentration from April to August of 2018 was 137 g/m^3, which reduced to 87 g/m^3 in 2020 for the same time periods (decreased by 36.36%).

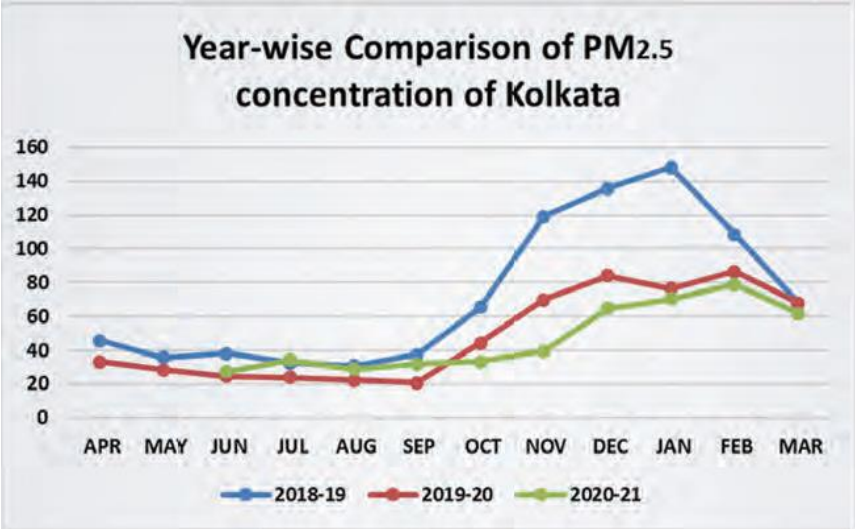


Figure 2.9.5: Graphical chart shows the $PM_{2.5}$ concentration in COVID and Pre COVID period

Source: A Guide Book of WBPCB Department of Environment, Government of West Bengal

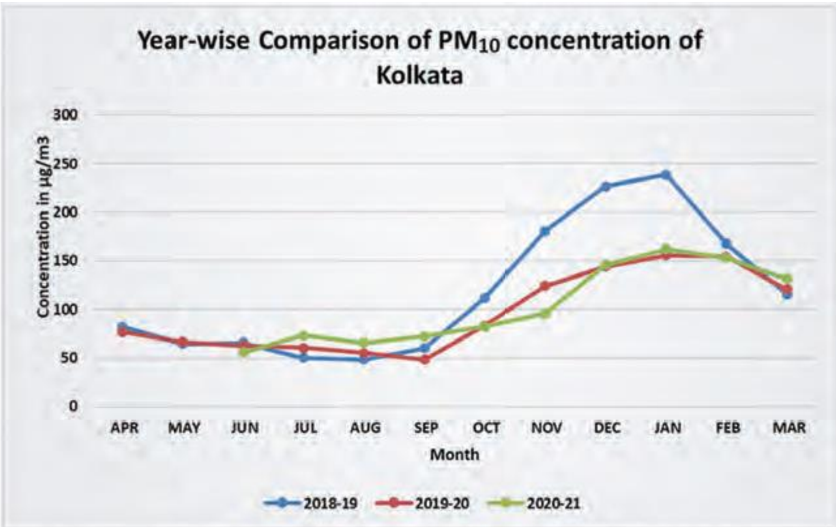


Figure 2.9.6 : Graphical chart shows the PM_{10} concentration in COVID and Pre COVID period

Source: A Guide Book of WBPCB Department of Environment, Government of West Bengal

On March 17, 2020, a UK-returned student who was found positive for COVID-19 led to the first positive case being reported in West Bengal, the fourth-most populous state in the nation. Countries have strictly limited the movement of people and transportation to prevent the spread of the disease, reducing human interaction, enforcing strict quarantine, banning large-scale private and public gatherings, promoting social segregation, restricting private and public transportation, and changing economic practices. Since March 24, 2020, India has been under a state of lockdown that began with a voluntary public curfew on March 22 and continued for 21 days starting on March 24. Pollutant emissions have decreased as a result of the producing sectors being shut down, restrictions on human mobility, and a managed public transport system. Numerous academic studies have demonstrated how the lockout has improved the quality of the surrounding air, particularly in India (Gautam 2020; Mahato *et al*., 2020; Sikarwar and Rani 2020; Srivastava *et al*., 2020).

2.10 Land Surface Temperature (LST) and Air Temperature in Kolkata

Surface or Air Temperature measurement can be used to locate Urban Heat Islands. Air Temperatures are significantly yet indirectly influenced by surface temperature. For instance, parks and other vegetated places which frequently have cooler surface temperature, help to chill the air. The most complete image of a city's heat island is provided by the combination of satellite data for surface temperature and data from monitoring stations or traverses for air temperature.

In contrast to air temperature, Land Surface Temperature is the temperature of the ground that may be determined through thermal reflection. Metropolitan heat island is the result of elevated temperatures in urban areas and the nearby rural areas as a result of materials used, pollution levels, etc. on the land. A measurement of the air's heat or cold is its temperature. It is the weather parameter that is most frequently measured. The "surface" of the Earth would feel warm to the touch at a given point based on its LST. The "surface" is whatever the satellite views as it peers through the atmosphere to the earth. (The Earth Observatory is part of the EOS Project Science Office at NASA). Understanding the processes relating to a climate in each location and its urbanization is made easier thanks to the association found between LST and Air Temperature (Augusto Cezar Lima do Nascimento, Emerson Galvani, *et al.)*

Observed from the thermal zone of the sensor onboard, Land Surface Temperature is a direction-based radiometric temperature of the earth's collective surfaces (Sismanidis, *et al*., 2016). It is a fundamental component of the earth's thermal behaviour and a crucial indicator of the planet's energy balance and climate change (AATSR and SLSTR, 2018). It serves as a significant greenhouse impact and global warming indicator (Jia *et al.*, 2007) and defines local, regional, and global processes over the planet's surface and is extremely important since it is closely connected to the sensible and latent heat fluxes (Mann stein, 1987).

Table 2.10.1: Surface Heat Island studies in India

Surface Heat Island studies in India		
Study area	Satellite	Salient features
Delhi(Mallick*etal*.,2012)	LANDSATTM	Using the normalized differential moisture index(NDMI), emissivity is calculated
		Surface temperatures can be predicted if NDMI values are known, according to a significant association between surface temperatures and NDMI over a range of LULC classes.

Surface Heat Island studies in India		
Study area	Satellite	Salient features
Delhi(Mohan*etal*.,2013)	MODIS-TERRA	In terms of UHI amplitude and hotspots, the comparison between UHI based on in situ ambient temperatures and satellite derived land surface temperatures is good at night but poor during the day.
		When compared to in situ skin temperature data, MODIS derived LSTs overestimated temperatures during the day and underestimated temperatures during the night.
Delhi(Mallick*etal*.,2013)	ASTERandLandsat7ETMintheth ermalInfra-redregion3to14µm.	LST estimation using satellite data collected at night.
		When compared to the suburbs, Delhi's Central Business District (CBD), including Connaught Place, which is a high density built-up area and commercial/industrial sectors exhibit heat islands.
		There is a strong link between impervious surface area and relative surface temperature (ISA)
Delhi(Pandey*etal*.,2014)	MODIS-TERRA monthlyLSTproductMODIS1C3 .005at5.6kmresolution	The intensity of the nocturnal heat island is lowest (0_2 K) during the monsoon season and highest in March (46K)
		Delhi experiences daytime cool islands twice a year in the months of May, June, and October, December.
		Aerosol optical depth and UHII have a significant negative association (AOD)
Noida (Suhail *et al*.,2019)	Landsat8OLITIRS	Spatial distribution of UHIs and their interrelationship with land use over NOIDA city is reported.
		The results show that two clusters were developed in north and mid-east par to the city due to accumulation of high-density building and industrial units
Tirunelveli, Tamilnadu (Padmanabhan *et al.,* 2019)	Landsat7ETM	Surface permeability and temperature quantified using Soil-Adjusted Vegetation Index (SAVI) and Land Surface Temperature (LST) index appropriately.
		South eastern built-up areas in Tirunelveli were represent as a developing UHI hotspot, with a caution for the Western riparian zone for UHI emergence in 2017
44citiesinIndia (Raj*et al*.,2020)	MODIS	Long-term (18 years) investigation of SUHII for 44 major Indian cities
		Positive SUHII distinguish during day (up to 2ºC) and night for most cities
		Vegetation plays a key role in entering the day time SUHII
		The expand night time SUHII in all season's for most cities indicate increasing trend in temperature in cities due to the impact of the rapid urbanization.
Chandigarh (Sultana and Satyanarayana, 2020)	Landsat7and8	Rapid increase (10%) in built-up area is noticed over the Chandigarh during 2000 to 2018.
		Dry Built-up Index (DBI) and Dry Bare Soil Index (DBSI) are employed to differentiate the built up areas from the dry lands effectively.
		Identified an increase in UHI intensity of range 10.8to12.8˚C (6.3 to 7.5˚C) for summer (winter) season.
Chennai (Kesavan *et al*.,	Landsat 7 and 8	LST estimation and forecasting as well as the

Surface Heat Island studies in India		
Study area	Satellite	Salient features
2021)		detection of UHI using the Autoregressive Integrated Moving Average (ARIMA) model have both been accomplished utilizing remote sensing techniques.
		The model study's LST maps showed expanding UHI hotspots in the city's southeastern and western regions, where development is occurring quickly.
Delhi (Kumari *et al.*, 2021)	MODIS Terra	UHI's effect on Delhi's electricity usage
		Over the course of eight Delhi districts from April 2012 to March 2017, UHI creation led to an average annual increase in power consumption of 2600 GWh (or 11.4%).
Hyderabad (Puppala and Singh,2021)	Landsat 8 OLI TIRS	The temperature is rising throughout time, and the areas with greater habitation and vegetation are experiencing this phenomenon more severely.
		Planning green areas for each of the current and planned buildings is advised to balance development and the UHI effect.
Kolkata (Dutta *et al.*, 2021a)	Landsat 5 TM and Landsat 8	Investigations on the factors (LULC) influencing the intensity of the UHI were thorough.
		In each decade, the vegetation index decreased by -0.267, whereas the increase in the impervious surface index was, on average, 0.097 at new UHI locations.
		Daytime cooling of 0.938ºC was observed between urban built up areas and green parks, which were separated by 50 m.
Lucknow (Shukla and Jain, 2021)	Landsat 5, 7 and 8	In Lucknow, India, drivers and effects of several types of sprawl expansion were evaluated from 2005 to 2016.

2.11 Urban Heat Island effects (UHIe) in Kolkata

A city or metropolitan region that has grown noticeably warmer than the neighboring rural areas as a result of occupancy is known as an Urban Heat Island. When winds are light, the temperature differential is often more pronounced and is larger at night than during the day. UHI is most noticeable during the summer and winter months. When cities replace natural land cover with dense clusters of pavement, buildings, and other surfaces that absorb and hold heat, urban heat islands are created. This effect raises energy prices (for air conditioning, for example), Air Pollution levels, and the incidence and death of heat-related illnesses (According to United States Environmental Agency, EPA 23-Mar-2022).

Cities today are increasingly vulnerable to heat waves and the UHI phenomena as a result of growing demographic pressure, which changes the landscape toward expanding urban regions. This has now progressed to the point where the UHI impact is becoming more prevalent, stronger, and lasting for longer periods of time, which worsens the thermal danger for the locals (Founda and Santamouris, 2017). UHI is a phenomenon that occurs in cities, raising city temperatures above those of neighbouring suburban or rural locations (Liang and Shi, 2009).

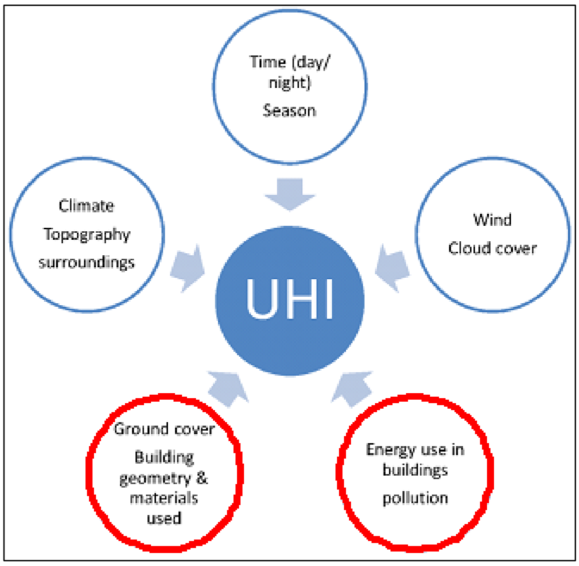


Figure 2.11.1: Causes of Urban Heat Island Effect

Source: http://cimss.ssec.wisc.edu

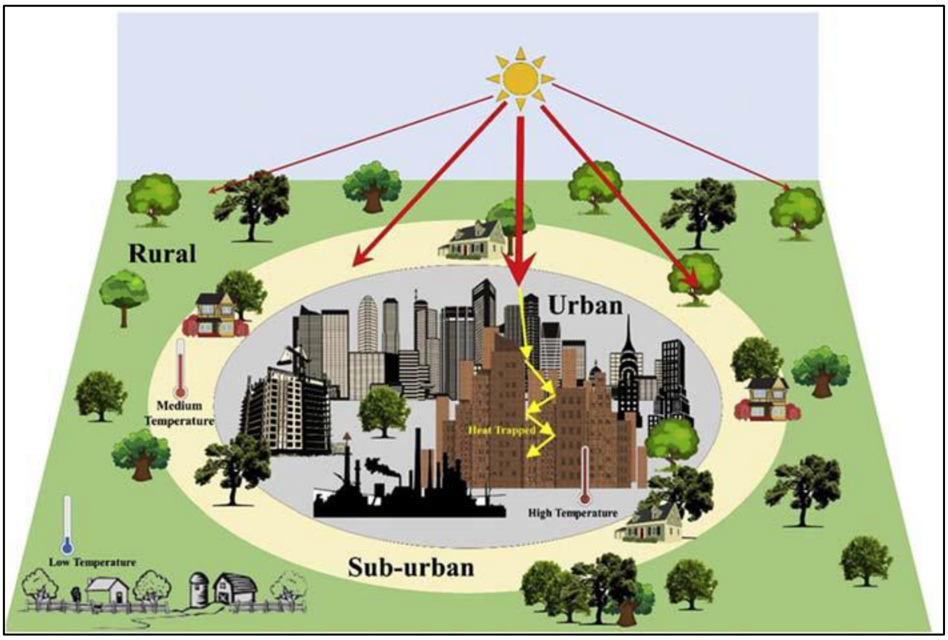


Figure 2.11.2: Temperature distribution in urban, suburban, and rural areas signifying UHI.

Source: http://cimss.ssec.wisc.edu

These can be derived from the variation in vegetation, water, and impervious surface percentages. There are two sorts of UHIs:

1. Atmospheric UHI (AUHI): The AUHI effect occurs when air temperature rises as a result of heat being absorbed by particles in the atmosphere. Based on height, it is further divided into the following two groups: UHI canopy layer (Heat islands that exist in the air layer above ground-level structures or vegetation) and UHI for boundary layers (Heat islands are prevalent in the area above vegetation and rooftops).
2. Surface UHI (SUHI): Due to the presence of a sizable area covered in impermeable

surfaces, metropolitan areas experience higher surface temperatures. Multiple internal reflections, increased shortwave radiation absorption, an increase in anthropogenic heat sources, difficulties transmitting long wave radiation, decreased evapotranspiration rates, changes in wind gust and turbulence, decreased radiative cooling, etc. are some of the causes of UHI (Dash *et al.*, 2002).

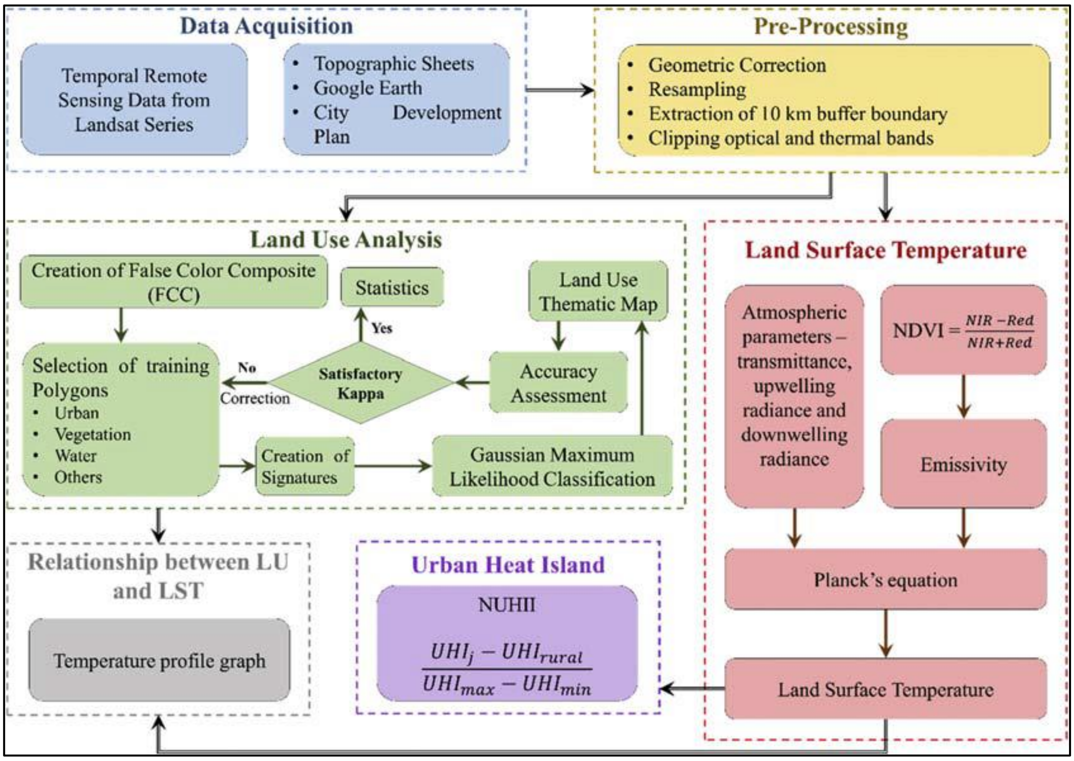


Figure 2.11.3: Five steps of research work

Source: Method used in the book - "Global Urban Heat Island Mitigation", Ansar Khan, Hashem Akbari, *et al.*, 2022

The research was conducted in five steps, as shown in figure 2.10.3: (1) Data collection and pre-processing, (2) Land use analysis, (3) Quantification of emissivity and Land Surface Temperature, (4) Estimation of Normalized Urban Heat Island Index (NUHII), and (5) Derivation of the relationship between LU and LST.

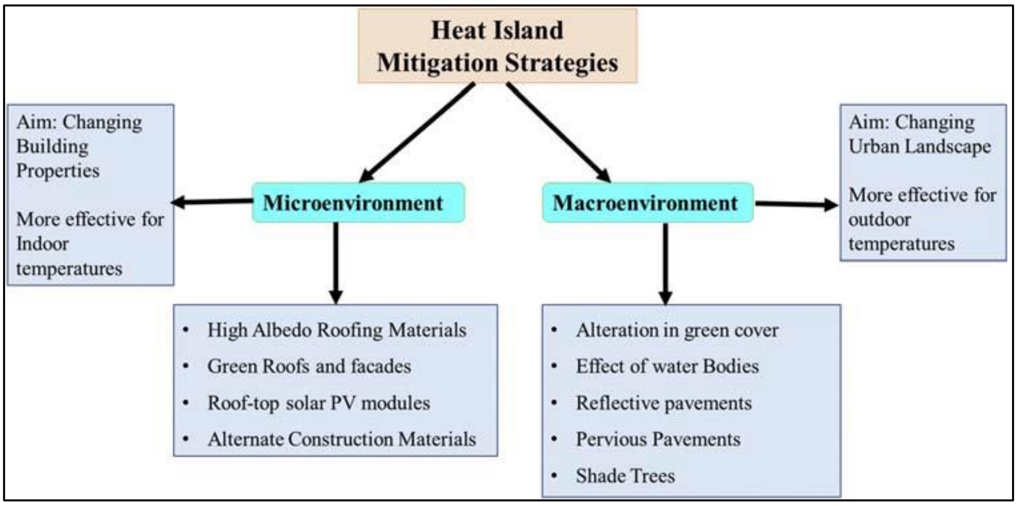


Figure2.11.4: UHI mitigation measures

Source: Displays the common measure that are employed for UHI mitigation, according to the work of Dr. Ansar Khan, H. Akbari *et al*. 2022

2.12 Research Gaps

A research gap mention to pathless or undetermined areas with scope for further research. When someone become interested in a paper or topic, often recognize there are some places where additional research is necessary but has not yet been evaluated by other scholars.

2.12.1 Research Gaps of this study

Many of the past research works had focused on the research problem identification. There are data sources collected by many government and non-government organizations. However, no such comprehensive study on UHI, its relationship with LULC and Air Quality with real-time data collection within Kolkata and its suburbs was carried out. The present thesis has aimed at fulfilling the gap in systematic and collective way with suggestion, improvement and optimization of the above-mentioned parameters as an initial step towards implementation.

- Limited Longitudinal Studies: Numerous previous studies may have looked at Kolkata's Air Quality, LULC change, and Urban Heat Island (UHI) effects separately. More longitudinal studies that examine these variables across protracted time periods are required to better understand their dynamic linkages and patterns.
- Spatial Variability: While some studies may have examined the spatial differences of UHI impacts, it's possible that there is a dearth of studies concentrating on particular areas or microclimates inside Kolkata. It would be helpful to conduct in-depth analyses of the spatial patterns of UHI impacts and their relationships with LULC traits at the neighborhood level.
- Urban Green Spaces: Some research may have briefly examined the role of green spaces

in reducing the effects of UHI and enhancing air quality. To comprehend the precise types of green spaces that are most productive, their distribution, and the effects of urban greening activities on UHI and Air Quality, more research is nevertheless required.

- Impact on Human Health: Although some studies may have discussed the potential consequences of UHI on human health, additional research is required to examine the health effects of heat exposure and air pollution in various Kolkata neighborhoods.
- Climate Change Adaptation measures: The effectiveness of specific urban design and climate mitigation measures in addressing UHI effects and Air Quality may be discussed in existing literature. Comprehensive analyses of various adaption techniques and their potential for long-term climate resilience in the context of Kolkata, however, may be lacking.
- Data integration: For UHI and LULC analysis, some research studies may have employed ground-based measurements or remote sensing data, whereas monitoring stations may have provided data on Air Quality. There is a study void in merging these different datasets to find clear connections between Kolkata's UHI, LULC, and Air Quality.
- Few researches may have taken social and demographic aspects into account when analyzing the effects of UHI and Air Quality in Kolkata. A more complete knowledge of the problem can be gained by looking into how factors like population density, income levels, and housing styles might interact with UHI and air pollution.
- Policy Evaluation: Although some studies may have suggested policy recommendations, there may be a dearth of research assessing the execution and impacts of current policies and urban planning strategies intended to lessen the effects of UHI and enhance air quality in Kolkata.
- There is a need for in-depth research on exploring the inter-relationship between Urban Heat Island effect, LULC changes and variation in ambient Air Quality for the city of Kolkata.
- Analysis using real time Air Quality data which is not yet performed across the area of concern.

2.12.2 Conclusion from literature study throws Research Gap

Urban Heat Island (UHI) Effect in Kolkata: According to the literature assessment, Kolkata has an urban heat island effect since it becomes hotter there than it does in the rural areas nearby. The UHI intensity varies between different urban zones and neighborhoods, and it has been discovered that changes in urban Land Use Land Cover (LULC) patterns have an impact on how intensely the UHI is felt.

Relationship between UHI and LULC: UHI intensity and different types of LULC are shown to be significantly correlated in Kolkata, according to the research. Green spaces and bodies of water have a moderating effect on the intensity of UHI, whereas built-up places, especially those with concrete surfaces, typically exhibit stronger UHI effects.

Effect on Air Quality: According to the studies, Kolkata's air quality and UHI intensity are significantly correlated. The Air Quality Index (AQI), which measures air pollution, generally shows that areas where UHI effects are more pronounced also have greater levels of air pollution. The existence of UHI may worsen air pollution and have detrimental effects on human health.

Role of Green Spaces: According to studies, green spaces are crucial for reducing the effects of UHI and enhancing air quality in Kolkata's metropolitan areas. Green infrastructure and vegetation have the ability to lessen the intensity of UHI and improve air quality.

Research Gaps: The literature review identifies a number of research gaps, including the dearth of comprehensive policy evaluations and data integration, the paucity of longitudinal studies and the need for detailed spatial analyses at the neighborhood level.

Policy Implications: In order to combat the consequences of UHI and enhance air quality in Kolkata, it is important to establish appropriate urban planning and climate mitigation initiatives. For reducing the effects of UHI and boosting urban resilience, it can be essential to incorporate green spaces into urban plans, put heat mitigation measures into place, and encourage sustainable land use practices.

Recommendations: Based on the literature analysis, it is advised that more study be done in order to fully comprehend the relationships between UHI impacts, LULC alterations, and Air Quality in Kolkata. To provide a more comprehensive understanding of the subject, future studies should take into account filling in the known research gaps.

2.13 Conclusion

The study has a tendency to emphasise local environmental factors and climatic change while ignoring their physical counterparts. The study is primarily spatio-temporal in nature, which is the domain of geographers, urban planners, climatologists, environmentalists, and so on. The study's foundation is made up of enriched literature from various relevant Journal and research papers on Land Use Land Cover, Air Quality, Urban Heat Island, and Urbanization. It has made an effort to draw attention to the differences and inequalities that exist throughout space, which can be a State, Megacity, District or Municipal Corporation. In addition to analysing spatial changes, the work also gave proper consideration to the temporal variations of the various characteristics of the local climate and Air Quality. Since tropical nations like the Indian States in general, the research is both current and relevant. This chapter also covered several case studies in which the LULC change, UHI, LST, and microclimate were investigated in relation to reducing the urban heat island, regulating the air quality, and controlling land surface temperature. This chapter serves as the basis for the subsequent chapter, which categorises various investigations, such as the interactions between UHI, air quality and LULC as generic types based on various aspects of data analysis, statistical methods and land use classification of various traffic intersections and various land use land cover areas over time and space.

Chapter 3: Aims and Objectives

3.1 Introduction

Identifying the main goals or research topics of any study is essential. What is the main objective or purpose of the study? What areas of study, issues, or issues does the initiative aim to address, and why? Many projects encounter difficulties because not enough time and effort are put into clearly outlining the project's research aims at the outset. As a result, valuable time and resources may be squandered gathering study data that is pointless or irrelevant. The procedure for defining a project's research goals and questions is covered in this chapter. It provides advice on how to make sure your research goals and questions are well-planned and stated. In order to help those who may be having trouble putting their goals on paper, it also includes examples of both well-written and poorly-written research aims and objectives.

Aims and objectives produce an outstanding foundation for the case for held up in a research grant request (Parker Derrington Ltd Research Grant Writer, 2014). Aims are the apprehension and realization that you require in order to answer your research question. Well-designed aims create obvious connection between research project and the great, significant question that persuade it.

3.2 Research Problem

The first and most important stage in the research process is to identify and correctly define the research topic. The problem must be developed by the researcher and identified before it can be designated for study.

The fast expansion of city limits in almost most of the metropolitan cities all over the world coupled with the emission of sub-Micronics particles both from vehicular traffics and industrial stacks in the vicinity of township has caused an exponential rise in particulate matters PM_{10} and $PM_{2.5}$. These have serious health hazards not only for the present population, but it poses a big threat for the coming generation to a greater extent for the entire nation as a whole.

The growth of urbanization horizontally as well as vertically is slowly taking up water bodies and greeneries. This has become one of the major sources of the rise in temperature and change in annual weather pattern as observed in this decade. This resulted in increased use of air conditioning machines which are now an essential household item in offices, establishments, market places and even in education institutions. This contributes global warming and is directly proportional to urbanization and temperature rise and vice versa.

As a developing nation the above growth is inevitable and it is need of hour to find measures to reduce urban heat island effect (UHI) and optimize land use and land control (LULC) for better city life. To achieve that end a detail study on UHI with respect to LULC is required. The quality of air which is a most important parameter needs to be assessed and how this value is correlated with UHI and LULC is to be examined.

3.3 Aim of the Study

To assess the extent of the urban heat island effect with respect to urban Land Use and Land Cover (LULC) change and ambient air quality changes.

3.4 Objectives of the study

The objective of the present study is to contribute towards understanding the Urban Heat Island (UHI) which is an important criterion of global climatic change and also urban development context. The focus is to identify the intensity of Urban Heat Island effect with respect to urban Land Use Land Cover (LULC) change and ambient Air Quality changes of the results i.e. expressed in the form of design guidelines or modifications. This assessment is of the interrelationship and correlation among UHI, LULC and Air Quality pattern. In this work the following aspects are investigated:

- To study the Urban Heat Island (UHI) effect with respect to different LULC changes;
- To study the correlation between Urban Heat Island (UHI) effect and Ambient Air Quality, with a special emphasis on respirable and fine Particulate Matter(PM_{10} and $PM_{2.5}$);
- To investigate the interrelationship and correlation among UHI, LULC and Ambient Air Quality for Kolkata;
- To make and recommend strategies for mitigating UHI and amelioration of the Ambient Air Quality for various LULC classifications.

3.5 Research Questions

- Whether LULC change has any effect on Urban Heat Islands (UHIs) of the city?
- Whether LULC change has any effect on Ambient Air Quality scenario?
- Whether the increase of Air Quality has any role is the UHI change in the city?
- Whether there is any relationship between LULC, Ambient Air Quality and UHI of an area or place?

3.6 Probable Research hypothesis

- In Kolkata, there is a strong correlation between urban Land Use Land Cover (LULC) change and Urban Heat Island (UHI) intensity, and UHI effects are greatly influenced by LULC changes.
- Urban Heat Island (UHI) intensity varies significantly among various land use categories (such as built-up regions, green spaces, and water bodies) in Kolkata, with certain land uses having greater UHI effects than others.
- In Kolkata, there is a strong correlation between the Urban Heat Island (UHI) intensity and the Air Quality Index (AQI), and a higher UHI intensity is linked to worsening Air Quality.

3.7 Scopes of the Study

- To study the LULC change in Kolkata for last two to three decades.
- To understand the impact of LULC change on Ambient Air Quality for the city of Kolkata for last two decades.
- To observe the impact of LULC change and Air Quality change on Air Temperature and Urban Heat Island effect in Kolkata.
- To analyze and highlight the interrelationship among LULC, Ambient Air Quality and UHI.
- To recommend strategies for mitigating the Urban Heat Island effects in Kolkata with respect to LULC change and Ambient Air Quality

3.8 Research Methodology

In other words, any techniques that the researcher employs when analysing his research topic are referred to as research methodologies. The available data and the unknowable parts of the problem must be related to one another in order to make an amalgamation conceivable because finding a solution for a given issue is the aim of research, particularly applied research. With this in mind, the three categories of research methodology are as follows:

1. The methods that are uneasy about data collecting are included in the first group. These techniques will be applied when the data presently at hand are insufficient to reach the necessary conclusion.
2. The statistical methods used to show correlations between the data and the variables make up the second group.
3. The third group consists of techniques used to gauge the accuracy of outcomes obtained.

The last two kinds of research methodologies mentioned above are typically considered to be the analytical instruments of research. Utilizing research technique, the research problem may be tackled carefully. It may be thought of as a science that investigates how precisely research is carried out. Examine the various techniques, a researcher normally uses to analyse his research problem, as well as the reasoning behind them. The researcher must be familiar with both the methodology and the research methods/techniques. In addition to knowing how to create specific tests or indices, calculate mean, mode, median, standard deviation, or chi-square, and use specific research techniques, researchers also need to understand which of these strategies are relevant and which ones are not, as well as what they would mean, indicate, and justify. Researchers also require being aware of the presumptions underlying certain procedures and the standards by which they can determine whether methods and approaches are appropriate for which challenges. All of this means that the researcher must create his approach specifically for his topic because methodologies might vary from problem to problem.

The following sections make up the technique used in this study -

- **Pre-Field:** The West Bengal Pollution Control Board (WPCB), the Indian Meteorological Department (IMD), and meteorological reports from Netaji Subhash Chandra Bose International Airport were used to collect information, maps, and secondary data regarding the status of ambient air quality throughout this phase. Various government and non-government sources were used for the other data. A structured work flow was created through analysis and assistance from various literature reviews, books, and journals. Examples include decadal changes in land use and land cover, analyses of land surface temperatures, research into the urban heat island effect, and reviews of various biophysical indices (NDWI, NDVI, NDBI etc.)
- **Field:** After the literature evaluation and pre-field activities are finished, choose a study area that is highly inhabited with more than 44 lacs of people (according to the census, 2011), making it challenging to carry out the main survey. To address this issue, stratified sampling using the sensors was carried out at random. In order to collect temperature data for this field study, the study uses a temperature logger, a Raspberry Pi equipped with a temperature sensor circuit, SDS011 NOVA PM Sensors, and Python software. Raspberry Pi is used to collect data by connecting sensors at various locations, which then read in real-time or on a regular basis. The city has also been divided into five quadrants, and varied LULC areas from each quadrant, including those in the north, south, east, and west of Kolkata, have been taken into consideration. To more precisely describe the scenario, pertinent photos that were taken during the field survey are now available.

- **Post Field:** In order to analyze the data and information obtained in order to comprehend the current status of changing patterns of Land Use, Land Cover, Land Surface Temperature, as well as the scenario of Urban Heat Islands and changes in Air Quality, this stage entails the computation of a master data table by the statistical application, cartographic representation, and the preparation of maps using QGIS, 21stCenturyGIS, ArcGIS software and MS-Excel. This study also measured the amount of traffic and the health risk posed by vehicle emissions in a sensitive area of Kolkata. Maps have been made more beautiful using Adobe Photoshop. Additionally, a comparison of NDVI, NDBI and NDWI with regard to various Land Use and Land Cover Change for the years 2010, 2015, and 2020 is included. Finally, some ideas for actions and techniques to reduce vehicular emissions in Kolkata are offered.

3.9 Data processing, analysis and presentation

A. The average data excel sheet and data chart underwent comprehensive raw data processing. Through the use of an appropriate tabulation approach, all the large amounts of data were condensed into homogeneous groups to obtain meaningful relationships.
B. With the aid of various appropriate statistical, cartographic, GIS, and remote sensing techniques, all the gathered data were organised in the same kind of brief, logical and compact form for further computation and analysis.
C. Different spatial patterns of the various parameters have been examined using choropleth mapping and 21stCenturyGIS software. Using statistical analysis, both main and secondary data have been represented using bar graphs, pie graphs, flow diagrams and linear regression analysis.

Indicator	Correlations and map building
LULC	High urban development is represented by changing patterns.
UHI	A high figure denotes the highest temperature.
LST	High values symbolize the highest surface temperature.
NDVI	A high value denotes a high level of vegetation cover.
NDBI	High values represent the highest building density.
NDWI	Maximum water bodies are indicated with a high value.
Air Quality	Spatial variation based on the AQ index.
Air Quality	Dispersion map of AQ (PM_{10} and $PM_{2.5}$)

D. The selection of developmental measures and the statistical analysis of those indicators form the basis for the discussion of the spatial pattern of the district's level of development.

E. Finally, a map demonstrating the relationship between air temperature, land use patterns and air quality has been created using the ArcGIS and 21stCenturyGIS software (PM_{10} and $PM_{2.5}$).

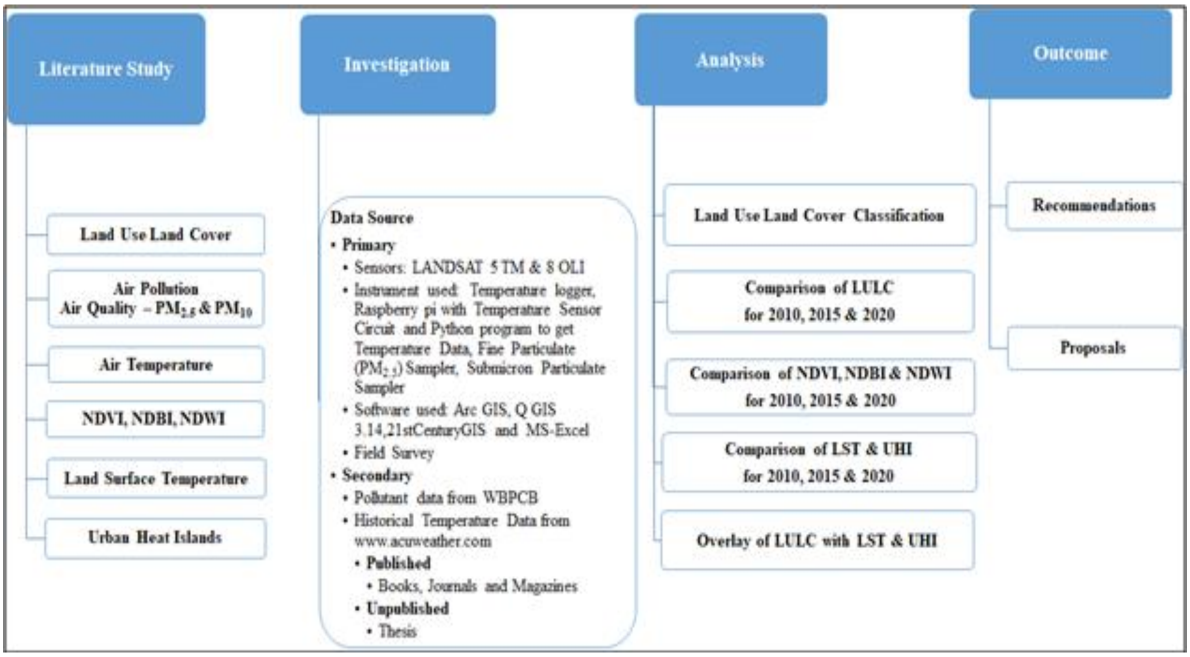


Figure 3.9.1: Methodological Work Flow of this Study

3.10 Data Collection

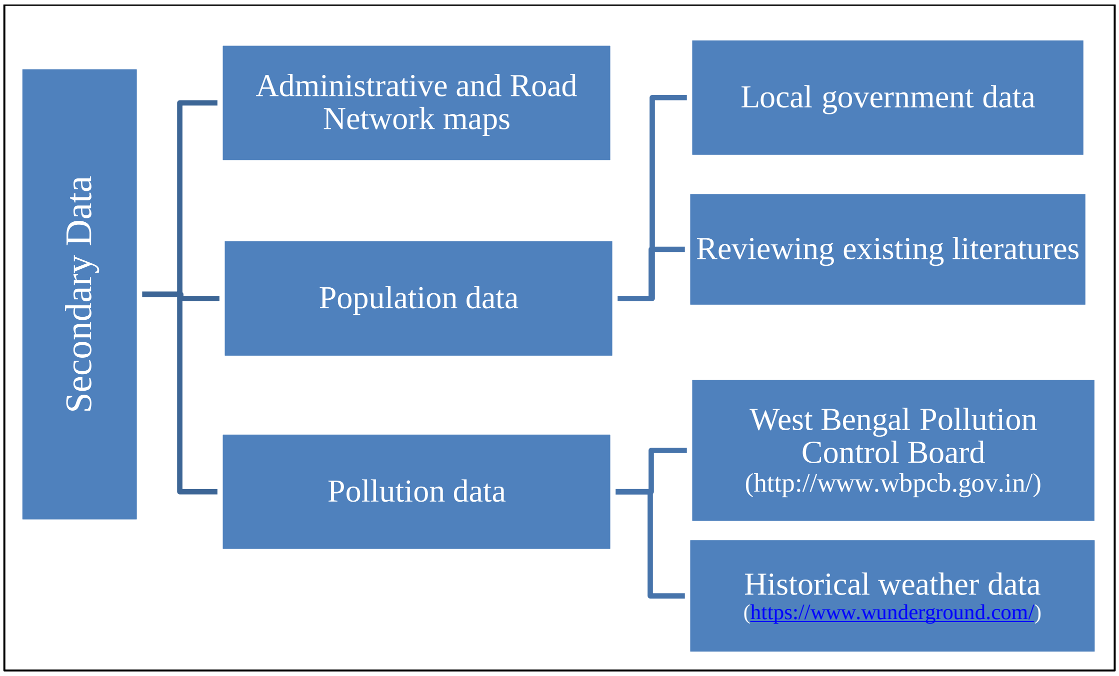


Figure 3.10.1: A source of Secondary Data

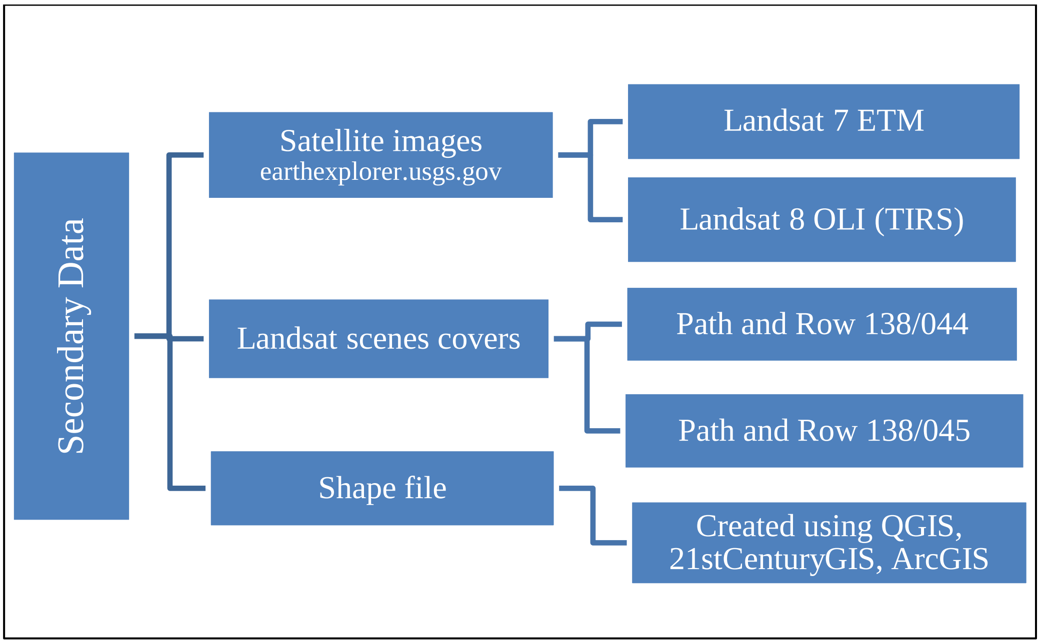


Figure 3.10.2: Another Source of Secondary Data

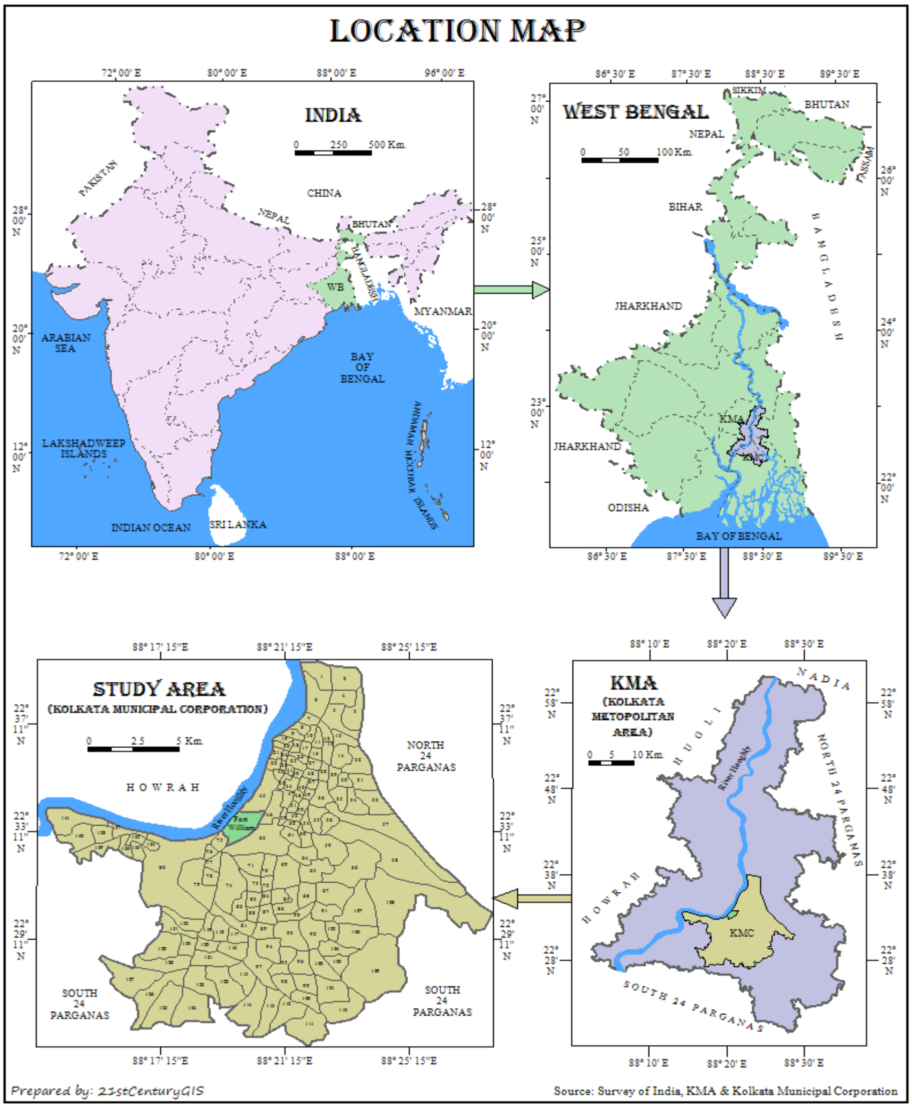


Figure 3.10.3: Study Area **Source: Prepared by the Author**

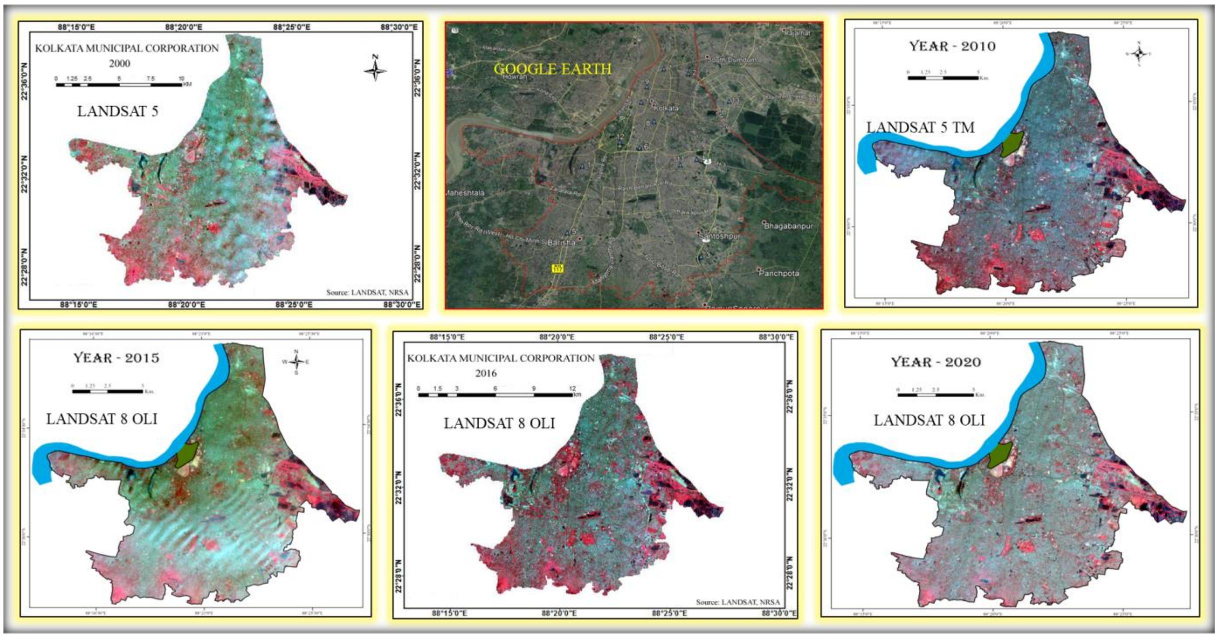


Figure 3.10.4: Satellite imagery of different year, used in this study

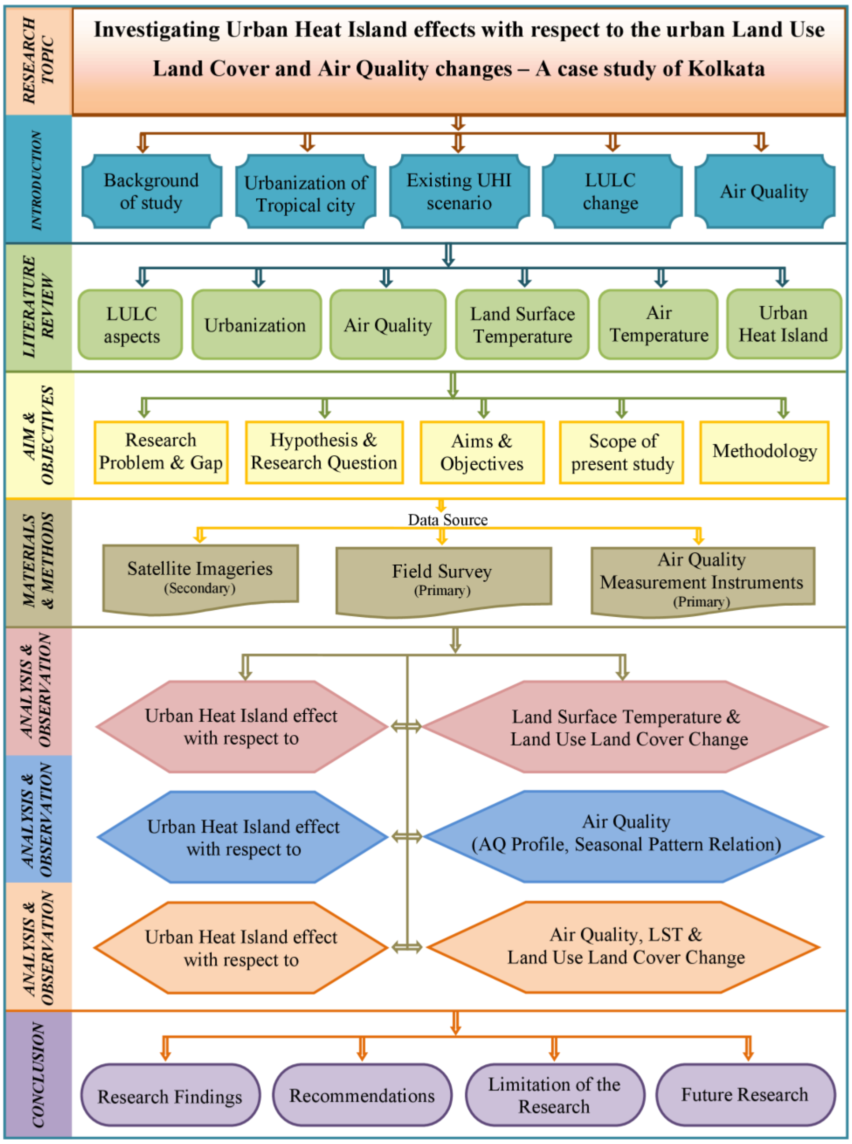


Figure 3.10.5: Research Work Flow **Source: Author**

3.11 Conclusion

Based on the aim and objectives of the present study, the research questions were framed, the hypotheses were drawn and the relevant methodology was applied. The key themes of this thesis dictate the flow of the work and the approach that has been taken. The results and conclusion drafted also focus on addressing the objectives of this research.

Chapter 4: Materials and Methods

This part of the work has been published in -

1. *Sohini Sen, Debashish Das, Anupam Deb Sarkar, Raja Ghosh, "Investigating Real-Time Ambient Air Quality Status and Land Surface Temperature during Kalipuja / Diwali Festival in different Land use types – Case study Kolkata", International Journal of Advances in Mechanical and Civil Engineering (IJAMCE), Volume-7, Issue-1, pp. 21-27), ISSN (P): 2394- 2817, International Journal of Advances in Mechanical and Civil Engineering (IJAMCE) December 2019. Peer Reviewed Journal.*
2. *Sohini Sen, Ashwini Kumar Singh, Debashish Das, Anupam Deb Sarkar, Raja Ghosh "A Study of the Spatio-temporal Variations in PM_{10} and $PM_{2.5}$ with Air Temperature, Traffic Volume and Different Land Use Types during the Diwali Festival Period: A case study of Kolkata, India", ISSN: 0046- 9017 (Print), ISSN : 2456 – 6519 The Indian Journal of Spatial Science, 2021.*

4.1 Introduction

Explaining the difference between research methodologies and research methodology seems appropriate at this point. Any techniques or systems used to guide research can be referred to as research methodologies. Thus, research procedures or methods refer to the approaches used by researchers.

There are times when differences are drawn between research methodologies and research procedures. Research techniques are the procedures and tools employed for successfully completing research operations, such as collecting data, putting thought into it, and other similar activities. Research techniques relate to the actions and tools used to choose and put together a research technique.

According to the aforementioned description, this new study demonstrates that low-cost laser scattering based sensors generate results that are almost as accurate as those from earlier sensor generations (Sohini Sen, Debashish Das, Anupam Deb Sarkar *et al*., 2019). In this case study, the data collected using the standard devices is not feasible as data collected in remote locations with no power backup is required for the study. This research conducted a comparison study of ambient air quality monitoring with low-cost, widely used SDS011PM Sensor at various locations across Kolkata Metropolitan area and monitoring of particulate matter with high volume sampler (APM 460 BL) and Sampling of fine particles (Gravimetric Method) standardised by USEPA. In this research demonstrates that the outputs are consistent among devices and line up with the basic information provided by the West Bengal Pollution Control Board.

The terms "fine" and "coarse" refer to the two main atmospheric particle distributions with overlap in the 1 to 3 diameter range in the original definitions of the terminology. Currently, coarse particles are referred to as PM_{10} (particulates with a diameter of 10μm), while tiny particles are known as $PM_{2.5}$ (particulates with a diameter of 2.5μm). The vast majority of man-made particles have a diameter between 0.1μm and 10μm. Particulates larger than 10 μm is typically made up of silica-rich sand and dirt that is carried by winds from various locations.

Due to the chemical complexity of airborne particles, it is necessary to take into account the composition and origins of several primary and secondary components (USEPA, 1996). Many different sources directly emit primary particles into the atmosphere. Chemical reactions lead to the formation of secondary particles in the atmosphere. Sulphate, strong acids, ammonium, nitrate, organic chemicals, trace metals, elemental carbon, and water are the main constituents of $PM_{2.5}$ particles. The main precursors of fine secondary particulate matter are sulphide dioxide, nitrogen oxides and a few organic molecules.

Due to their size and operating conditions, standard Air Quality measurement equipment like high volume samplers (APM 460 BL) and sampling of fine particles (gravimetric method) have always been difficult to use. This is especially true when monitoring locations where power for these systems is scarce or nonexistent, and carrying that equipment in remote locations is difficult (Sen, S., Das, D. *et al*.) which is actually in this case. The locations used in this study has problem of providing powers to the standard devices like high volume samplers (APM 460 BL). This study suggests the usage of a Raspberry Pi 3 board that is completely programmable, affordable, and open-source free to utilize internally as a data transfer gateway for the sensors. The three primary components of the proposed architecture are a Raspberry Pi sensor data aggregator, a web application for real-time data visualization utilizing the PubNub web service method. The sensors utilized here are the DHT22 sensor for collecting data on temperature and humidity and the SDS011 sensor for collecting data on particulate matters ($PM_{2.5}$ and PM_{10}) (Sohini Sen, Debashish Das, Anupam Deb Sarkar, 2019). Monitoring the levels of $PM_{2.5}$ and PM_{10} have done due to the driving forces behind this study. The dispersion of PM_{10} over Kolkata, the capital of India's West Bengal state have been incorporated for the period of different years, namely 2018 to 2021, the monitoring (sample collection) and data analysis were done following the standard methodology advised by the Environmental Protection Agency (EPA), USA. EPA-developed AERMOD model were used (EPA2005; Cimorelli *et al*., 2005; Kesarkar *et al*., 2007) to look into the dispersion of pollutants over Kolkata City.

Compared to the current gadgets, the suggested architecture offers a more affordable and user-friendly environment. The sensors coupled with a Raspberry Pi 3 gather information and transmit it in real time via portable Wi-Fi devices like a cell phone to a centralized web server. The architecture included a feature that allowed data to be stored on the Raspberry Pi device in the event that the Wi-Fi network was unavailable for data transfer to the web server. The observer data was collected using this architecture and data collected using common devices like the APM 460 BLetc.

4.2 Air Quality Measurement Instruments

Current thinking places Particulate Matter (PM) among the most dangerous air contaminants. Although manmade activities are also to blame for the production of PM, natural sources (such as aerosols of sea spray, volcanic ash or desert dust) are also a possibility. The primary sources of that contamination can be categorised as being in transportation, agriculture, industrial operations and domestic fuel combustion. The harmful consequences of particles on health are now widely known. The main physiological impacts of PM exposure are on the cardiovascular and respiratory systems. Furthermore, particles were recognised as human carcinogens by the International Agency for Research on Cancer (IARC).The ability to increase the temporal and spatial accuracy of Particulate Matter data is provided by low-cost sensors. However, before taking any monitoring action, such sensors should indeed be calibrated in settings similar to the final ones.

Giechaskiel *et al.* claim that dispersion photometers, which gauge the strength of scattered light from one or more angles, are among the tools used to study light scattering by a group of particles. A photometer detector is used in a scattering photometer to measure the scattering light. Hinds explained that the optical detecting volume has a combination of all the particles that make up the light-scattering photometers, which measure the scattered light from all of them. The majority of commercial light scattering devices, according to the authors, use visible light (600 nm or less) and measure angles of 90°, 45° or less than 30°. Vincent referred to one of the scattering photometers as the Respirable Aerosol Monitor (RAM).

4.2.1 Fine Particulate Sampler

In the cement and chemical industries, fine particle samplers are utilized. Specifications: Particle Size: Impactor-separated PM_{10} from omni directional air inflow $PM_{2.5}$ separations through a WINS Impactor come next (R.L. Pfeiffer).

Plate 4.2.1.1: Fine Particulate ($PM_{2.5}$) Sampler

4.2.2 Submicron Particulate Sampler

Equipment that separates out the size fraction of concern is used to gather particles. According to https://www.intechopen.com, the most frequently used equipment for monitoring particulate matter either measure its concentration or size distribution. The equipment that uses a gravimetric (weighing) method produces the most precise readings. Particles gather in the filter when air is drawn through a pre-weighed filter. For the development of drug delivery systems, biological research, environmental analysis, and particulate matter quality control, quick and accurate size measurement of single submicron particles (100-1000 nm) is crucial (http://pubs.acs.org). The choice is challenging because there are numerous types of equipment available for monitoring particulate particles, according to Nussbaumer *et al.* According to Obaidullah *et al.*, Particulate Matter can also range in size from nanometers to micrometers, which adds to the difficulty of selecting the right equipment.

Plate 4.2.2.1: Submicron Particulate Sampler

4.2.3 Dust-Track™ Ii Aerosol Monitor:

The Dust Track™ II Aerosol Monitor offers gravimetric sampling and real-time aerosol mass readings for usage in process monitoring, remote monitoring, interior air quality, outdoor environmental monitoring, and emissions. Battery-powered, data-logging, light-scattering laser photometers called Dust Track™ II Aerosol Monitors provide you with instantaneous aerosol mass readings. In order to maintain the optics clean for increased dependability and less maintenance, they use a sheath air system that separates the aerosol in the optics chamber. The Dust Track™ II offers an appropriate solution for severe industrial environments, construction and environmental sites, various outside applications, as well as cleans office settings, in desktop, desktop with external pump, and handheld models. Dust, smoke, fumes and mists are among the aerosol pollutants that the Dust Track™ II monitors measure (website: www.tsi.com). Using a variety of inlet conditioners, measure the aerosol concentrations for the PM_1, $PM_{2.5}$, Respirable and PM_{10} size fractions graphical user interface with a colour touch screen that is simple to use. At each location, measuring of CO_2, size-segregated particulate matter (PM_1, $PM_{2.5}$, and PM_{10}) and meteorological done. The study also utilised a motion-activated camera to record video of each train to help us identify them. (Jaffe, D.A., Hof, G., Malashanka, S. *et al.*)

Plate 4.2.2.2: Dust-Track™ Ii Aerosol Monitor

Plate 4.2.2.3: Hioki LR8514 wireless Humidity and Temperature logger

Hioki LR8514 wireless Humidity and Temperature logger

Exceptional-speed data recorders called Hioki Memory Hi Loggers can record many channels of voltage, temperature, resistance, or humidity information. Some models offer total channel isolation and have high noise immunity. The Hioki LR8514 Wireless Humidity Logger (updated edition 2018, WIRELESS VOLTAGE/TEMP LOGGER. HIOKI LR8512B980-07) makes it simple to wirelessly collect temperature and humidity data and is the perfect instrument for regulating the environmental condition of production plants and agricultural areas.

4.3 Air Quality Measurement Instruments Description

The following are a few brief discussions of the key elements employed in the proposed:

*The Raspberry Pi3 Model B*is an excellent platform for creating automation systems. It is obvious that the Raspberry Pi3 Model B board is ideal for use as an automation system "hub," linking to other open-source hardware components like sensors. The Raspberry Pi3 Model B is a small single-board computer that can perform all the tasks typically performed by a desktop computer, including word processing, spreadsheets, internet browsing, programming, games and more. Model B Raspberry Pi, the Raspberry Pi3 Model B from the latest generation is quicker and more powerful than its predecessors because it is powered by the most recent Broadcom 2837 ARMv8 64bit CPU. It transforms into the ideal IOT-ready solution with built-in Wi-Fi and Bluetooth connectivity. It has a 1.2 GHz quad-core Broadcom BCM 2837 64bitARMv 8 processor, built-in Bluetooth Low Energy (BLE), Wi-Fi, HDMI, RCA, 40-pin extended GPIO, 1 GB RAM, and 4 USB 2 ports are all included.

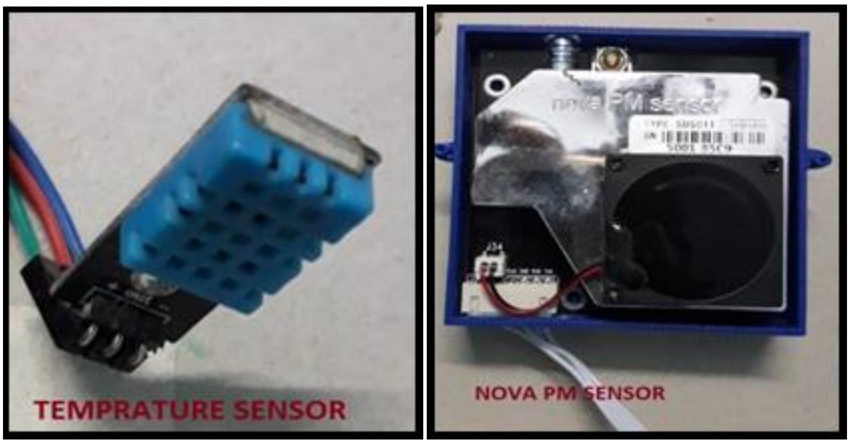


Plate 4.3.1: The monitoring sensor of temperature and particulate matter

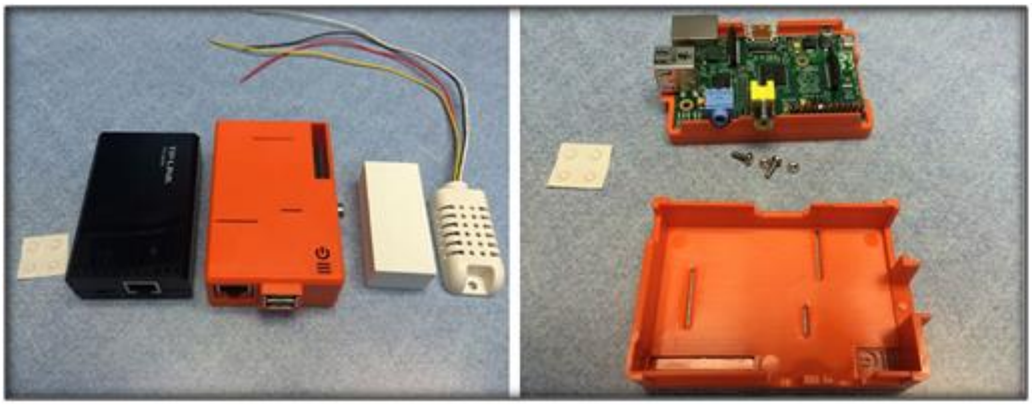


Plate 4.3.2: Casing of instrument

Operating systems based on the Linux kernel power the Raspberry Pi3 Model B. It uses the SD card to boot and operate. Other than the ROM, it has no internal memory. It includes an SD card port that can read cards with up to 32 GB of storage. The Python programming language is used to program the Raspberry Pi3 Model B's GPIO pins. When necessary, GPIO pins are assigned I/O devices like sensors.

GPIO: The row of GPIO (general purpose input/output) pins down the board's edge is a potent feature of the Raspberry Pi3 Model B.

GPIO pins: The programmed can be written on the pins to interact with the real environment in fascinating ways. A sensor or a signal from another computer or device can also serve as an input instead of a physical switch. The output, for instance, could convey a signal or data to another device or activate an LED. The Raspberry Pi 3B can send data back and forth and be controlled from anywhere if it is connected to a network. The Raspberry Pi3 model B is perfect for this. Connectivity and control of physical things through the internet is a powerful and fascinating thing.

4.4 Measurement Site, Instrument Description

Measurements were carried out at the Environmental and Ambient Air Quality and air temperature observation of Department of Architecture and Environmental Engineering of University of Jadavpur (The location is presented in field visit area in the supportive Material). The observatory is situated of different land use land cover (like dense built-up, water bodies, vegetation cover, open area, commercial area), and high and low traffic intersection zones. Individual home heating systems are the largest source of particulate matter emissions, city road transport, construction, road side chulha. The Observatory is equipped with PM_{10} and $PM_{2.5}$ measuring instrumentsSDS011 sensors were chosen mainly because of their low price (≤20$) and small size.

Plate 4.4.1: Working principle of NOVA Sensor

Although in a portable form, the SDS011 sensor from Nova Fitness also proved its value for particle assessments.

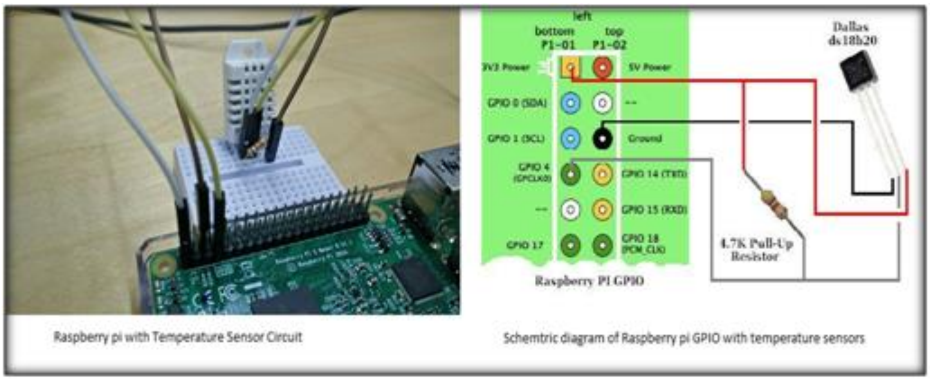


Plate 4.4.2: Raspberry Pi with Temperature Sensor Circuit

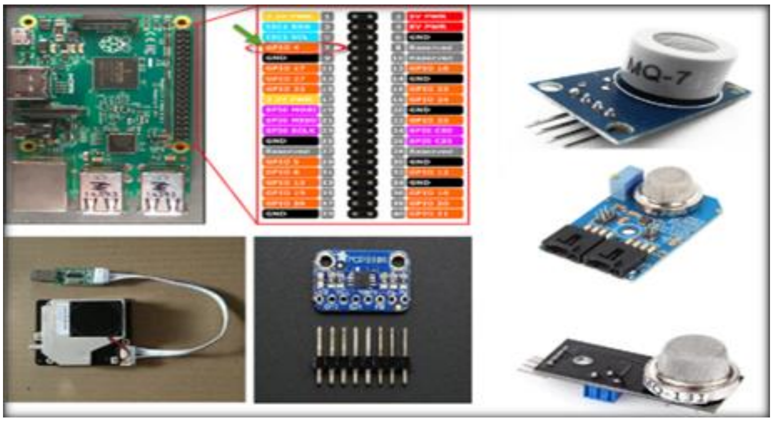


Plate 4.4.3: Different devices of Raspberry Pi

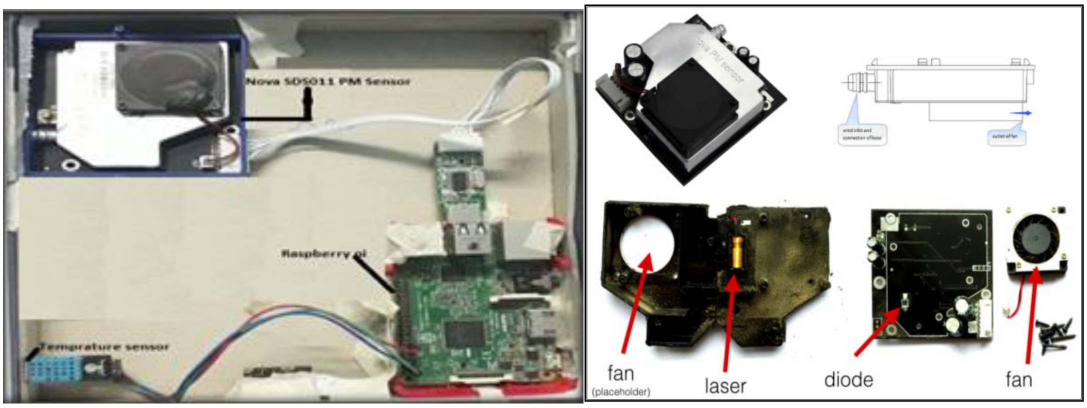


Plate 4.4.4: Complete set up of deviceCertification: Sensor has passed CE/FCC/RoHS certification

Source: http://www.inovafitness.com/index.html

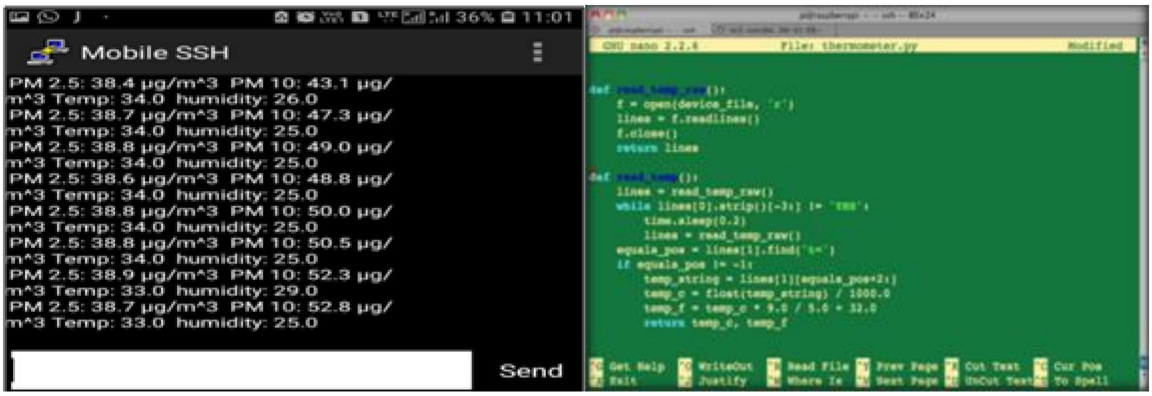


Plate 4.4.5: Nodejs – Java script library for server side&Nodejs Server – Nodejs Library / MySQL Database

Certification: Sensor have passed CE/FCC/RoHS certification

Source: http://www.inovafitness.com/index.html

4.5 Field Survey

Plate 4.5.1: Physical Survey (Road side or Traffic Zone, Open Space and roof top Vegetative Cover) for Air Temperature and Air Pollutant (PM_{10} and $PM_{2.5}$)

Plate 4.5.2: ABP Ananda Live show of Real Time Air Quality Monitoring of different Dense Built up and High Traffic area in Diwali period, Kolkata, 2018

Plate 4.5.3: Vegetation Cover

Plate 4.5.4: Open Space

Plate 4.5.5: Water bodies (East Kolkata Wetland)

Plate 4.5.6: High traffic congested area

Plate 4.5.7: Slum area

Plate 4.5.8: Traffic congested area

Plate 4.5.9: Road side chulha (coal oven)

Plate 4.5.10: Dense built up area

Plate 4.5.11: Area under construction

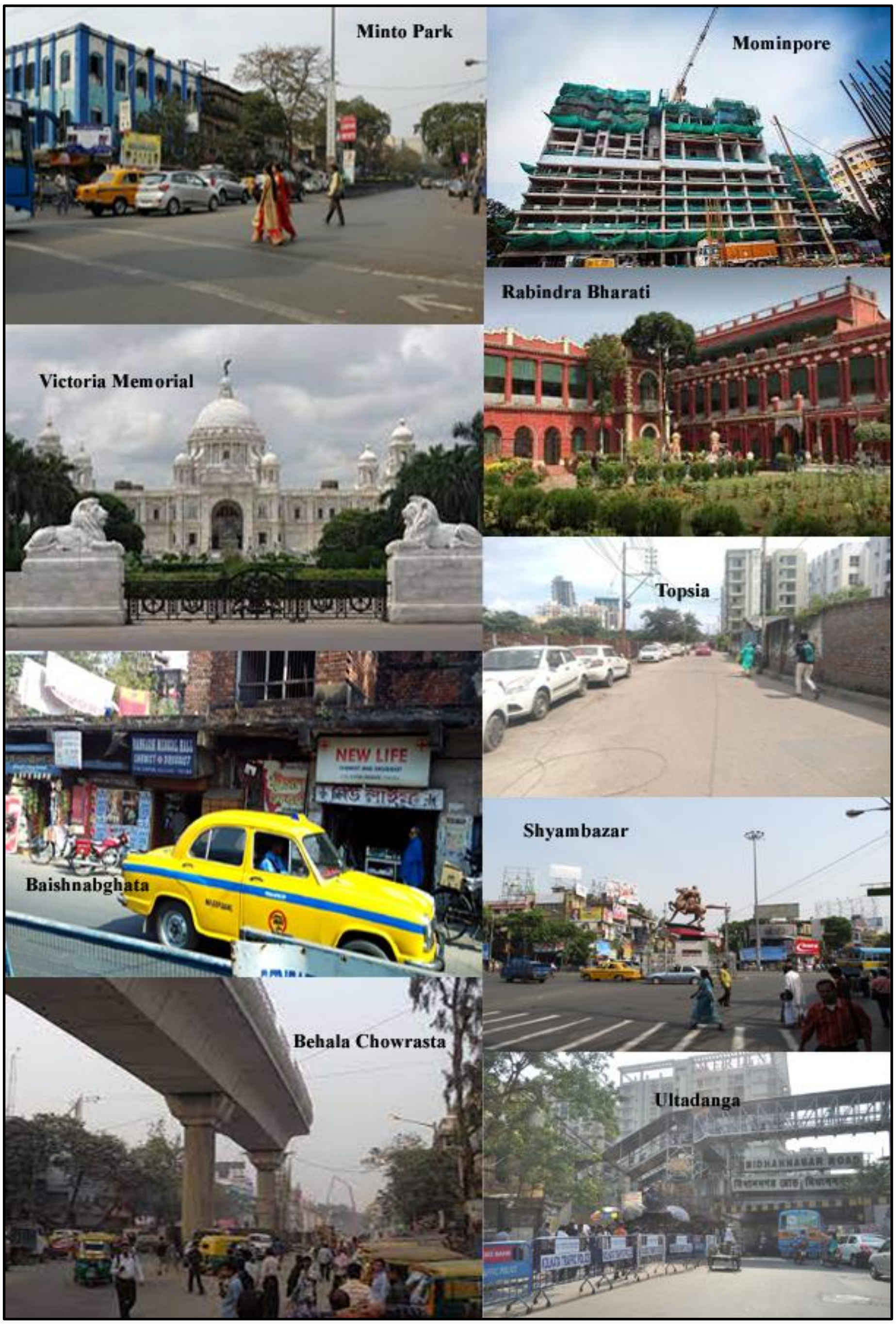


Plate 4.5.12: Pollution Monitoring Stations of different Land use

Though Kolkata is an unplanned city, there are some areas having planned dwellings, constructed according to the rules of Kolkata Municipal Corporation, leaving spaces in all sides and recognised as 'Built up' area. But the dwellings, mainly in the North Kolkata and some portion South Kolkata like Behala Chowrasta areas constructed without any sanctioned building plan from the concerned department, violating the rules of Kolkata Municipal Corporation like not having space between dwellings, recognised as 'Dense Built up'. Baishnabghata (Patuli) is one of the areas under KMC, which has been formed a township with high rise buildings, park and play grounds, water bodies, roads with footpaths etc. properly to maintain the ecosystem and known as 'Mid rise Built up'.

Table 4.5.1: Pollution and Air Temperature Monitoring Stations of different Land Use

Sl. No.	Monitoring Station (Surveyed area 500 sq. m. and up to 12 m. height from the surface)	Purpose of Station
1	Minto Park	Built up & High Traffic
2	Victoria Memorial	Open Space & Traffic
3	Baishnabghata	Mid rise Built up & High Traffic
4	Behala Chowrasta	Dense Built up & High Traffic
5	Mominnpore	Built up & Traffic
6	Rabindra Bharati	Vegetative Cover & High Traffic
7	Topsia	Built up & Traffic
8	Shyambazar	Dense Built up & High Traffic
9	Ultadanga	Dense Built up & High Traffic

The monitoring stations of different land use and traffic categories mentioned in Table 4.5.1 have been taken into account to find out the air pollutions aspect within the study area. It seems that the land use type 'Dense Built up' and 'High Traffic' zones contribute more air pollutant in the environment which confirm the outcome of the study.

The acquired data's validity has been examined using information from the WBPCB and US consulate. The method used comparing the data gathered by the sensors with information from the US Consulate, the Indian Meteorological Department (IMD), and WBPCB at the same time or location, at various times of the day, and throughout the year throughout various seasons. The sensor data and data from the gadget now used in Jadavpur University were also examined, and validated that the relationship is linear (Figure: 4.6.1, 4.6.2 & 4.6.3) .In order to monitor the accuracy of the analysis, this approach was continued for the entirety of this study.

4.6 Validation of NOVA Sensor

The data from the Nova PM sensor and the PM data from the US consulate are linearly correlated, with R^2 that is nearly 1.The association between the Nova PM Sensor and devices like particulate samplers and suspended particulate samplers of Civil Engineering Department of Jadavpur likewise exhibits a similar pattern and R^2 value.

The data validation is only to validate the functioning and correctness of this study. The existing devices have some limitation like portability and operate without power. But our devices remove that gaps or limitation by running it of low power source and easy to carry at the station of choice.

Table 4.6.1: $PM_{2.5}$ and PM_{10} data for Rainy and Winter Season at 8B Bus Stop, Jadavpur

Source	$PM_{2.5}$		PM_{10}	
	Rainy	Winter	Rainy	Winter
JADAVPUR UNIVERSITY	59.39	153.57	59.33	206.37
AUTHOR	61.77	151.23	61.79	198.45

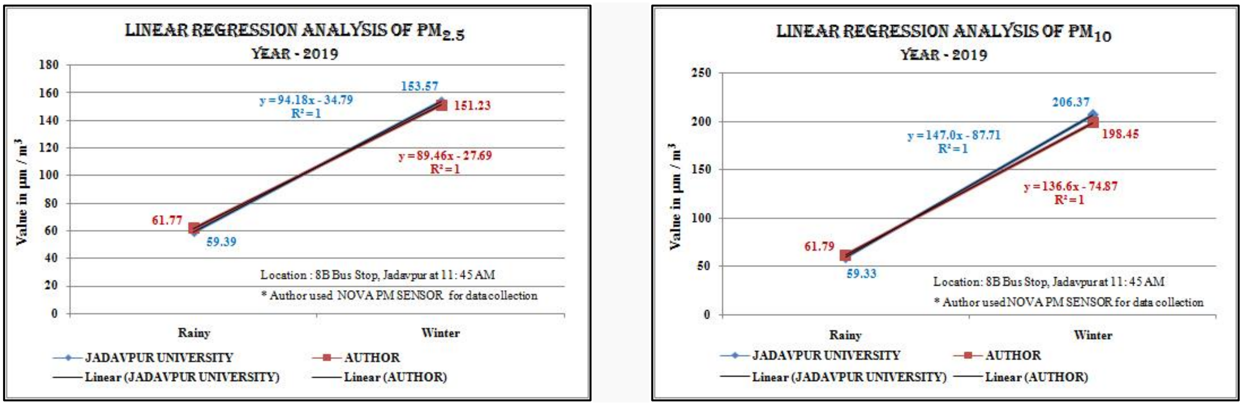


Figure 4.6.1: Linear Regression Analysis of $PM_{2.5}$ and PM_{10}forRainyand Winter Season ,based on the data collected from Submicron Particulate Sampler, Fine Particulate ($PM_{2.5}$) Sampler of Jadavpur University and PM NOVA Sensor used by the Author(Source: Primary Survey)

Table 4.6.2: $PM_{2.5}$ and PM_{10} data for Rainy and Winter Season at US Consulate Center

Source	$PM_{2.5}$		PM_{10}	
	Rainy	Winter	Rainy	Winter
US CONSULATE CENTER	44.56	118	85.91	134
AUTHOR	51.43	121.35	89.64	141.33

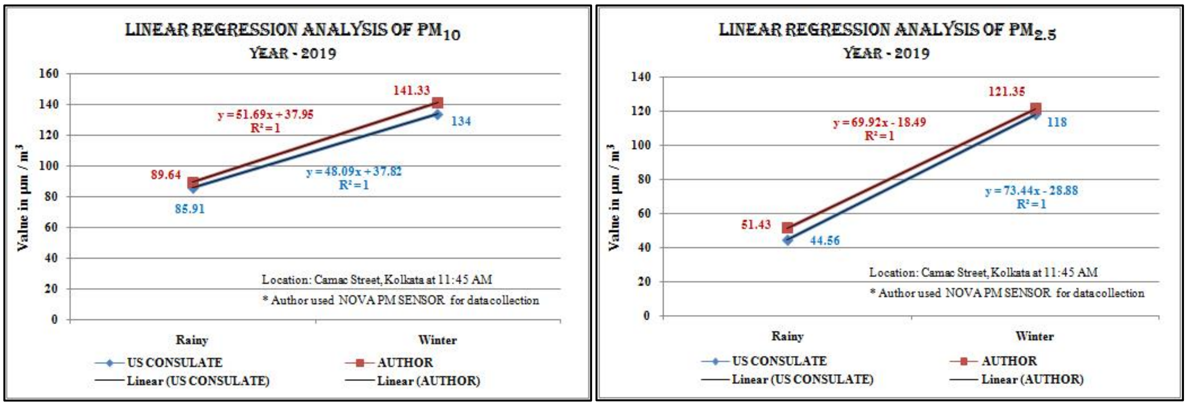


Figure 4.6.2: Linear Regression Analysis of PM_{10} and $PM_{2.5}$for Rainy and Winter Season, based on the data of US Consulate center at Kolkata and PM NOVA Sensor used by the Author

(Source: Primary Survey)

Despite the fact that the results from the West Bengal Pollution Control Board(WBPCB) and Nova PM are not similar and R2 values are nearly 0.143 and 0.298 in rainy season and 0.00 to 0.002 in winter season, there are a few variances that can be explained as follows.

1. The nature of particulate matter depends on the altitude, concentration decreases as height increases and here the height of detection sensor station of WBPCB is higher than the Nova PM sensor used by the Author at monitoring stations.

2. Nova PM sensors are easy to use and maintain, whereas WBPCB sensors are not, which might result in corrupted data, collected over a longer period of time.

3. Lack of sufficient knowledge of the sensor's mode of operation and the measurement methods employed by WBPCB monitoring sites.

Table 4.6.3: $PM_{2.5}$ data for Rainy Season collected from the different stations of West Bengal Pollution Control Board and PM NOVA Sensor used by the Author

LOCATION	$PM_{2.5}$ (RAINY SEASON)	
	WBPCB	AUTHOR
8B BUS STOP, JADAVPUR	16.11	18.91
BEHALA CHOWRASTA	17.94	21.39
HYDE ROAD	59.23	38.21
MOMINPUR	29.33	31.83
SHYAMBAZAR	22.94	26.96
TOLLYGUNGE	64.39	66.81
TOPSIA	29.32	30.29

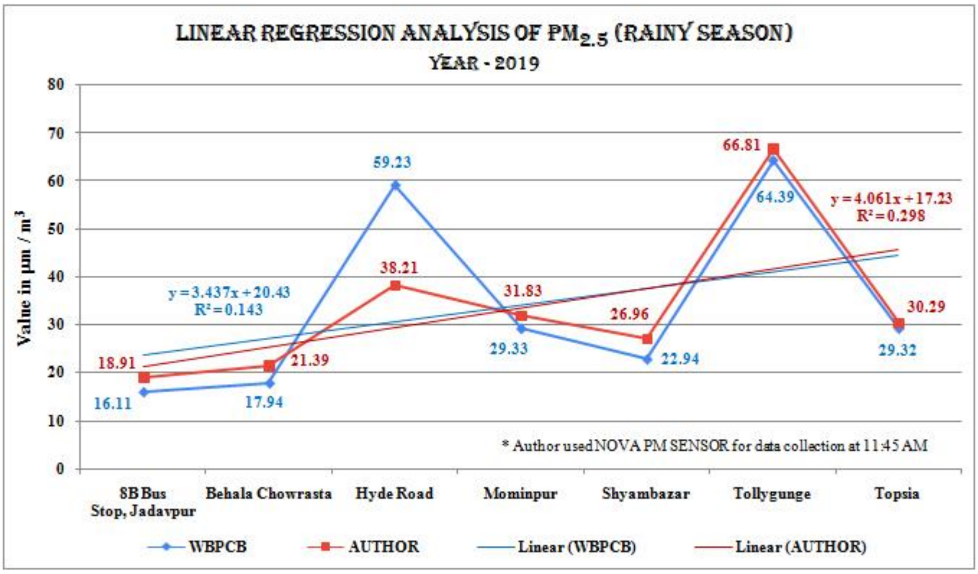


Figure 4.6.3: Linear Regression Analysis of $PM_{2.5}$ for Rainy Season, data collected from the different stations of West Bengal Pollution Control Board and PM NOVA Sensor used by the Author (Source: Primary Survey)

Table 4.6.4: $PM_{2.5}$ data for Winter Season collected from the different stations of West Bengal Pollution Control Board and PM NOVA Sensor used by the Author

LOCATION	$PM_{2.5}$ (WINTER SEASON)	
	WBPCB	AUTHOR
8B BUS STOP, JADAVPUR	125	121.34
BEHALA CHOWRASTA	52.77	91.44
HYDE ROAD	89.54	119.31
MOMINPUR	42.62	56.23
SHYAMBAZAR	33.21	48.63
TOLLYGUNGE	38.11	41.33
TOPSIA	159.38	189.33

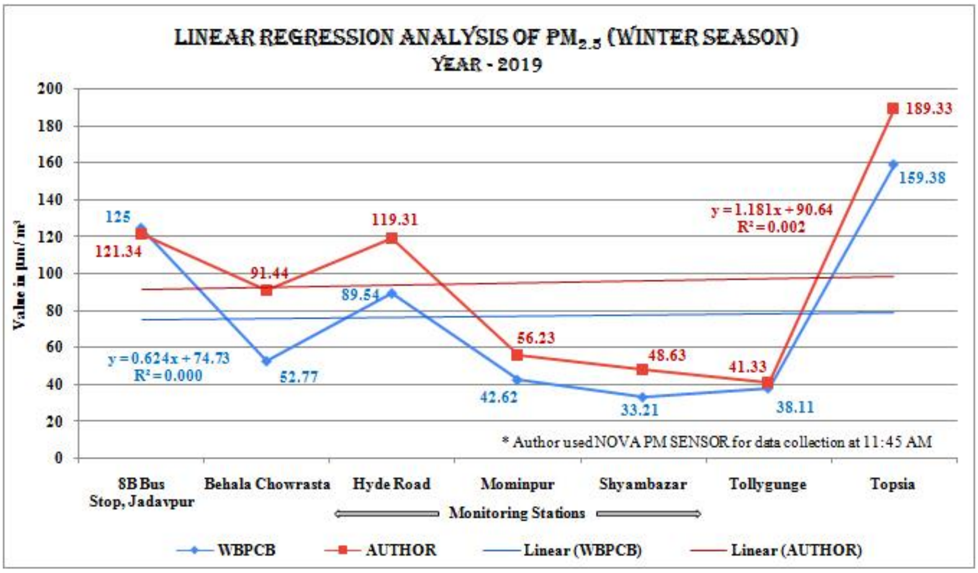


Figure 4.6.4: Linear Regression Analysis of $PM_{2.5}$ for Winter Season, data collected from the different stations of West Bengal Pollution Control Board and PM NOVA Sensor used by the Author (Source: Primary Survey)

Table 4.6.5: PM_{10} data for Rainy Season collected from the different stations of West Bengal Pollution Control Board and PM NOVA Sensor used by the Author

LOCATION	PM_{10} (RAINY SEASON)	
	WBPCB	AUTHOR
8B BUS STOP, JADAVPUR	38.66	40.39
BEHALA CHOWRASTA	42.75	48.69
HYDE ROAD	73.96	79.34
MOMINPUR	40.31	46.46
SHYAMBAZAR	61.10	53.13
TOLLYGUNGE	86.38	88.96
TOPSIA	45.56	47.87

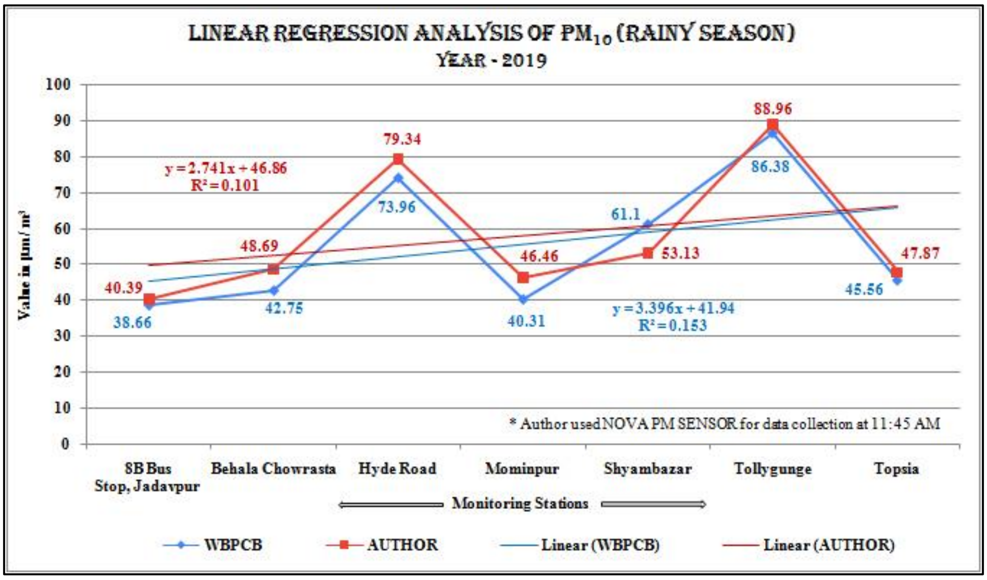


Figure 4.6.5: Linear Regression Analysis of $PM_{10}$for Rainy Season, data collected from the different stations of West Bengal Pollution Control Board and PM NOVA Sensor used by the Author (Source: Primary Survey)

Table 4.6.6: PM_{10} data for Winter Season collected from the different stations of West Bengal Pollution Control Board and PM NOVA Sensor used by the Author

LOCATION	PM_{10} (WINTER SEASON)	
	WBPCB	AUTHOR
8B BUS STOP, JADAVPUR	141	139.61
BEHALA CHOWRASTA	111.53	131.52
HYDE ROAD	142.31	168.74
MOMINPUR	65.22	72.38
SHYAMBAZAR	82.38	91.45
TOLLYGUNGE	59.61	65.32
TOPSIA	276.67	269.83

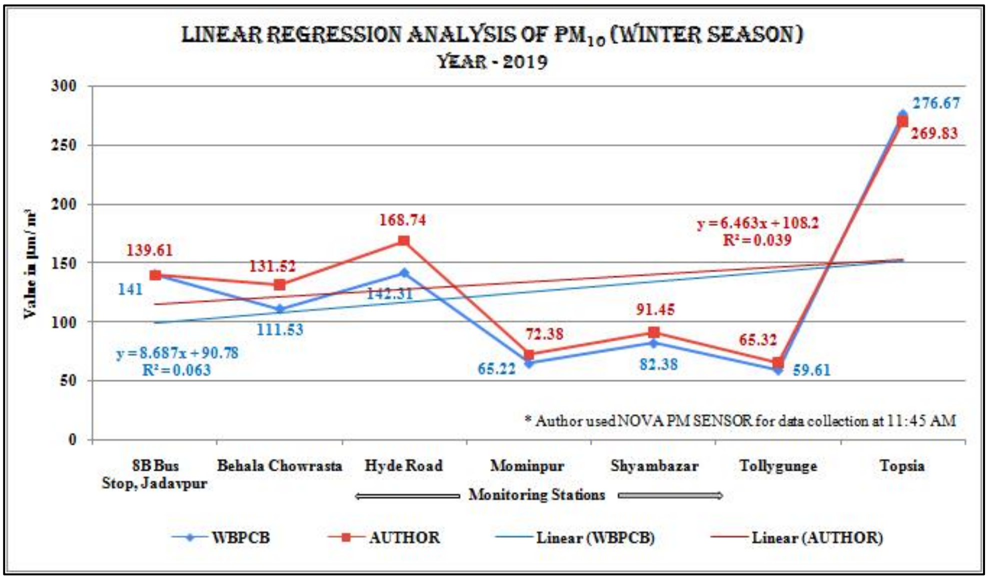


Figure 4.6.6: Linear Regression Analysis of PM_{10} for Winter Season, data collected from the different stations of West Bengal Pollution Control Board and PM NOVA Sensor used by the Author (Source: Primary Survey)

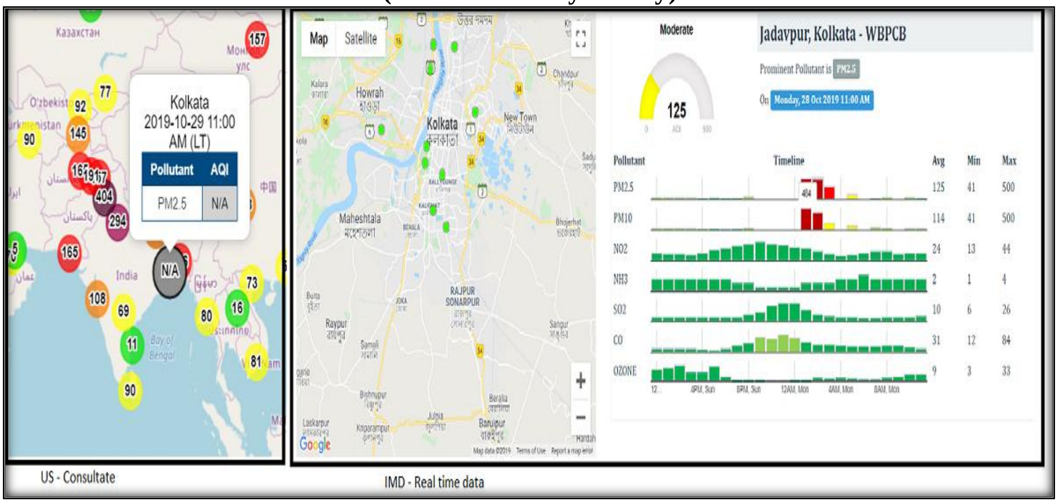


Figure 4.6.7: Sources of data

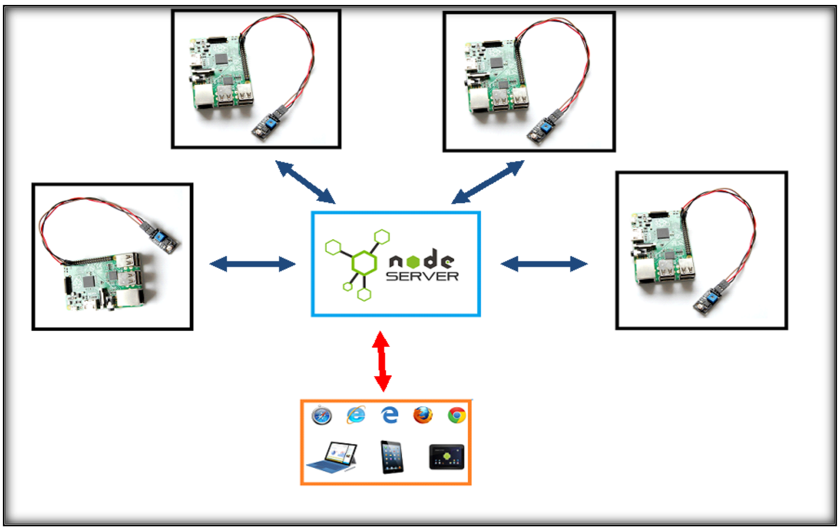


Plate 4.6.1: Node Server

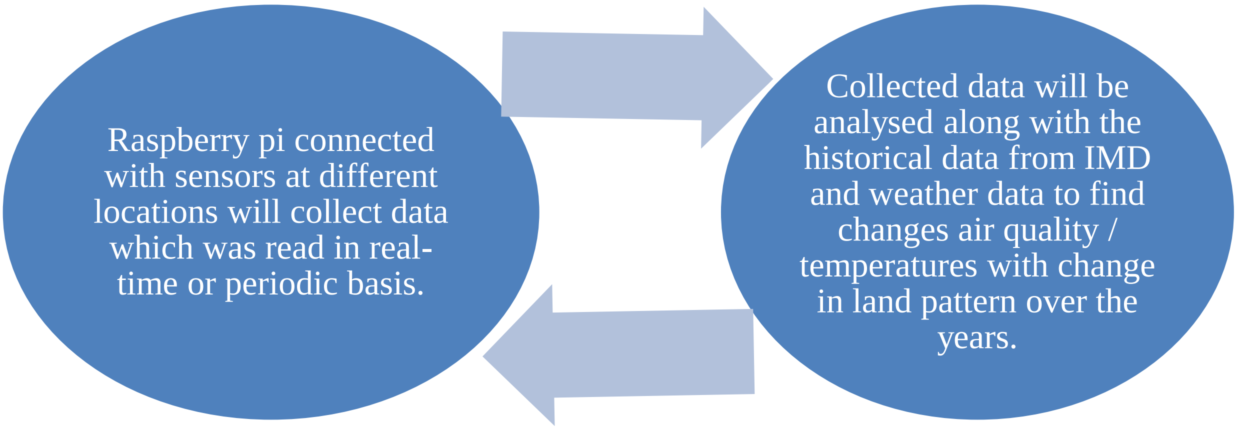


Figure 4.6.8: Processing of data from Raspberry Pi along with the IMD data

4.7 Conclusion

From the overview of multivariate approaches provided above, it is clear that these methods are crucial since they allow for the inclusion of all the data from an investigation in a single study. There are numerous low-cost PM sensor versions on the market now. The Submicron Particulate Sampler and PM sensors were compared, and the results showed that the trend of $PM_{2.5}$ and PM_{10} changed with temperature and atmospheric air. It's crucial to keep in mind that the raw outputs from commercially available devices may greatly overestimate the $PM_{2.5}$ concentrations. (The present study's findings indicated that a factor of 2.5 - 5 might be discernible). It might be because to calibrate the sensors the manufacturer of the sensors uses particles with completely different properties from the particulate matter in the air being studied. For this reason, PM sensors should be calibrated (or recalibrated) in the actual setting of the readings. The results from the associated higher-class instrument are used as the basis for the most popular calibration technique.

Overall, the research showed that inexpensive PM optical sensors may be useful equipment for monitoring air temperature and ambient quality. The findings of this study can aid in the selection of suitable circumstances for sensor operations and calibration by measuring system authors and users of inexpensive PM sensors.

Chapter 5: Analysis and Observation on Urban Heat Island effect with respect to Land Surface Temperature and Land Use Land Cover change

This part of the work has been published in -

1. *Sohini Sen, Debashish Das, Raja Ghosh(June 2019), "Investigating PM_{10} level with respect to the Urban Land use and its effect in Urban Heat Island", Indian Journal of Regional Science. Vol-L1, No-1,pp.27-39,ISSN: 0046- 9017(Print), ISSN : 2456 – 6519 (Online) Indian Journal of Regional Science, June 2019.*

2. *Sohini Sen, Debashish Das, Pankaj Chakraborty, Raja Ghosh, "Assessment of LULC changes and it's impact on Surface Temperature and Urban Heat Island conditions in Kolkata during SARS COVID 19 period".*

5.1 Introduction

Due to the rising urbanization of cities around the world, significant changes in urban climate can be observed. To ensure sustainable urban development, it is crucial to strike a balance between urban growth and the quality of the eco-thermal environment. Urban planning, mitigation, and management, as well as urban geography, are just a few of the domains where research on the Urban Heat Island (UHI) is of utmost importance. The current study focuses on estimating the Land Surface Temperature (LST) of the Kolkata metropolitan area in India, emphasizing the relationship between indexes for Normalized Difference Built-Up (NDBI), Normalized Difference Water (NDWI), and Normalized Difference Vegetation (NDVI),and non-UHI and Urban Heat Island (UHI) areas inside the city boundary images from three separate years taken by the Landsat 8 Operational Land Imager and Thermal Infrared Sensor were used throughout the entire investigation. The northern, western, and central regions of the city are where the UHI has primarily been constructed. Green spaces, which have lower temperatures, are being replaced by land uses, such as central business districts (CBD), commercial areas, dense dwelling areas, and traffic intersections, which have greater thermal contents. Because of the increased heat in metropolitan areas, more energy is needed to cool buildings, which worsens the Air Quality and has detrimental health effects. For instance, increased temperatures lead to increased ozone (O_3) and Particulate Matter (PM) pollution production (Lo and Quattrochi, 2003; Cardelino and Chameides, 2000).

Infilling development mode and built-up area show a positive relationship with the LST and UHI parameter, according to estimated linear regression analysis (both spatial and non-spatial). On the other hand, edge growth and the corresponding areas covered by urbanized green and non-green open spaces are adversely connected with LST and UHI parameters. Urbanization inevitably has an impact on the environment, as seen by increased Land Surface Temperatures (LST), UHIs, and Air Pollution. According to numerous studies, complicated regional elements as well as urban and street geometry also affect the Air Temperature in urban canyons (Bärring, Mattsson, and Lindqvist 1985).According to LST research, the conversion of surface soil, water content, and vegetation can affect the balance of land surface energy (Li and Zhou, 2011).

Urbanization is a dynamic process that contributes significantly to human-caused climate change. Urban heat island (UHI) is a phenomenon that results from a variety of natural and artificial elements interacting (Memon *et al*., 2008a, b; Unger *et al*., 2001) (Hafner and Kidder, 1999, Poreh, 1995).Urban Heat Islands not only raise the temperature above that of the surrounding areas' averages, but they may also worsen the environment by reducing rainfall, which in turn raises pollution and airborne suspended solid particle matter levels. During the 100 years that ended in 2005, the earth's surface temperature rose by 0.18ºC to 0.74ºC.According to forecasts from climate models included in the most recent assessment from the International Panel on Climate Change (IPCC), the average global surface temperature would probably shoot up by another 1.1ºC to 6.4° C throughout the 21st century. Because of the increased heat in metropolitan areas, more energy must be used to cool buildings, which worsens the air quality and has detrimental health effects. For instance, greater temperatures cause more ozone (O_3) pollution to be produced (Lo and Quattrochi, 2003; Cardelino and Chameides, 2000). The UHI signal indicates a wide range of significant land surface changes that have an impact on ecosystem function, local weather, and possibly climate as well as human health, Imhoff, Zhang, Wolfe, Bounoua, *et al*., 2010.Conditions favoring the rise in temperatures over the urban areas relative to nearby rural areas include a decreased sky-view factor, the replacement of soil cover with concrete or asphalt surfaces, and the emission of a significant amount of waste heat from transportation, commercial, residential, and industrial sectors. (P. Pandey *et al.*, Science of the Total Environment 414 (2012), 494-507).

Many major cities in S/SEA have Air Quality problems, which are largely caused by the region's fast industrialization, urbanization, and rise in energy demand (Foell *et al*., 1995, Ohara and Murano 2001, Gurjar *et al*., 2016).The South/Southeast Asia Research Initiative (SARI), supported by the NASA LCLUC programmed, investigated these Land Cover Land Use Changes (LCLUC) issues and related air pollution (www.lcluc.umd.edu).

There is growing interest in the mapping of urban thermal conditions and their relationship to Land Use and Land Cover (LULC) and air pollution.

Land Use and Land Cover Change (LUCC) study using remote sensing has a long history and has advanced. (Singh, 1989; Jensen, 1996; Coppin *et al*., 2004; Lu *et al*., 2004; Liu *et al*., 2008; Dewan and Yamaguchi, 2009a, 2009b; Dewan *et al*., 2012; Wei *et al*., 2015). Understanding the interactions between human activities and the environment requires the use of LUCC (Dewan *et al*., 2012). Despite being hindered urban environment's complexity in both space and spectral terms, remote sensing (Jensen and Cowen 1999; Her old *et al*., 2004) appears to be a suitable source of urban data for these researches (Donnay *et al*., 2001). Based on this concept, the primary goal of this research is to comprehend the relationship between urban land use classification and the Urban Heat Island pattern of the city of Kolkata, where the numerous significant environmental issues have regularly arisen as a result of the fast growth of metropolitan centers and their peripheries., and to identify the impact of Land Use Land Cover Changes over Air Pollution and the Urban Heat Island Effect in different years (i.e., 1996 and 2016) using a variety of different methods.

5.2 Study Area

The current study area is the Kolkata, the capital of West Bengal and India's third-most populous metropolis. It is situated in the country's east along the Hooghly River's banks. Area-wise, the Kolkata Municipal Corporation covers 186.35 km^2. The 1,886.67 km^2 (728.45 sq mi) Kolkata metropolitan 39 local municipalities and 3 municipal corporations, as well as the Kolkata Municipal Corporation, make up the region. The city is near sea level and its average elevation being 17 feet. It has been chosen as the research region because it is a contemporary metropolis with a lengthy history and a combination of various land uses and land covers that are prone to atmospheric turbulence.

Location of Kolkata: Latitude and Longitude of Kolkata is 22.5667° N, 88.3667° E

5.3 Location Map of Kolkata Municipal Corporation

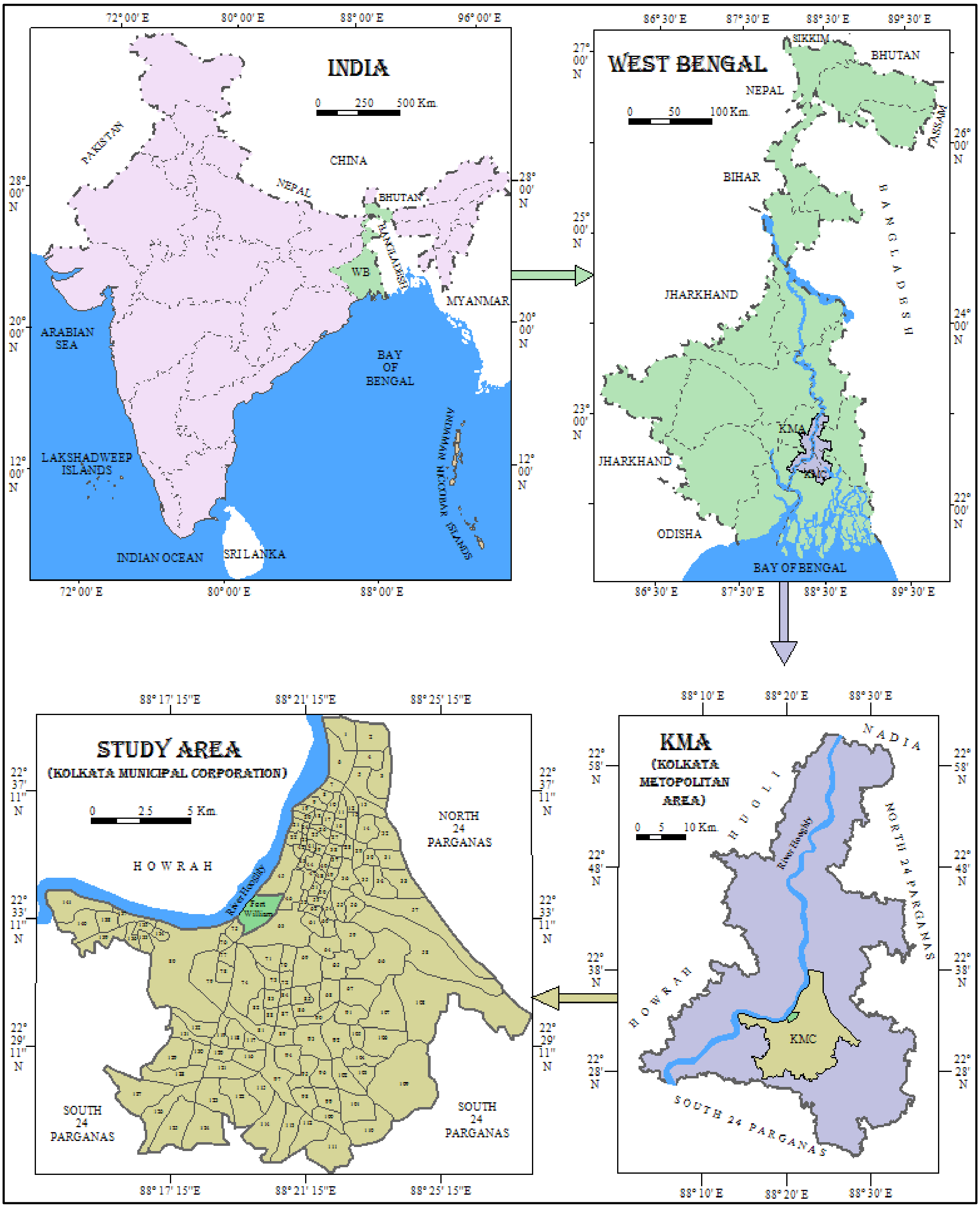


Figure 5.3.1: Location map of Study Area

5.4 Meteorological Status in Kolkata

- The climates in Kolkata are tropical, moist, and dry (Koppen climatic classification Aw).
- The yearly mean temperature is 24.8°C (80°F), while the monthly mean temperature ranges from 15°C to 30°C (59°F to 86°F).

- During dry periods, the maximum temperatures frequently approach 40°C (104°F) in May and June. Summers are hot and humid with low 30°C temperatures.
- Winter typically lasts only two and a half months; with seasonal lows between December and January ranging from 9°C to 11°C (48.2°F to 51.8°F).Humidity is around 96% in the mornings and 67% in the afternoons.
- Annual rainfall of 1,582 millimeter (62.3inches).

5.5 Data Collection

Data collected for this study can be classified into primary and secondary data. The secondary data include satellite images which were downloaded from Earth Explorer website (earthexplorer.usgs.gov).The images used for both analyses include LANDSAT 5TM and 8 OLI (November 2000 and February 2016).The research area is covered by two Landsat sceneries (row and path 138/044 and 138/045). Shape files for the study area have been digitized. Administrative and road network maps of the studied area, population statistics, including those from the local government, and a review of prior literature comprise the secondary data employed in this study (Census of Kolkata 2000 and 2016).

In this study the information about pollution gathered from various West Bengal Pollution Control Board weather stations and their website (http://www.wbpcb.gov.in/).The prominent weather underground website (https://www.wunderground.com/) has provided the historical weather data.

The second phase of the data collection process was in the years of 2010,2015 and 2020 respectively, secondary data used in this study shown below. Imageries of early January for the years 2011, 2016 and 2021 have been considered to get the details of all perspectives throughout the years 2010, 2015 and 2020 respectively.

Table 5.5.1: Remote Sensing data used in the study

Sensors	Date Acquired	Path/Row	Bands	Resolutions (meters)	Datum/ UTM Zone	Source
Landsat 5 TM	02-01-2011	138/44	4, 3, 2 & 6	30	WGS84/45	USGS
Landsat 8 OLI (TIRS)	06-01-2016	138/44	5,4,3&10	30	WGS84/45	USGS
Landsat 8 OLI (TIRS)	03-01-2021	138/44	5,4,3&10	30	WGS84/45	USGS

5.6 Methodology and outcome

The main resource for studying environmental dynamics at the local or global scale is data from remote sensing. These statistics are used to determine the detection of change during the last few decades. For the visualization, categorization, and analysis of a region, remote sensing data (such as Landsat data, Sentinel data, Spot images, etc.) are particularly helpful. Based on their resolution, electromagnetic spectrum, energy source, imaging medium, and number of bands, these data can be grouped. Greater degree of accuracy will be attained during categorization the greater the resolution of satellite data (spatial resolution, spectral resolution, radiometric resolution, and temporal resolution).

Landsat data are typically utilized for categorization. Based on its wavelength, Landsat data are divided into numerous bands (blue band, green band, red band, infrared band, thermal band, panchromatic). Data resolution is increased by using a panchromatic band. Landsat 5 TM (Thematic Mapper) data having 7 bands while Landsat 8 Operational Land Image (OLI) and data from a Thermal Infrared Sensor (TIRS) has eleven bands. Only four bands (Green, Red, NIR and SWIR)are engaged for the study of the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Built-Up Index (NDBI) and The Normalized Difference Water Index (NDWI).

As the case study area is Kolkata Municipal Corporation, the investigation of Urban Heat Island (UHI) and its effects with respect to the Land Use Land Cover (LULC)has been initiated by physical verification for collecting the field data in different locations for the year 2020. GIS & Remote Sensing technologies have also been applied for LULC map and to identify the UHI with its effect within the case study area for the year 2000, 2016 and 2020.

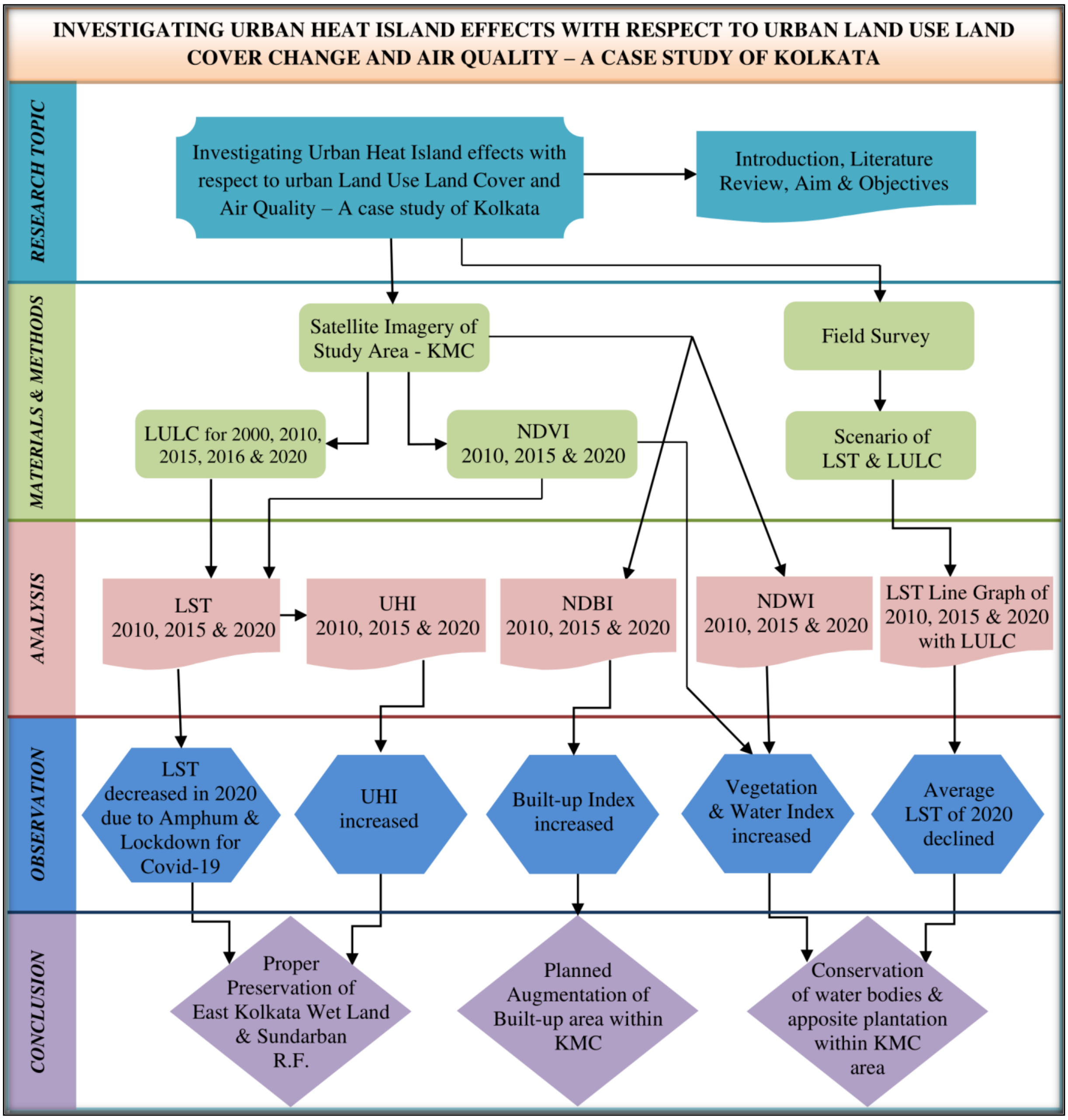


Figure 5.6.1: Flowchart of Methodology

5.7 Result and Discussion

5.7.1 Analysis of Land use Land Cover

Using data from Landsat 5 TM and 8, patterns of Land Use and Land Cover were plotted for the years 2000 and 2015. Based on topographic maps those were scaled to 1:50,000, each Landsat picture was corrected to the UTM WGS 84 coordinate system. Bands 4, 3, 2 for Landsat 5 TM and 5, 4, 3 for Landsat 8 OLI were determined to be the most successful at differentiating each class and were chosen for classification. These pictures were resampled using the nearest neighbors' technique with a pixel size of 30m for all bands.

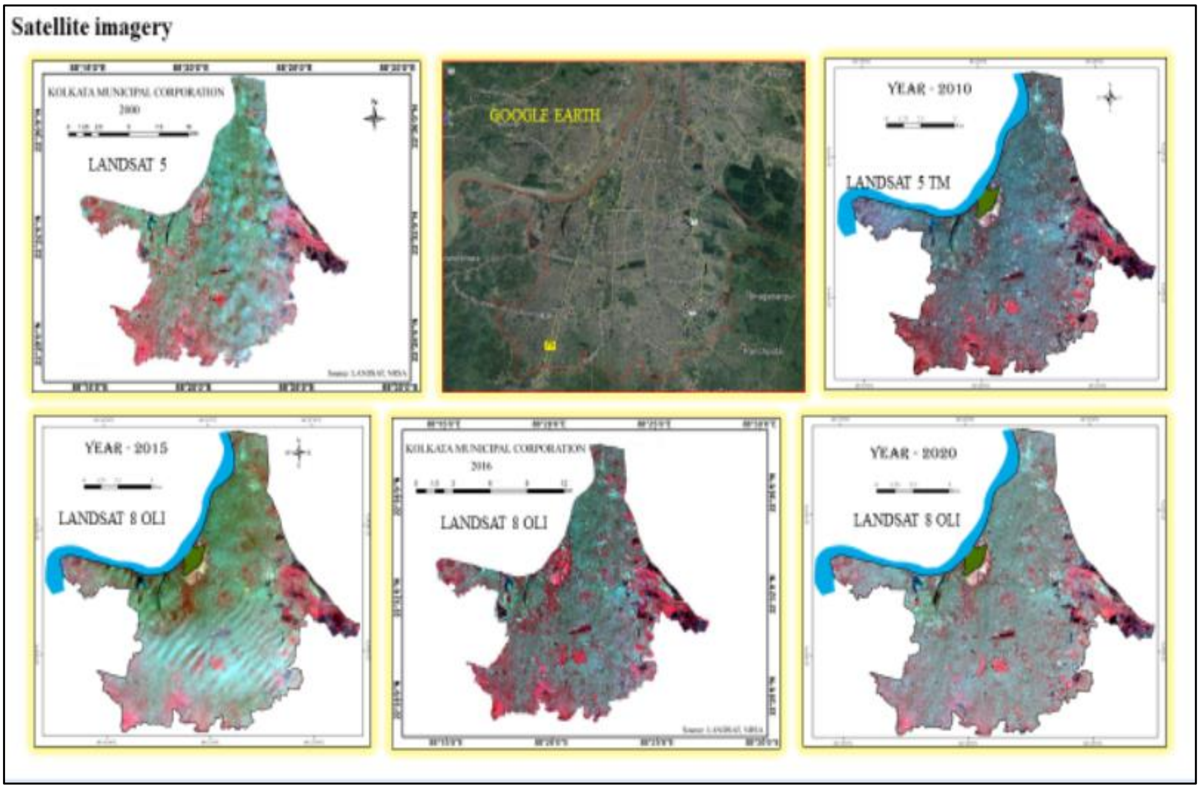


Figure 5.7.1.1: Satellite imageries of KMC for the year 2000,2010, 2015,2016 and 2020

5.7.2 Changes of Land Use Land Cover pattern (2000&2016)

According to Remote Sensing and GIS data, the area of built-up has increased by more than twice as much between 2000 and 2016. Urban and built-up areas were 63.13% in 2000 and 65.84% in 2016 respectively (figure 5.7.2.1).During this 16 years period, urban land use increased by around 2%.The water bodies decreased from 5.45% (2000) to 3.75% by 2016.The vegetation cover decreased from30.7% in 2000 to 29.73% by 2016 and also the open space decreased from 0.72% in 2000 to 0.68% by the year 2016.These changes as shown in table 5.7.2.1imply that the various land use land cover type witnessed as an increase of built up area at the exchange of water body and open space by 2016.This rapid increase of built up area and depletion of vegetation cover result in the reduction of natural cooling effects of shading and evapotranspiration of plants. This in turn encourages the expansions of Urban Heat Islands in Kolkata and its environment.

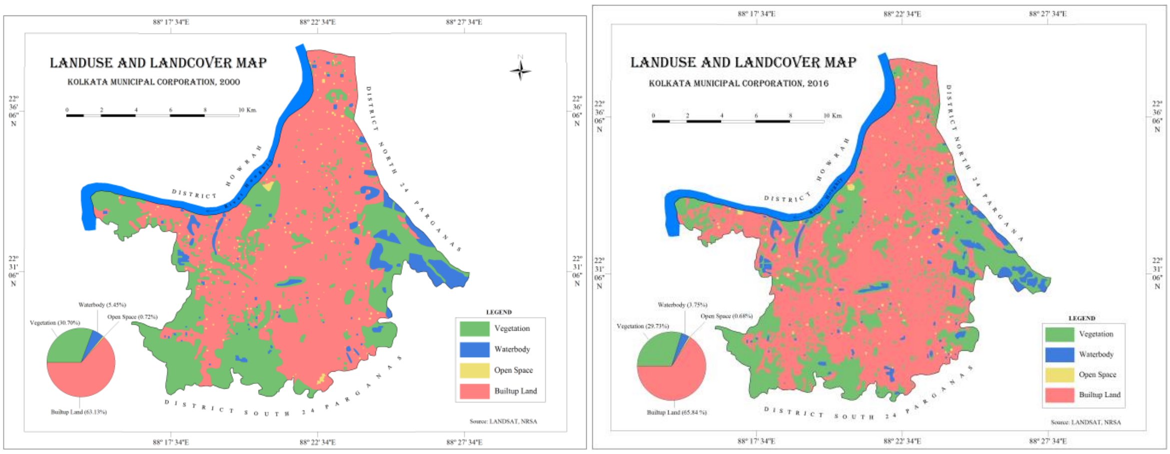


Figure5.7.2.1: Land use land cover maps of KMC for the year 2000 and 2016

Table 5.7.2.1: The LULC distribution for Kolkata Municipal Corporation from 2000 to 2016

Land Use Land Cover (LULC)	2000 (area in %)	2016 (area in %)
Vegetation	30.7	29.73
Water bodies	5.45	3.75
Open Space	0.72	0.68
Built-up Area	63.13	65.84

Source: Landsat 5 TM for 2000 and Landsat 8 OLI for 2016

5.7.3 Classified Land Use Land Cover from Satellite Imageries for 2010, 2015 & 2020

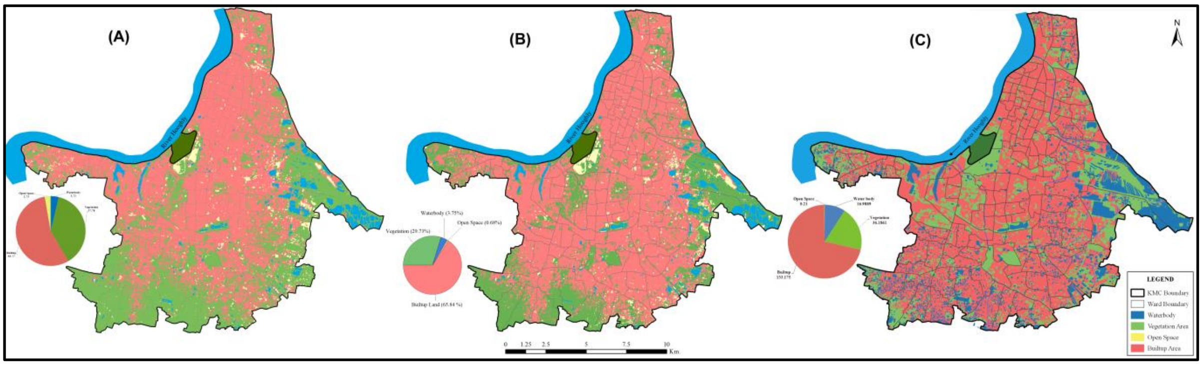


Figure 5.7.3.1: Land Use Land Cover maps of KMC for the year 2010 (A), 2015 (B) and 2020 (C)

Table 5.7.3.1: Accuracy assessment statistics

Accuracy assessment statistics of the image-based LULC classification		
Study Year	Overall Accuracy (%)	Kappa Coefficient (%)
2010	92	88.03
2015	94	91.36
2020	96	94.61

Table 5.7.3.2: Percentages LULC area for the year 2010, 2015 and 2020

Sl. No.	LULC	% of Area in 2010	% of Area in 2015	Change % 2010-2015	% of Area in 2020	Change % 2015-2020
1	Waterbody	5.72	4.75	-0.97	9.12	4.37
2	Vegetation	37.78	28.73	-9.05	31.21	2.48
3	Open Space	2.73	1.68	-1.05	1.21	-0.47
4	Built up	53.77	64.84	11.07	58.46	-6.38

Source: Landsat 5 TM for 2010, Landsat 8 OLI for 2015 and 2020

5.7.4 Conversion of Land Use Land Cover for 2010, 2015 & 2020

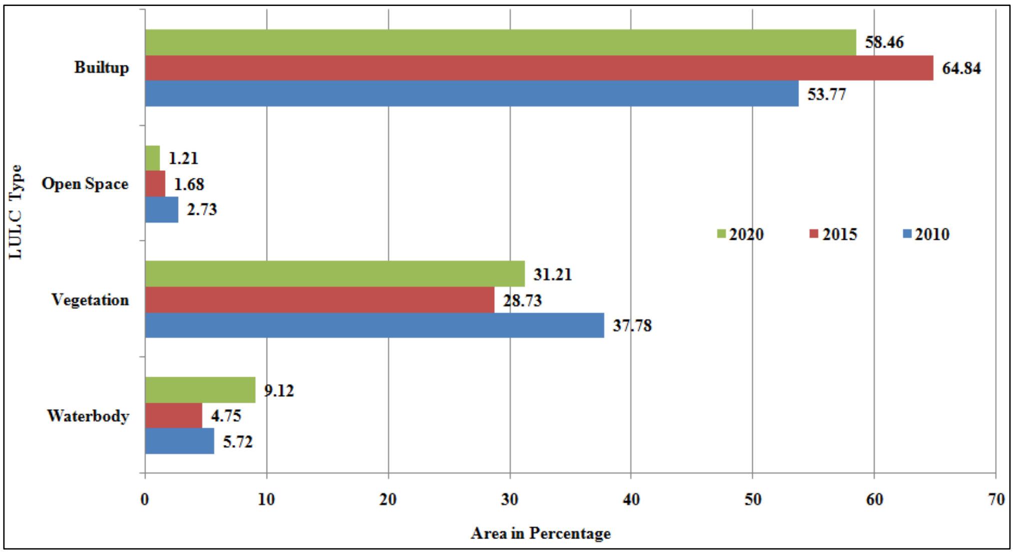


Figure 5.7.4.1: Graphical representation for percentages of LULC area change

Source: Prepared by author using non-spatial data

Table 5.7.4.1: Change of LULC areas from 2010 to 2015

Changed Feature (2010 - 2015)	Changed Area (Sq. Km.)
Builtup - Builtup	87.12
Builtup - Vegetation	4.14
Builtup - Waterbody	0.43
Builtup - Open Space	0.89
Open Space - Builtup	2.06
Open Space - Vegetation	1.47
Open Space - Waterbody	0.03
Open Space - Open Space	2.80
Vegetation - Builtup	31.37
Vegetation - Vegetation	43.45
Vegetation - Waterbody	1.35
Vegetation - Open Space	1.87
Waterbody - Builtup	2.59
Waterbody - Vegetation	1.50
Waterbody - Waterbody	5.23
Waterbody - Open Space	0.05

Source: Landsat 5 TM for 2010, Landsat 8 OLI for 2015

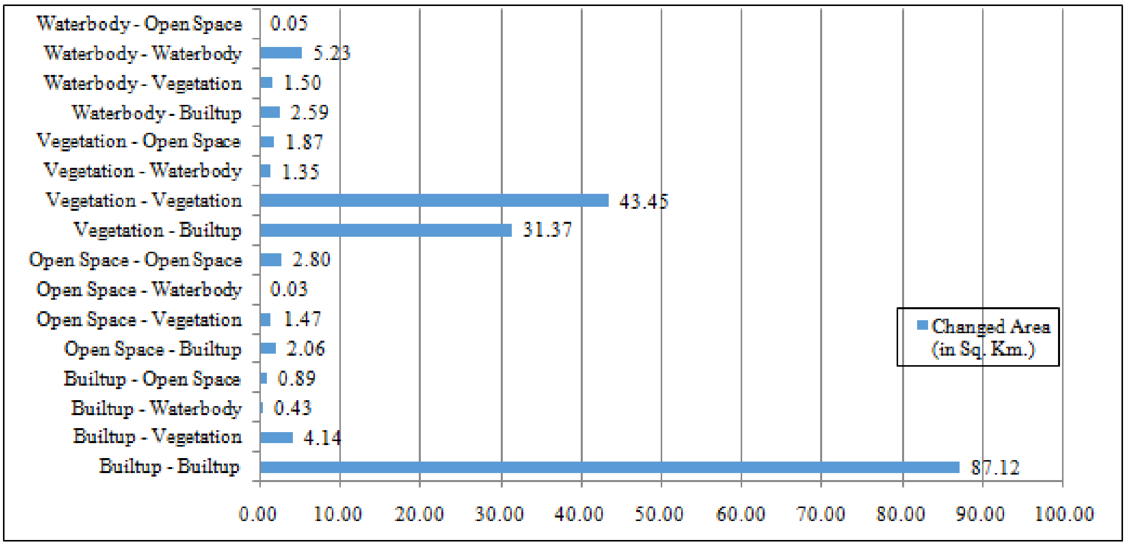


Figure 5.7.4.2: Change of LULC areas from 2010 to 2015

Table 5.7.4.2: Change of LULC areas from 2015 to 2020

Changed Feature (2015 - 2020)	Changed Area (in Sq. Km.)
Builtup - Builtup	89.15
Builtup - Vegetation	14.84
Builtup - Waterbody	17.06
Open Space - Builtup	1.33
Open Space - Vegetation	3.32
Open Space - Waterbody	0.95
Vegetation - Builtup	14.57
Vegetation - Vegetation	18.31
Vegetation - Waterbody	17.65
Waterbody - Builtup	0.38
Waterbody - Vegetation	0.43
Waterbody – Water body	6.22

Source: Landsat 8 OLI for 2015 and 2020

* Built up areas have been converted to Vegetation and Waterbody due to mostly demolition of single dwell units vacant until have converted to multistoried, which are not natural phenomena. But, during ground truth verification, it was found true and also satellite image of 2015 and 2020 show the same. Surprising information found that in KMC area, after death of parents (owner of single dwell units), successors are interested to stay in separate manner from each other with multistoried flats. Due to Covid-19 pandemic lockdown, the constructions of multistoried dwell units been suspended for a long periods and parallel effects of super cyclones “Bulbul” and “Fani”, those vacant areas became filled with water body or shrubs (greeneries).

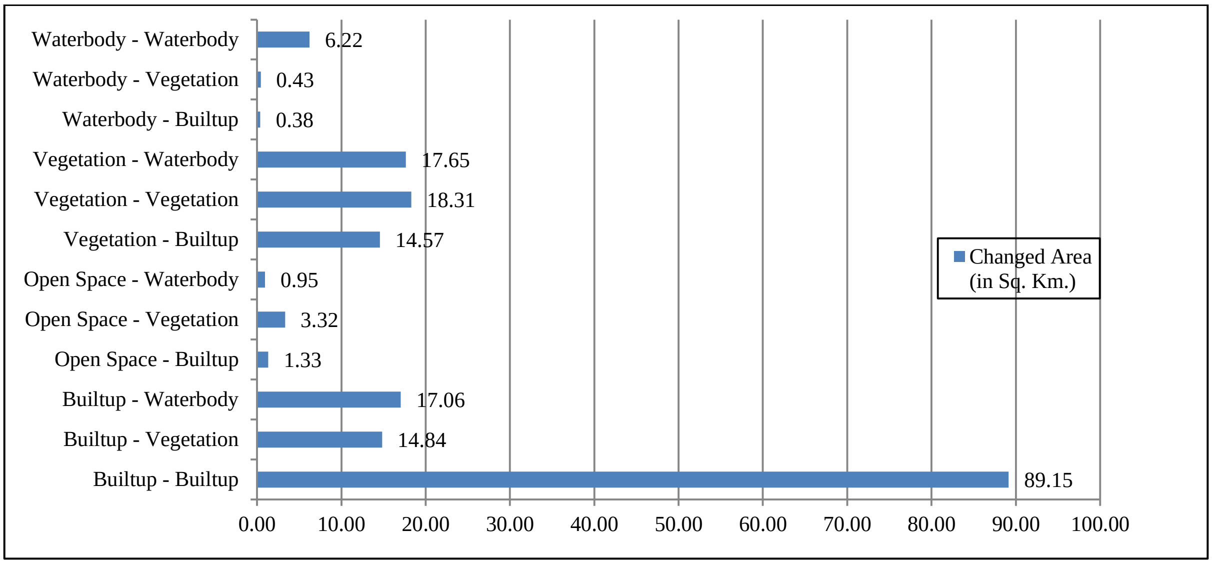


Figure 5.7.4.3: Change of LULC areas from 2015 to 2020

Table 5.7.4.3: Scenario of LST and Land Use Land Cover in Kolkata Metropolitan

Station Name	Latitude	Longitude	LST 2000	LST 2016	Land Use Type & Colour
Mominpur	22.527067	88.321946	30	32	Builtup area (BU)
Ultadanga	22.595489	88.382633	28	29	Dense Builtup (DBU)
Baishnabghata	22.470776	88.391671	24	25	Mid rise Builtup (MRBU)
Topsia	22.539706	88.387482	23	24	Builtup area (BU)
Behala Chowrasta	22.486557	88.313647	26	27	Dense Builtup (DBU)
Minto Park	22.540393	88.354960	25	25	Builtup area (BU)
Shyambazar	22.601271	88.373950	28	29	Dense Builtup (DBU)
Moulali	22.560612	88.364416	28	29	Dense Builtup (DBU)
Rabindrabharati	22.626990	88.378885	28	28	Vegetation cover (VC)
Hide Road	22.525445	88.305774	27	28	Builtup area (BU)
Picnic Garden	22.529011	88.381753	25	26	Builtup area (BU)
Victoria Memorial	22.541449	88.341528	23	25	Open area (OA)
Paribesh Bhawan	22.562501	88.408574	22	23	Vegetation cover (VC)

Source: West Bengal Pollution Control Board (WBPCB), Indian Meteorological Department (IMD), Netaji Subhash Chandra Bose International Airport Weather Report

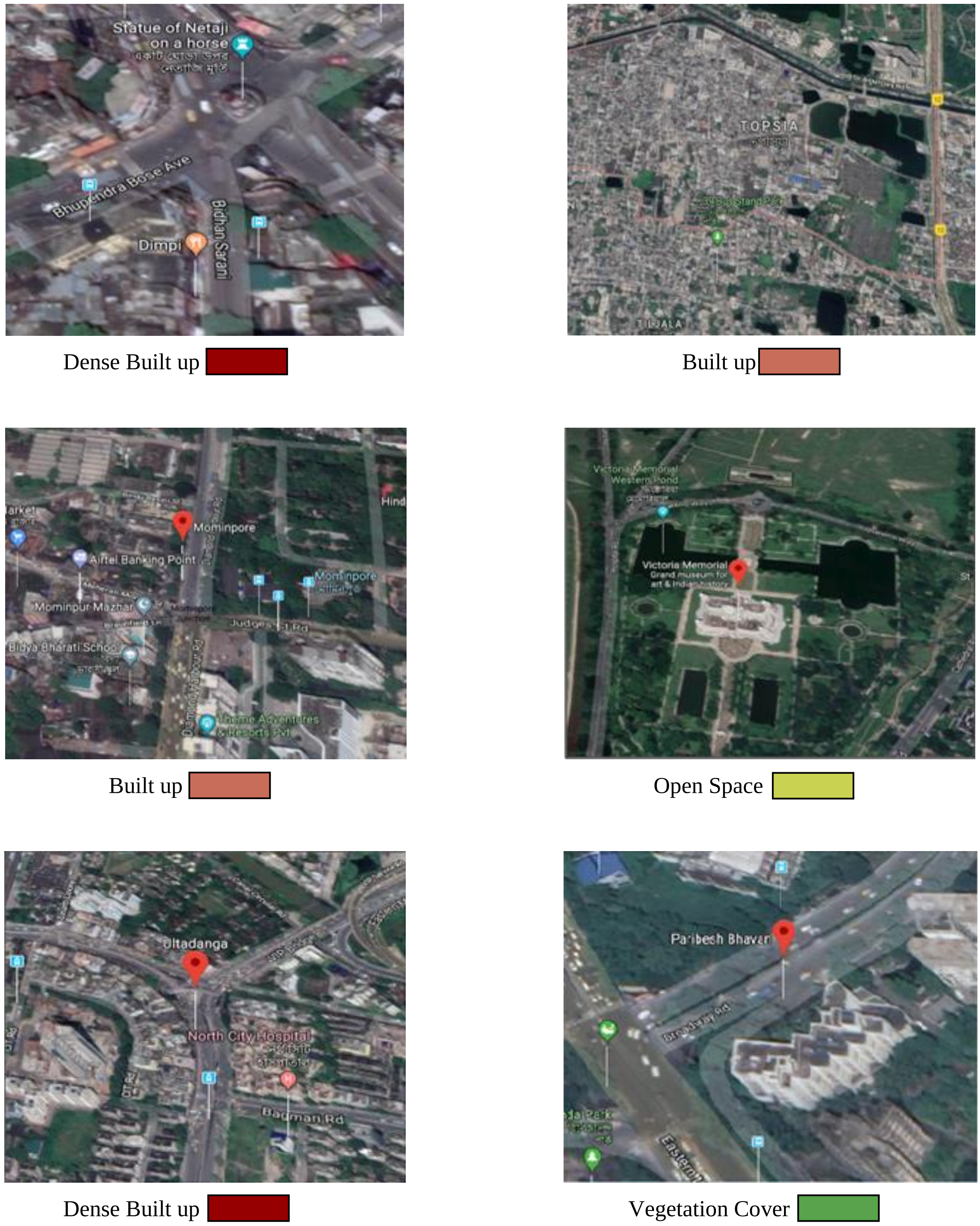


Plate 5.7.4.1: Different Land use pattern in Kolkata and WBPCB station area.

5.7.5 Analysis of Land Surface Temperature

Figure 5.7.5.1 shows the spatial distribution of surface temperature over land use type using Landsat imageries. In Kolkata Municipal Corporation, the lowest and highest Land Surface Temperature ranged from 22.23ºC for 2000 and 23.21ºC for 2016 and from 30.12ºC for 2000 and 32.11ºC for 2016 respectively. It is observed that the variations in temperature are mainly due to the various land use areas and the different kinds of activities like high traffic zone, dense built up area. Table 5.7.5.1 shows the surface temperature values over different Land Use Land Cover classes for Kolkata.

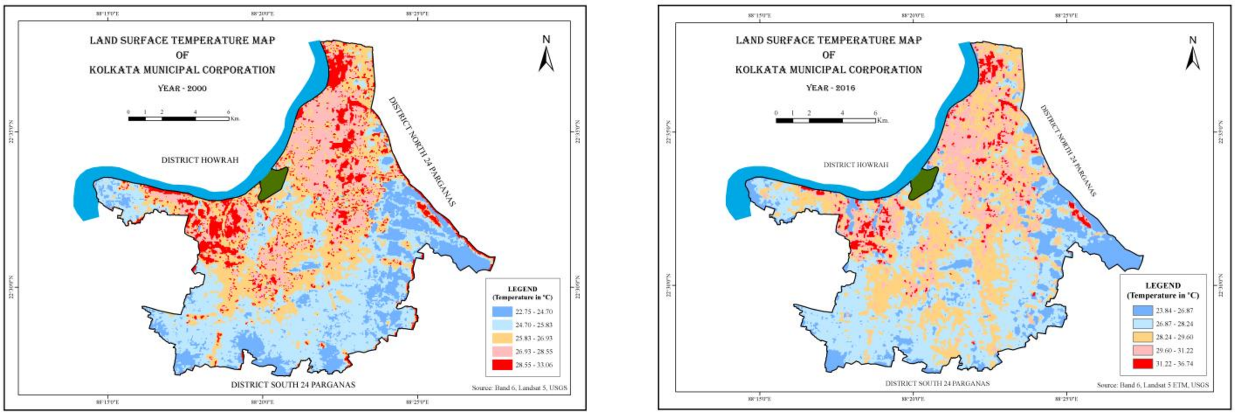


Figure 5.7.5.1: Land Surface Temperature maps of KMC for the year 2000 and 2016

Table 5.7.5.1: Land Surface Temperature categories with areas of KMC for the year 2000 and 2016

Year -	2000		2016	
Categories	**Temperature (°C)**	**Area in sq. km.**	**Temperature (°C)**	**Area in sq. km.**
Very Low	22.75 - 24.70	8.9550	23.84 - 26.87	27.3490
Low	24.70 - 25.83	48.9483	26.87 - 28.24	66.1046
Moderate	25.83 - 26.93	76.2304	28.24 - 29.60	55.8266
High	26.93 - 28.55	41.3622	29.60 - 31.22	30.0559
Very High	28.55 - 33.06	10.8541	31.22 - 36.74	7.0139

5.7.6 Comparative analysis of Urban Land Use Pattern & LST

Choropleth maps were generated to show the spatial distribution of PM_{10} and temperature variation for the year 2000 and 2016. Every metropolitan or built-up region has a temperature that is comparatively high. There are some easily discernible "hot patches" (the highest temperature class). The largest hotspot was discovered in 2000 in Kolkata's northern and western metropolitan areas, which were areas of dense population and heavy traffic. Other noticeable hot spots were detected in the western corner of the proper city, which were Mominpur, Behala Chowrasta having dense built up with high traffic zone.

Table 5.7.6.1: Land Surface Temperature category with areas of KMC for the year 2010, 2015 and 2020

Land Surface Temperature						
Year -	**2010**		**2015**		**2020**	
Category	**Temperature (ºC)**	**Area (Sq. Km.)**	**Temperature (ºC)**	**Area (Sq. Km.)**	**Temperature (ºC)**	**Area (Sq. Km.)**
Very Low	17.25 – 20.43	6.4497	19.02 - 21.49	8.04623	17.40 – 18.97	27.8541
Low	20.43 – 21.72	25.6423	21.49 - 22.76	40.1233	18.97 – 19.71	61.4564
Moderate	21.72 – 22.62	61.092	22.76 - 23.70	75.9686	19.71 – 20.36	49.249
High	22.62 – 23.91	64.996	23.70 - 25.01	48.1948	20.36 – 21.23	34.9695
Very High	23.91 – 28.66	28.17	25.01 - 29.85	14.0171	21.23 – 24.10	12.8212

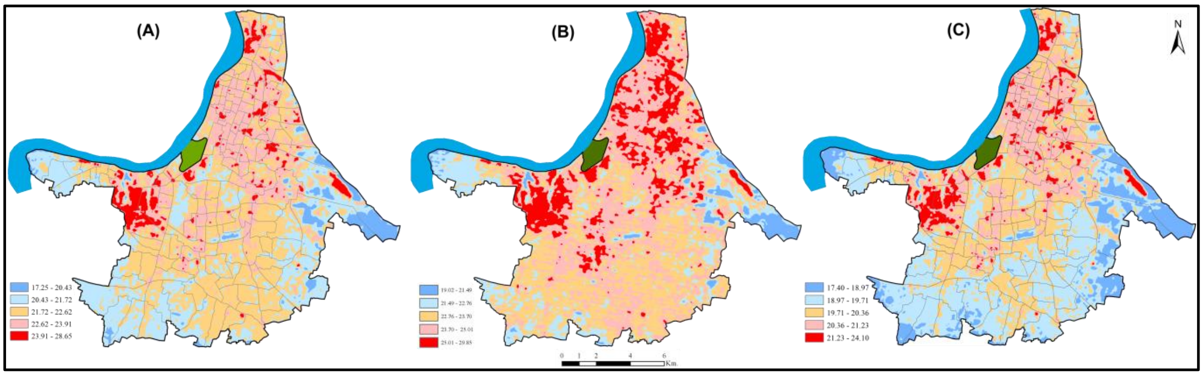


Fig 5.7.6.1: Land Surface Temperature (LST) of KMC for the year 2010 (A), 2015 (B) and 2020 (C)

Thermal band 6, 10 (10.40 - 12.50 µm) 10 TIRS 1 (10.60 - 11.19 µm) of 30m resolution for Landsat 5 TM and 8 OLI TIRS (Thermal Infra Red Sensor) respectively have been used to analyze the LST of KMC area for the year 2010 (A), 2015 (B) and 2020 (C); LST has been categorized into five zones namely 'Very Low', 'Low', 'Moderate', 'High' and 'Very Low'. The minimum and maximum LST values of KMC area were 17.25ºC and 28.66ºCfor the year 2010, whereas 19.02ºC and 29.85ºC for the year 2015. It seems within the 5 years of time span, the raise of minimum and maximum surface temperatures were 1.77ºC and 1.19ºC.But interestingly in the year 2020, the Land Surface Temperate has been decreased as the minimum 17.40ºC and the maximum is 24.10ºC to the tune of 1.62ºC as minimum and 5.75ºC as maximum which is the sign of improvement in the context of Land Surface Temperature of Kolkata. The super cyclone 'Fani' and 'Bulbul' during the month of April and November 2019 respectively along with the lockdown (complete and partial) period due to Covid-19 pandemic situation are the major causes to decrease the LST of Kolkata in the year 2020.

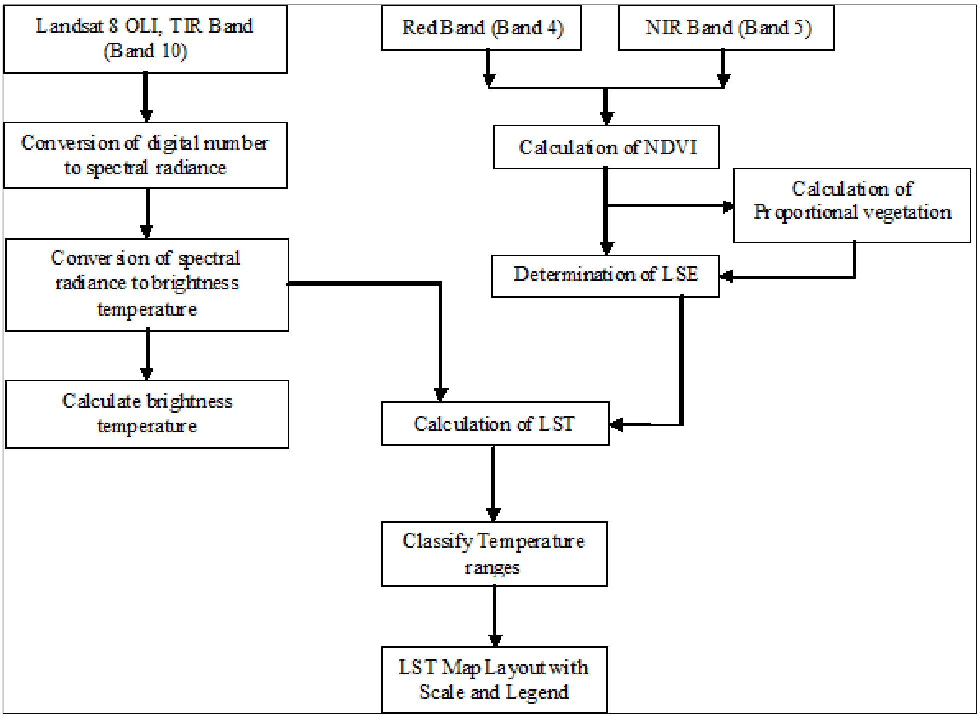


Figure 5.7.6.2: Flowchart of the LST process of 2020

5.7.7 UHI and Non UHI Zone

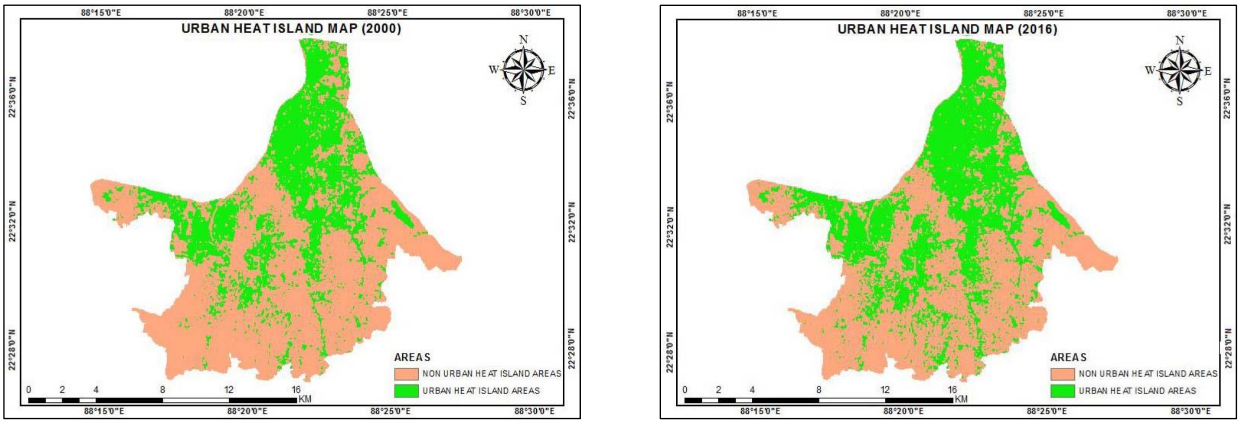


Figure 5.7.7.1: Urban Heat Island areas for 2000 and 2016

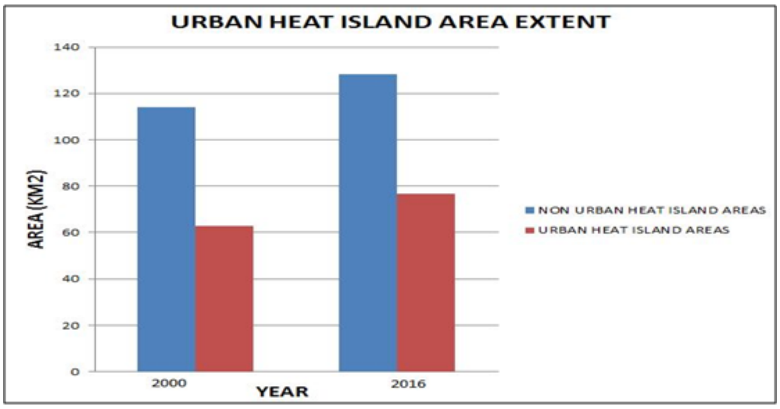


Figure 5.7.7.2: Extent of UHI areas

1. Green colour represents UHI zone's (dense built up area and low vegetation area)
2. High Land Surface Temperature indicates UHI zone
3. From the map it indicates north and central Kolkata high Land Surface Temperature (LST). So in KMC this is the one of the UHI zone.

5.7.8 The spatial and temporal distribution of mean values of UHI (MUHI) and effect for each area (hereafter refer as Thana) of KMC in 2010, 2015 and 2020

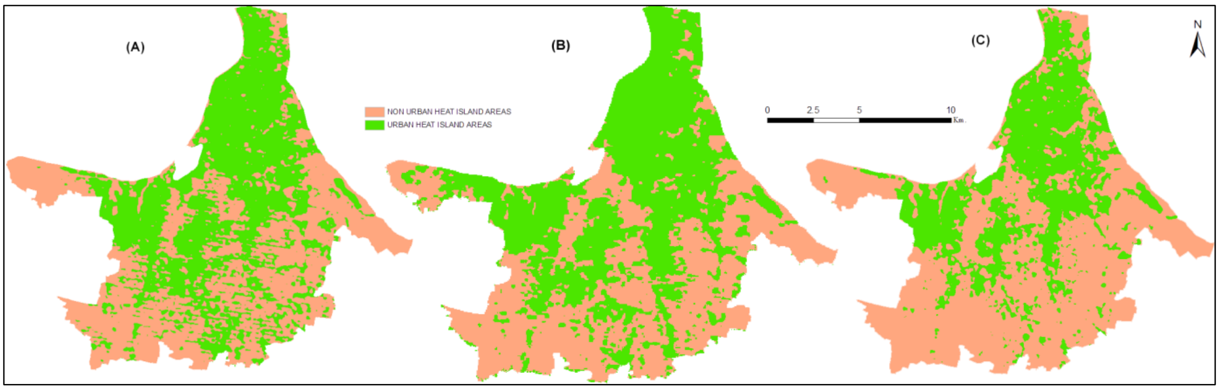


Figure 5.7.8.1: The spatial and temporal distribution of mean values of UHI

Source: Prepared by the authors using the formula UHI = $(T_s – T_m)$ / SD from the LST maps

The north-central portion of the region, which is regarded as the primary overpopulated (Built-up area) of KMC, is where the majority of the UHI impact is located.

Table 5.7.8.1: Areas of UHI and Non-UHI under KMC for the year 2010, 2015 and 2020

Area in Sq. Km.			
	2010	**2015**	**2020**
UHI	90.6781	118.1111	94.4778
Non-UHI	95.6719	68.2389	91.8722

5.7.9 Line Graph of temperature from sample survey locations in KMC for the years 2010, 2015 and 2020

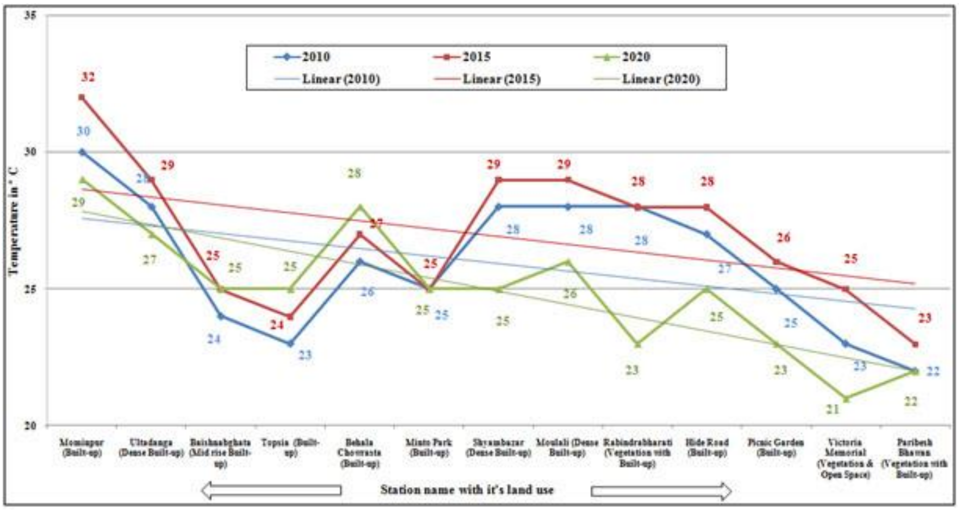


Figure 5.7.9.1: Line graph of temperature data of sample survey locations
Data: Appendix Table B1

5.7.10 Normalized Difference Vegetation Index of KMC for the year 2010 (A), 2015 (B) and 2020 (C) and Data Table

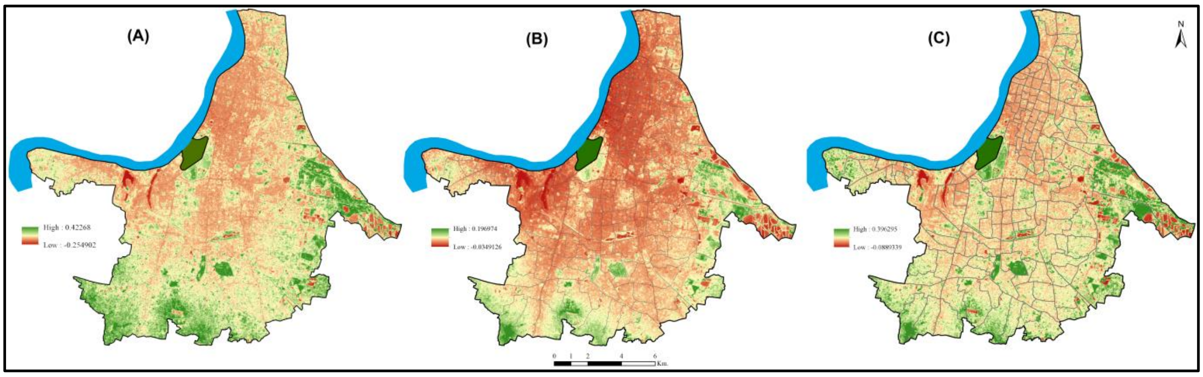


Figure 5.7.10.1: NDVI map of KMC for the year 2010, 2015 and 2021

Band 4 (NIR) with 3 (Red) for LANDSAT 5 TM and Band 5 (NIR) with 4 (Red) for LANDSAT 8 OLI are used to find out the NDVI values of KMC for the year 2010 (A), 2015 (B) and 2020 (C). It has been observed that the NDVI value for the year 2010, 0.422680 as high and -0.254902 as Low and by the year 2015, the high and low values became 0.46335 and -0.05426 respectively. But in the same context, the high value was 0.39630 and -0.08893 as low for the year 2020 shown by the indices analysis. Map and table data indicate that during the Covid-19 period of 2020, vegetation index has been improved significantly (*NIR* - Near Infra-Red).

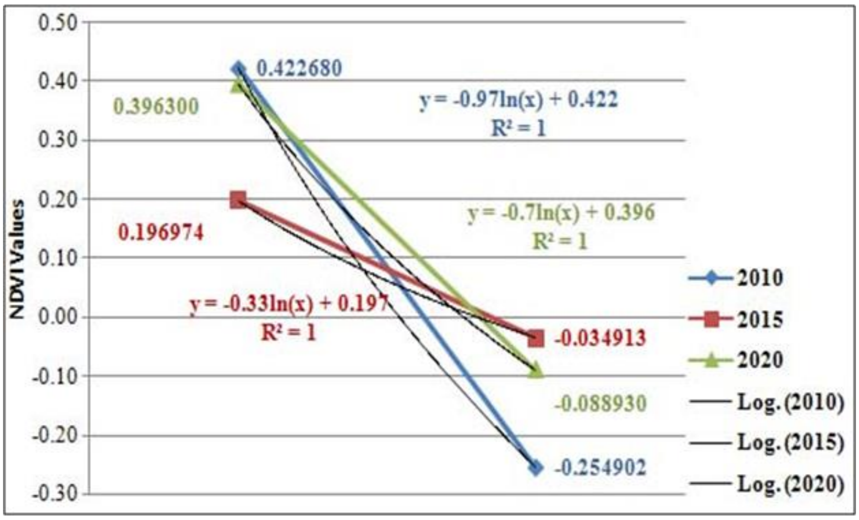


Figure 5.7.10.2: Logarithmic regression analysis of NDVI for 2010, 2015 and 2020

Table 5.7.10.1: Year wise NDVI values of KMC

Category	Year		
	2010	2015	2020
High	0.422680	0.1969740	0.39630
Low	-0.254902	-0.0349126	-0.08893

Source: Prepared by authors using the LANDSAT 5 and LANDSAT 8 OLI imagery of USGS

5.7.11 Normalized Difference Built-up Index of KMC for the year 2010 (A), 2015 (B) and 2020 (C) and Data Table

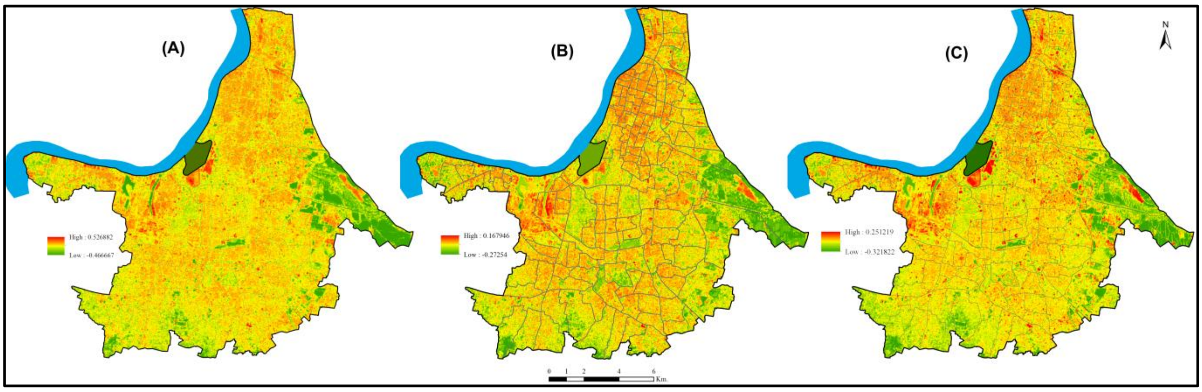


Figure 5.7.11.1: NDBI map of KMC for the year 2010, 2015 and 2020

Band 5 (SWIR) with 4 (NIR) for LANDSAT 5 TM and Band 6 (SWIR) with 5 (NIR) for LANDSAT 8 OLI are used to find out the NDBI values of KMC for the year 2010 (A), 2015 (B) and 2020 (C). The NDBI analysis of Kolkata Municipal Corporation shown by the above figure indicates that in the year 2010, the built-up index value was 0.526882 as high and -0.466667 as low; 0.167946 as high and -0.27254 as low for the year 2015, which indicate the downfall of the index values. Again the index values of 2020 signify that, the uplift of built up index value 0.251219 as high and -0.321822 as low, clearly indicating that the region covered with mostly concrete which is one of the key factor of hike in the surface temperature.

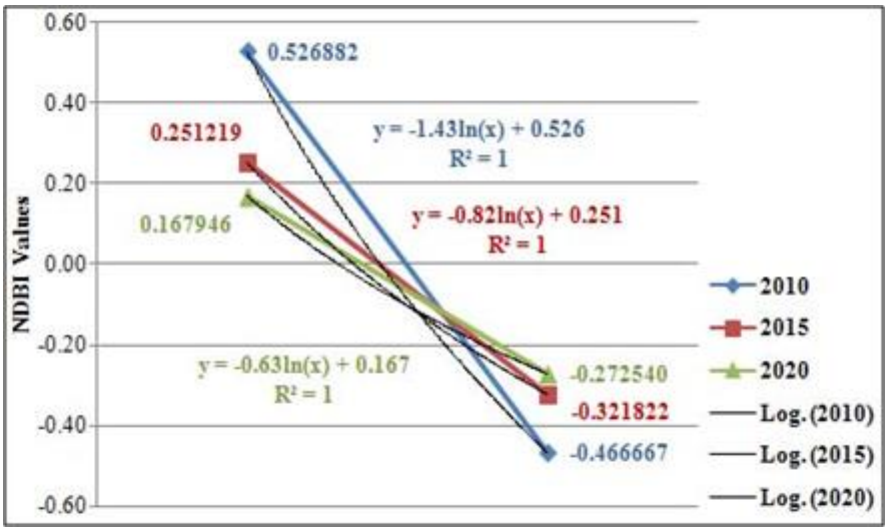


Figure5.7.11.2: Logarithmic regression analysis of NDBI for 2010, 2015 and 2020

Table 5.7.11.1: Year wise NDBI values of KMC

Category	NDBI		
	2010	2015	2020
High	0.526882	0.251219	0.167946
Low	-0.466667	-0.321822	-0.272540

Source: Prepared by authors using the LANDSAT 5 and 8 OLI imagery of USGS

5.7.12 Normalized Difference Water Index of KMC for the year 2010 (A), 2015 (B) and 2020 (C) and Data Table

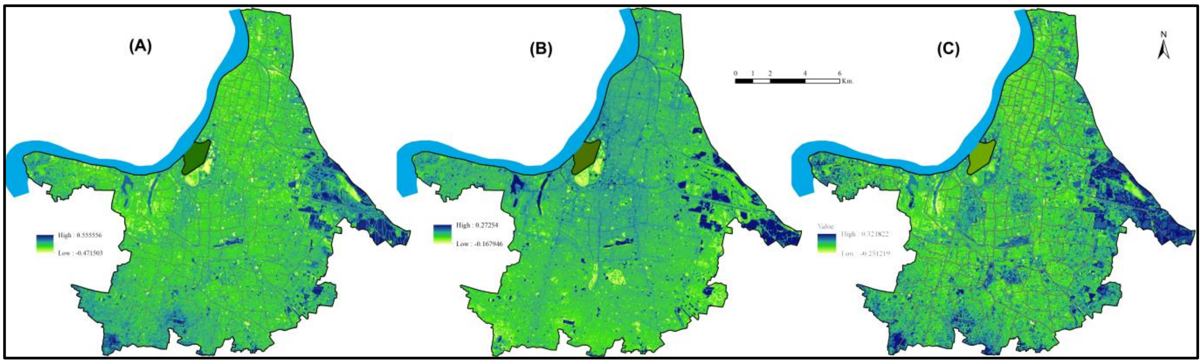


Figure 5.7.12.1: NDWI map of KMC for the year 2010, 2015 and 2020

Band 3 with Band 5 for LANDSAT 5 TM and Band 5 (NIR) with 6 (SWIR) for LANDSAT 8 OLI are used to find out the NDWI values of KMC for the year 2010 (A) 2015 (B) and 2020 (C). The NDWI analysis map of KMC signified that the water index value of this region was 0.555556 as high and -0.471503 as low in 2010, 0.27254 as high and -0.167946 as low for the year 2015 and the very severe cyclone ‘Fani’ and ‘Bulbul’ in the month of April and November 2019 respectively, affected this region very badly to the index of 0.321822 as high and -0.251219 as low for the year 2020. Agricultural lands and fisheries are being affected mostly by the consecutive cyclone along with vegetation and built-up area, which extent the hike of surface water table.

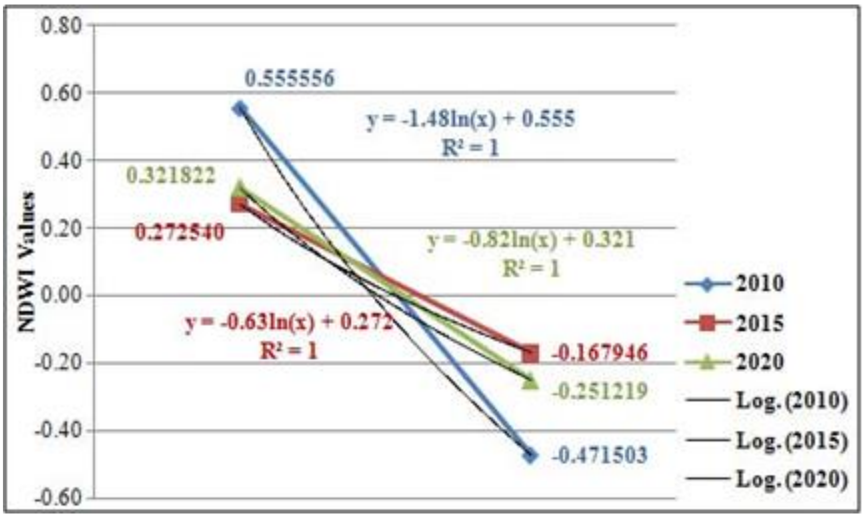


Figure 5.7.12.2: Logarithmic regression analysis of NDWI for 2010, 2015 and 2020

Table 5.7.12.1: Year wise NDWI values of KMC

Category	NDWI		
	2010	2015	2020
High	0.555556	0.272540	0.321822
Low	-0.471503	-0.167946	-0.251219

Source: Prepared by authors using the LANDSAT5 and 8 OLI imagery of USGS

5.7.13 The Spatio-Temporal distribution of land surface temperature profiles on built-up area

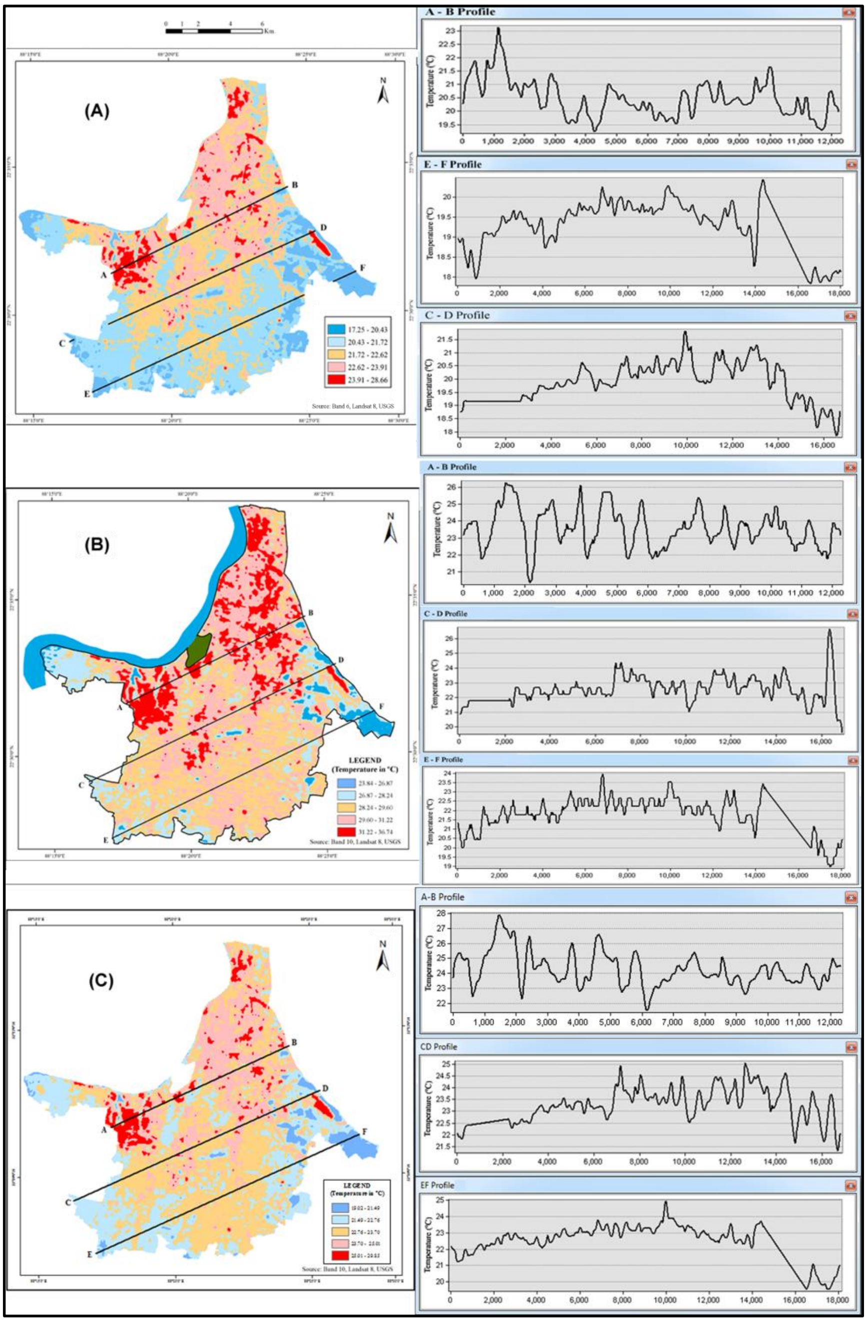


Fig 5.7.13.1: LST Profile of KMC for the year of 2010(A), 2015(B) and 2020(C)

The AB profile shows the maximum spatio-temporal development of Kolkata using the pixel values of LST image under the profile line, AB is due to the high built-up density. The CD profile shows medium and the EF is the least spatio-temporal development using the same pixel values of respective profile lines within the study area.

5.7.14 Comparison between NDWI, NDVI, NDBI, LST, UHI and LULC

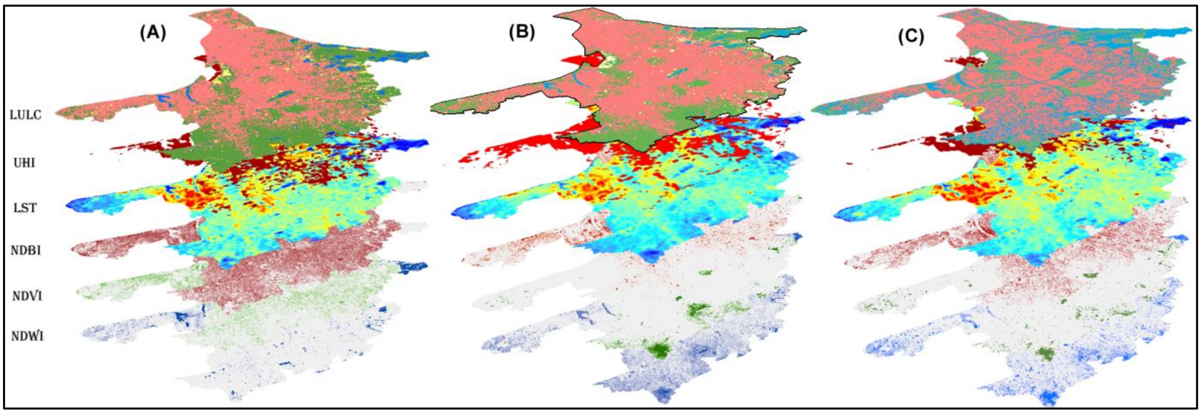


Fig 5.7.14.1: Overlaid NDWI, NDVI, NDBI, LST, UHI and LULC for the year 2010 (A), 2015 (B) and 2020 (C). Source: Prepared by the authors from LANDSAT8 OLI, USGS

NDWI, NDVI, NDBI, LST, UHI and LULC for the year 2010 (A), 2015 (B) and 2020 (C) have been overlaid as themes to show the spatial distribution of each within Kolkata Municipal Corporation. The research area's NDBI, NDVI, and NDWI relationships were investigated, and it was discovered that they were negatively correlated. This indicated that the urbanisation of the area had caused the conversion of green surfaces and water bodies to built-up or artificially constructed surfaces but in 2020, the people were homebound due to the primary reason of COVID-19 lockdown and hence the city has broad impact ecological changes.

The aforementioned findings demonstrate that expanding built-up surfaces eventually results in a rise in LST, which might be decreased by preserving or even increasing the amount of green space and water bodies in metropolitan areas.

5.7.15 Different land surface temperature zones overlaid on the land use land cover map of KMC for the year 2010 (A), 2015 (B) and 2020 (C)

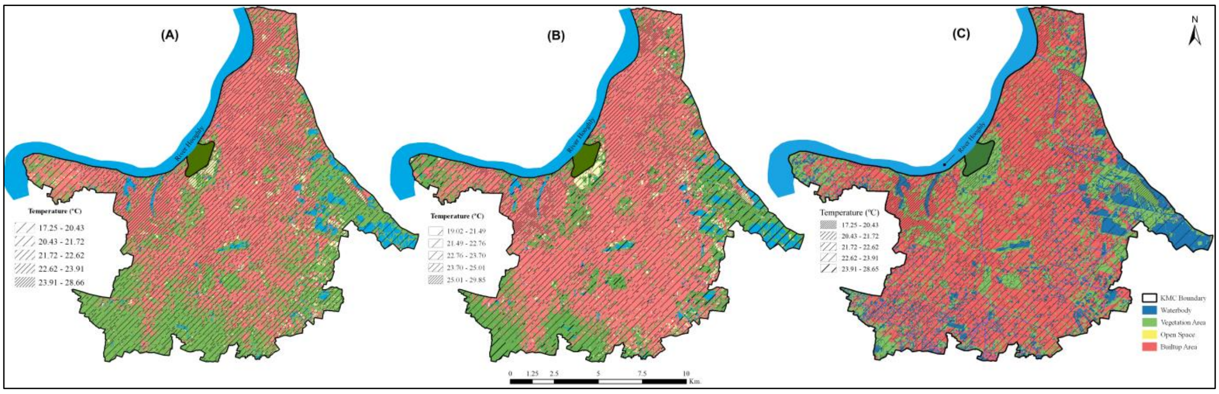


Figure 5.7.15.1: Different land surface temperature zones overlaid on the land use land cover map of KMC Source: Prepared by the authors from the LULC and LST maps of different years

The correlation map of Land Use Land Cover and Land Surface Temperature for the year 2015 shows that the built-up of north and port area within Kolkata Municipal Corporation exhibits maximum land surface temperature compare to the other region. The vegetation and water body covered area experienced lowest LST. Different Land Surface Temperature zones overlaid on the land use land cover map of Kolkata Municipal Corporation for the year 2010 (A), 2015 (B) and 2020 (C) are exemplify that the Garden Reach area and most of the north Kolkata region having land use type built up comprises the highest surface temperature whereas the East Kolkata Wetland of water body land use dissipate the lowest surface temperature within the study area. Comparatively south Kolkata region experiences low surface temperature due to the presence of water bodies and vegetations.

Table 5.7.15.1: Area of different LST categories on different LULC types

Areas (Sq. Km) within five LST (in °C) categories of different LULC types					
LULC	**VERY HIGH**	**HIGH**	**MODERATE**	**LOW**	**VERY LOW**
2010	**23.91 - 28.66**	**22.62 - 23.91**	**21.72 - 22.62**	**20.43 - 21.72**	**17.25 - 20.43**
Waterbody	0.077	0.222	0.571	1.880	4.173
Vegetation	3.933	17.273	32.180	15.035	1.833
Open Space	1.592	2.005	1.037	0.431	0.016
Builtup	24.480	45.481	27.287	6.451	0.393
2015	**25.01 - 29.85**	**23.70 - 25.01**	**22.76 - 23.70**	**21.49 - 22.76**	**19.02 - 21.49**
Waterbody	0.018	0.129	0.408	1.968	4.508
Vegetation	0.405	3.409	16.002	27.496	3.216
Open Space	0.903	1.636	1.990	1.002	0.068
Builtup	10.643	36.008	57.535	18.776	0.229
2020	**21.23 - 24.10**	**20.36 - 21.23**	**19.71 - 20.36**	**18.97 - 19.71**	**17.40 - 18.97**
Waterbody	0.565	4.053	12.486	14.081	7.661
Vegetation	1.725	6.602	13.646	12.266	1.673
Open Space	0.439	0.919	1.159	0.235	0.020
Builtup	10.950	31.393	48.346	17.826	0.305

5.7.16 Urban and non-urban heat islands area overlaid on the land use land cover of KMC for the year 2010 (A), 2015 (B) and 2020 (C)

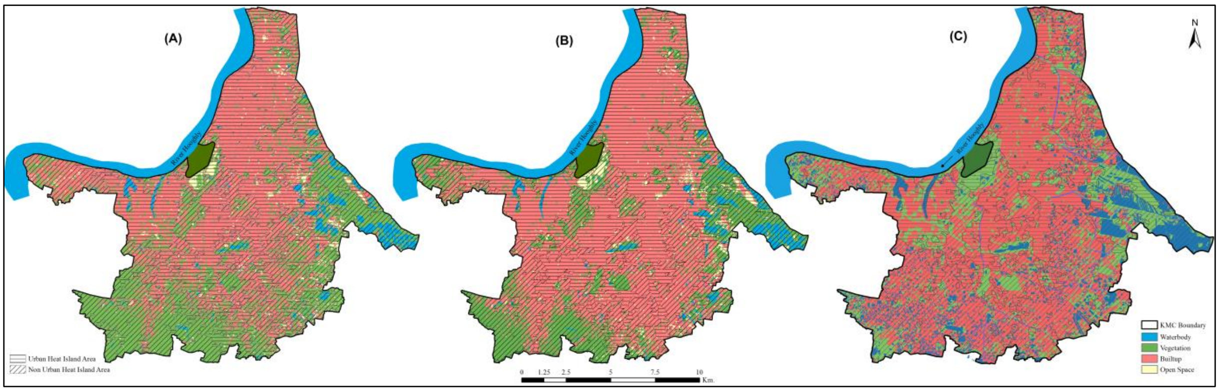


Figure 5.7.16.1: UHI and Non-UHI area overlaid of LULC of KMC
Source: Prepared by the authors from the LULC and UHI maps of different years

The overlay analysis demonstrates that the Garden Reach area, portion of central Kolkata and mostly the north Kolkata area fall under urban heat islands. Whereas the south, east and western part of Kolkata are within the non-urban islands The overlay maps of UHI on the LULC of Kolkata for the year 2010 (A), 2015 (B) and 2020 (C) describe that mainly the built up areas of north Kolkata and Garden Reach areas are very much correlated as the LST of those areas are high and fall under urban heat island zones within the study area. On the other side south Kolkata and East Kolkata Wetland areas having low surface temperature fall under Non-Urban Heat Islands within the study area.

Table 5.7.16.1: Areas of different LULC with UHI and Non-UHI

2010		
LULC	**Urban Heat Island (Sq. Km.)**	**Non Urban Heat Island (Sq. Km.)**
Waterbody	0.380	6.895
Vegetation	22.734	55.287
Open Space	4.014	2.345
Builtup	65.648	29.047
2015		
Waterbody	0.959	6.064
Vegetation	12.042	38.381
Open Space	2.686	2.911
Builtup	80.933	42.374
2020		
Waterbody	32.556	6.299
Vegetation	25.239	10.687
Open Space	1.119	1.653
Builtup	61.268	47.527

5.8 Findings

- From this study it is observed that there is significant builtup area and low vegetation cover in KMC region, developed Urban Heat Island zone and comparatively presence of water bodies. It is also found that there are low vegetation covers and low builtup area which infers Non-Urban Heat Island zone.
- In order to investigate the connection between biophysical indicators and LST, this study discovered that values produced from three years of data fluctuated during the course of the study periods; this makes it clear that the growth of urban built-up area in KMC has been a major factor in the rise in LST.
- In different years in Kolkata metropolitan, the results show the highest association

between LST and land use/land cover, including biological indices (NDVI, NDWI and NDBI).

- Observed from the present studies that due to COVID-19 pandemic situation where people were homebound, industries were locked, construction sites were deserted and hence the city has a better ecological status. It is revealed from the study that there had been better changes in the land surface temperature, the vegetation levels and the total water bodies (including soil moisture content) had also seen a record increase compared to what it was earlier.

5.9 Conclusion

This chapter shed light on how a region's surface temperature can be impacted by unplanned and rapid urbanisation. The goal of the study is to comprehend how LST contributes to the growth of UHI and subsequently impacts the health and welfare of people. The study also offered a real-world illustration of how UHI research might be enhanced by LST estimation and LU development (Land Use). This study's main goal was to describe the impacts of UHI and offer solutions for lessening them. One of the most noteworthy lessons from this chapter is that an increase in impervious surfaces, land use and land cover change can drastically modify a region's microclimate in terms of LST, which further initiates or amplifies positive UHIs. Overall, unplanned and uncontrolled development with fewer trees, green areas, and water bodies might cause the metropolitan region to warm up and exacerbate heat-related illnesses among the population. Therefore, it can be concluded that the problem of high surface temperature and the negative impacts of UHIs can be resolved by planting dense vegetation as opposed to scattered ones and by placing water bodies throughout the urban region.

Chapter 6: Analysis and Observation on Urban Heat Island Effect with respect to Air Quality (AQ profile, Seasonal pattern & Relation)

This part of the work has been published in -

1. *Sohini Sen, Debashish Das, Raja Ghosh(June 2019)"Investigating PM 10 level with respect to the Urban Land use and its effect in Urban Heat Island", Indian Journal of Regional Science. Vol-L1, No-1,pp.27-39,ISSN: 0046- 9017(Print),ISSN : 2456 – 6519 (Online) Indian Journal of Regional Science, June 2019.*
2. *Sohini Sen, Debashish Das, Anupam Deb Sarkar, Raja Ghosh "Investigating Real-Time Ambient Air Quality Status and Land Surface Temperature during Kalipuja/Diwali Festival in different Land use types – Case study Kolkata", International Journal of Advances in Mechanical and Civil Engineering (IJAMCE)Volume-7, Issue-1, pp.21-27)ISSN (P): 2394- 2817, International Journal of Advances in Mechanical and Civil Engineering (IJAMCE) Dec,2019.*

6.1 Introduction

Urbanization and population increase have put enormous pressure on the conversion of land from natural and agricultural uses to residential and urban uses, which has had a severe negative impact on ecosystem services (Justice *et al*., 2015). According to Bakhtiar Feizizadeh and Thomas Blaschke (2013), rapid population increase, urbanization, expansion, and encroachment into the few remaining agricultural and natural regions also contribute to the loss of vegetative cover. In recent years, land cover in emerging countries has drastically altered, especially in China (Wu *et al*., 2008; Zeng *et al*., 2014; Liu *et al*.,2014; Güneralp *et al*., 2015). Urban sprawl is frequently used to describe the abrupt changes in land cover.(Mundia and Aniya 2006; Jat*et al*., 2008; Dewan and Yamaguchi2009b; Dewan *et al*.,2012; Dewan,2012; Byomkesh *et al*., 2012; Liu *et al*., 2014),(Ali, 2006; Du *et al*., 2013), and deforestation (Zhang and Song,2006), resulting in the loss of agricultural land(Lopez *et al*.,2001), habitat destruction (Alphan, 2003), and the decline of the natural greenery are as (Swanwick *et al*., 2003; Kongand Nakagoshi, 2006). At local and global levels, these losses have a significant influence on urban environmental factors including biodiversity, climate change, and air pollution (Raul Ochoa *et al*., 2017).

Colloids of solid or liquid droplets floating in the atmosphere make up atmospheric particulate matter and their sizes range from0.001 to 20μm. In particular, PM_{10} and $PM_{2.5}$, having particulate aerodynamic diameters of less than 10and2.5μm, may do considerable harm to human health because it is filled with organic contaminants and viruses and is simple to inhale(Colvile *et al*., 2001; Brune Kreef and Holgate,2002; Xu, 2002; Espinosa *et al*.,2002; Marcazzan *et al*., 2003; Kocifaj *et al*., 2006; Huang *et al*., 2012). By absorbing and scattering light, atmospheric particulate matter can also contribute to poor atmospheric visibility (Wang *et al*., 2009; Chen *et al*., 2010; Han *et al*., 2011).

It is obvious that urbanization causes environmental impacts such as intensified Land Surface Temperature (LST), UHIs and Air-Quality. Numerous studies have demonstrated that various regional elements as well as urban and street layout influence the air temperature in urban canyons (Bärring, Mattsson, and Lindqvist, 1985). LST study demonstrates that the balance of land surface energy may be changed by the conversion of surface soil, water content, and vegetation (Li and Zhou, 2011).

Urbanization is a dynamic process that contributes significantly to human-caused climate change Urban Heat Island (UHI) is a mutual response of many environmental and manmade factors (Memon *et al*., 2008a,b; Unger *et al*.,2001) and has not been fully explored (Hafner and Kidder, 1999; Poreh, 1995). Urban Heat Islands not only create a temperature higher than average temperature of the adjoining areas, but may also lead to further deterioration of the environment causing less rainfall, consequently increasing pollution and suspended solid particulate matters in air. During the 100 years that ended in 2005, the average global surface temperature climbed by 0.18°C to 0.74°C. Climate model projections summarized in the latest International Panel of Climate Change (IPCC) report indicate that the 21st century will probably see an additional 1.1°C to 6.4°C of global Surface Temperature increase used to cool buildings, which worsens the air quality and has detrimental health impacts. For instance, increased warmth causes more Ozone (O3) pollution to be produced (Lo and Quattrochi, 2003; Cardelino and Chameides, 2000). The UHI signal indicates a wide range of significant land surface changes that have an influence on ecosystem function, local weather, and perhaps climate as well as human health. (Imhoff, Zhang, Wolfe, Bounoua *et al*., 2010) Conditions favoring the rise in temperatures over urban areas compared to neighboring rural areas include a decreased sky-view factor, the replacement of soil cover with concrete or asphalt surfaces, and the emission of a significant amount of waste heat from the transportation, commercial, residential, and industrial sectors(P. Pandey *et al.,* / Science of the Total Environment 414 (2012), 494-507).

Many major cities in S/SEA have air quality problems, which are mostly caused by the region's fast industrialization, urbanization, and rise in energy consumption (Foell *et al*., 1995, Ohara and Murano 2001, Gurjar *et al*., 2016). The South/Southeast Asia Research Initiative (SARI), supported by the NASA LCLUC programmed, investigated these land cover land use changes

(LCLUC) concerns and related air pollution.(www.lcluc.umd.edu).The mapping of urban thermal conditions and the relation with land use and land cover (LULC) and air pollution, has been increasing interest.

Remote sensing-based research on Land Use and Land Cover Change (LULCC) has a long history and has advanced (Singh, 1989; Jensen, 1996; Coppin *et al*., 2004; Lu *et al*., 2004; Liu *et al*., 2008; Dewan and Yamaguchi, 2009a, 2009b; Dewan *et al*., 2012; Wei *et al*., 2015). Understanding the interactions between human activities and the environment requires the use of LULC (Dewan *et al*., 2012). Despite being hindered by the spatial and spectral complexity of urban surroundings, remote sensing (Jensen and Cowen 1999; Herold *et al*., 2004) appears to be a suitable source of urban data for this research (Donnay *et al*., 2001). Based on this concept, the primary goal of this study is to understand the relationship between urban land use classification and the Urban Heat Island pattern of the city Kolkata where in many situations, the fast growth of metropolitan centers and their peripheries has resulted in a number of complicated issues relating to environment and identify the impact of land use changes over air pollution and urban heat island effect in different year (i.e.1996 and 2016) using remote sensing satellite image and locally collected pollution data.

6.2 Study Area

The current study area is the Kolkata metropolitan region, the capital of West Bengal and India's third-most populous metropolis. It is situated in the country's east along the Hooghly River's banks. Area-wise, the Kolkata Municipal Corporation covers 186.35 km^2. The Kolkata metropolitan region has 39 local municipalities and is made up of 3 municipal corporations, including the Kolkata Municipal Corporation, spanning a land area of 1,886.67 km^2 (728.45 sq mi). The city has an average elevation of 17 feet, which is close to sea level. It has been chosen as the research region because it is a contemporary metropolis with a lengthy history and a combination of various land uses and land covers that are prone to atmospheric turbulence.

Location of Kolkata: Latitude and Longitude of Kolkata is 22.5667° N, 88.3667° E

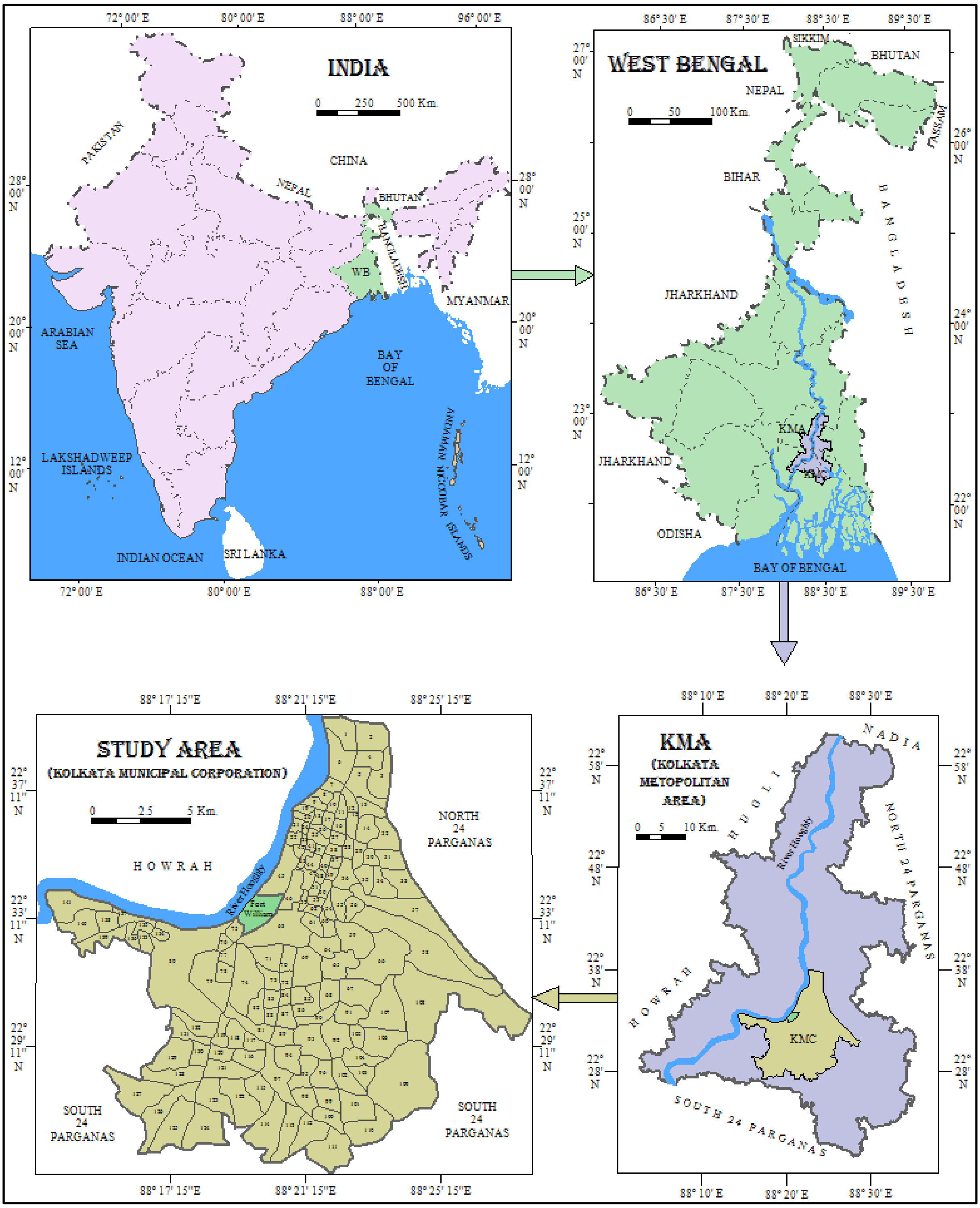


Figure 6.2.1: Location map of Study Area

6.3 Meteorological Status in Kolkata

The micro-meteorological parameters like temperature (°), relative humidity (%), wind speed (m/s) solar radiative flux (watt/m^2) over Kolkata during the study period in Pre-Diwali, Diwali, and Post-Diwali days. Except for solar radiative flux, which is given for the daytime only, the data were obtained from the West Bengal Pollution Control Board (WBPCB), the government of

West Bengal, India. They were averaged based on daytime (6 A.M. – 6 P.M.) and nighttime (6 P.M. – 6 A.M.). Over Kolkata during the course of the study period, it was discovered that the temperature, relative humidity, wind speed, and radiative flux fluctuated from 18 to 33°C, 45 to 98%, 0.8 to 3.3 m/s, and 35-740 watt/m2 accordingly.

Comparison to other days, it was discovered that Diwali night and the day after Diwali had a significantly lower mean wind speed (A. Chatterjee *et al.*, 2013). In comparison to other days (260-290 watt/m2), the daytime mean solar radiative flux on the post-Diwali day was higher (366 watt/m2).

6.4 Data Collection

Data collected for this study, classified into primary and secondary data. The imageries used for both analyses include LANDSAT 7 TM and 8 OLI (February 2000 and January 2016). Two Landsat scenes have been considered to cover the study area (path and row 138/044 and 138/045). Necessary shape files of the study area have been digitized. The secondary data used for this research include administrative boundaries and road networks of the study area with population data including those from the local government and reviewing existing literatures (Census of Kolkata 2000 and 2016).

Table 6.4.1: Satellite Data used in the study

Sensors	Date Acquired	Path/Row	Bands	Resolutions (meters)	Datum/ UTM Zone	Source
Landsat 7 TM	11-02-2001	138/44	4, 3, 2 & 6	30	WGS84/45	USGS
Landsat 8 OLI (TIRS)	06-01-2016	138/44	5,4,3&10	30	WGS84/45	USGS

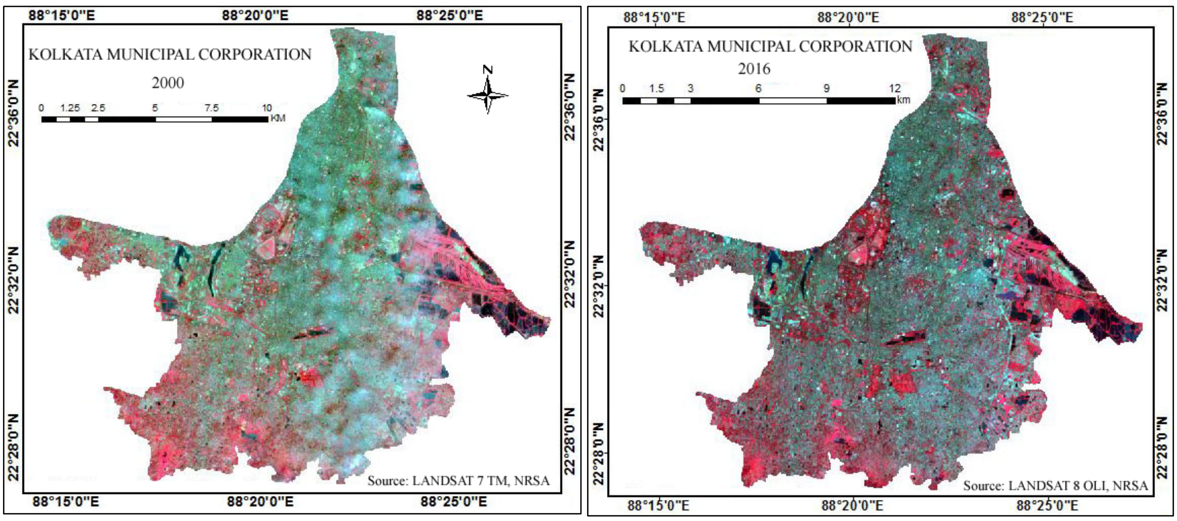


Figure 6.4.1: Satellite imageries of KMC for the year 2000 and 2016

For pollution data, this study has used data collected from different weather station of West Bengal Pollution Control Board and their website (http://www.wbpcb.gov.in/). The historical weather data has been obtained from the popular weather underground website (http://www.wunderground.com).

6.5 Methodology and outcome

These studies add to the body of knowledge by providing greater proof of the link between urban heat trends and air pollution. However, none of these studies have made full use of the cutting-edge satellite remote sensing and GIS technologies, which have been shown to be the most appropriate and efficient for processing spatial data, such as patterns of land use and cover. Through several steps of the correction process, current remote sensing technology enables the acquisition of reasonably good quality Land Surface Temperature estimates.(Voogt and Oke, 2003).The flexible environment offered by GIS technology makes it possible to enter digital data from a variety of sources, and it is an effective tool for studying numerical correlations between and within map layers. When analyzing the interactions between spatial variables such urban land use, pollution, and temperature fluctuation within an urban setting, it is desirable that an integrated strategy of remote sensing and GIS may be devised and utilized.

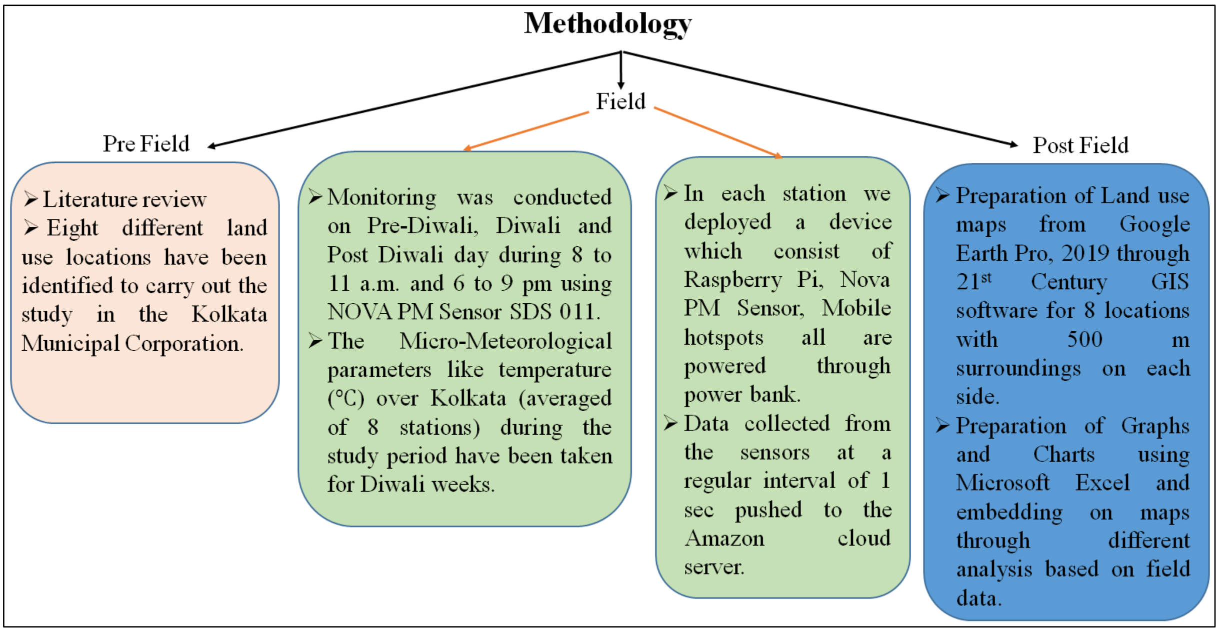


Figure 6.5.1: Methodology

6.6 Result and Discussion

6.6.1 Analysis of Land use land cover

Land use land cover patterns for 2000 and 2016 were mapped using Landsat 7 TM and 8 OLI data. Based on topographic maps those were scaled to 1:50,000, each Landsat picture was corrected to the UTM WGS 84 coordinate system. Bands 4, 3, 2 for Landsat 7 TM and 5, 4, 3 for Landsat 8 OLI were determined to be the most successful at differentiating each class and were chosen for classification. These pictures were resample using the nearest neighbor technique with a pixel size of 30m for all bands.

Table 6.6.1.1: Scenario of LST, PM_{10} and Land Use in Kolkata Metropolitan Area in 2000 and 2016

Station Name	Latitude	Longitude	LST 2000	LST 2016	PM_{10} $\mu g/m^3$ (2000) January - September	PM_{10} $\mu g/m^3$ (2016) January - September	Land Use Type & Colour
Mominpur	22.527067	88.321946	30	32	198 - 44	299 - 51.67	Builtup area (BU)
Ultadanga	22.595489	88.382633	28	29	259 - 68	323 - 57	Dense Builtup (DBU)
Baishnabghata	22.470776	88.391671	24	25	241 - 47	305 - 42	Mid rise Builtup (MRBU)
Topsia	22.539706	88.387482	23	24	271 - 62	299.33 - 62	Builtup area (BU)
Behala Chowrasta	22.486557	88.313647	26	27	271 - 60	352 - 59	Dense Builtup (DBU)
Minto Park	22.540393	88.354960	25	25	311 - 83	304 - 60.33	Builtup area (BU)
Shyambazar	22.601271	88.373950	28	29	272 - 60	369 - 71	Dense Builtup (DBU)
Moulali	22.560612	88.364416	28	29	236 - 59	323 - 55	Dense Builtup (DBU)
Rabindrabharati	22.626990	88.378885	28	28	165 - 38	349 - 61	Vegetation cover (VC)
Hide Road	22.525445	88.305774	27	28	201 - 44	310 - 62	Builtup area (BU)
Picnic Garden	22.529011	88.381753	25	26	277 - 59	321 - 82	Builtup area (BU)
Victoria Memorial	22.541449	88.341528	23	25	253 - 52	322 - 62	Open are (OA)
Paribesh Bhawan	22.562501	88.408574	22	23	178 - 50	268 - 37	Vegetation cover (VC)

Source: West Bengal Pollution Control Board (WPCB), Indian Meteorological Department (IMD) and Netaji Subhash Chandra Bose International Airport Weather Report

6.6.2 Analysis of respirable Particulate Matter (PM_{10}) scenario

As stated earlier, the air quality monitoring in KMA was started in 1955.But relatively systematic air quality monitoring in Kolkata was started in 1984 by NEERI under the CPCB sponsored NAMP. The NEERI monitors the air quality of Kolkata at three stations viz., Cossipore, Lalbazar and Kasba (initially the station was located at Bhowanipore and now shifted to Kasba).The monitoring of RPM was started in 1997.These three stations represent the industrial, commercial and residential areas of the city respectively.

However, during the last two decades the demographic characteristics as also the industrial and urban scenario of the city has changed considerably. Population explosion coupled with increase in number of small industries within the city, sharp rise in automobile population and establishment of settlements near industrial areas like Topsia, Tangra, Behala, Ultadanga etc. have changed the city’s demographic scenario. In true sense, no area of the city can be characterized as either industrial or commercial.

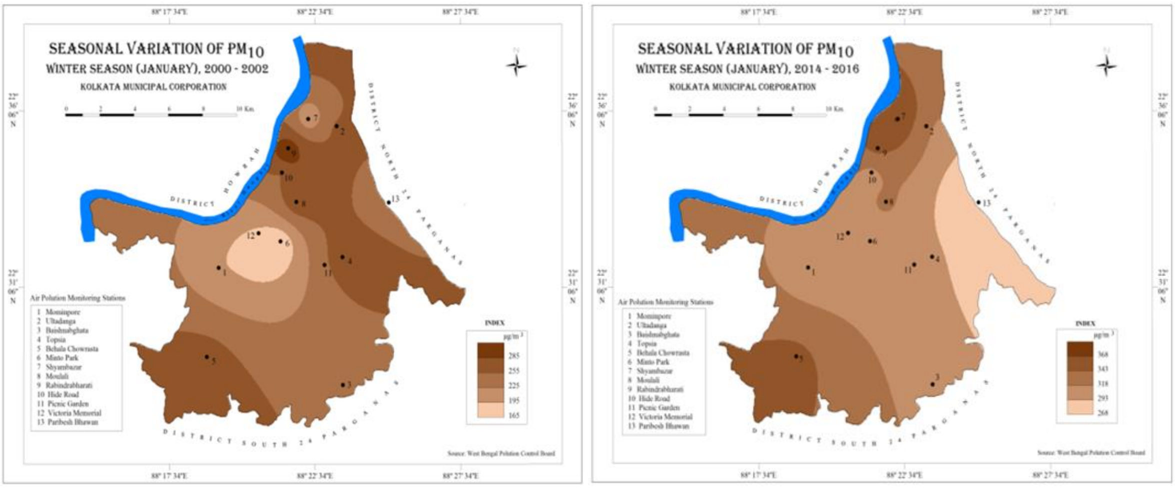


Figure 6.6.2.1: Seasonal variation of PM_{10} within KMC for the year 2000 and 2016 (January)

Respirable Particulate Matter (PM_{10}) range was high in winter season. In the month of January 2000, the maximum PM_{10} range was from 271µgm/m³ to 277µgm/m³ and respectively temperature range was 26˚C, 28˚c and 30˚C and in 2016, this range was from 304µgm/m³ to 369µgm/m³, respectively temperature range was 27˚C, 29˚C and32˚C in different land use area. There were three high levels of PM_{10} centers, one was located at Shyambazar, second at Minto Park, and the other two were located at Mominpur and Behala Chowrasta. The above data shows increased in surface temperature as well as Urban Heat Island forms and air pollutant.

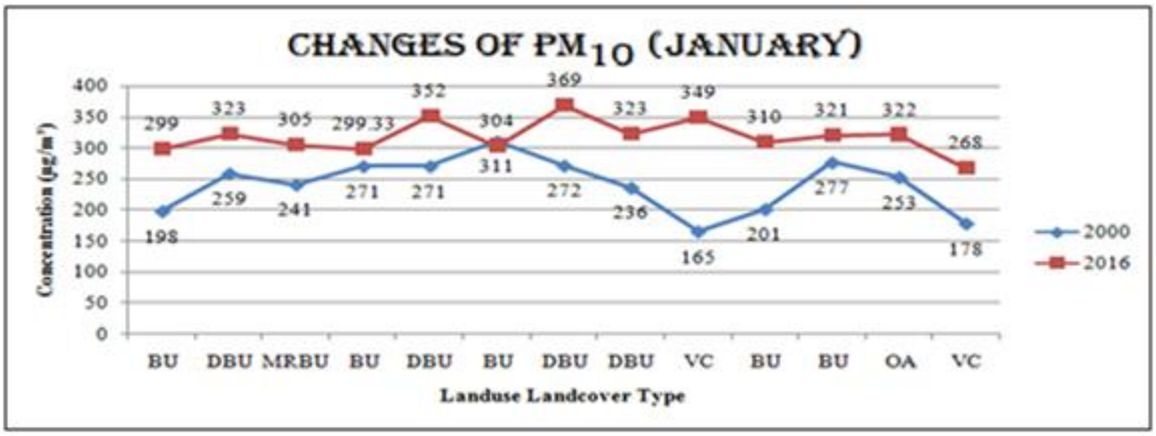


Figure 6.6.2.2: Changes of $PM_{10}$for the year 2000 and 2016 (January)

Source: KMC, LANDSAT Image of USGS & West Bengal Pollution Control Board

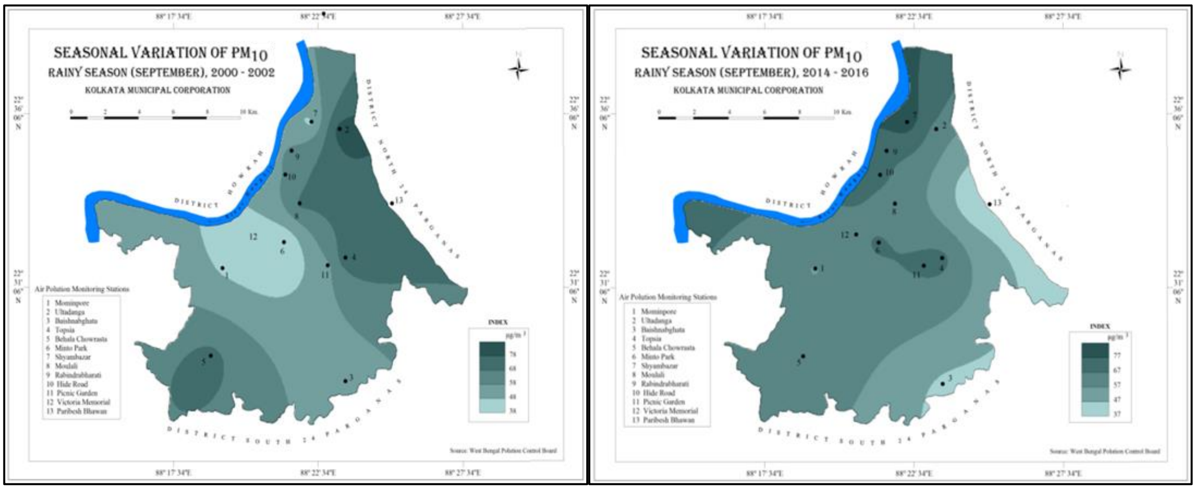


Figure 6.6.2.3: Seasonal variation of PM_{10} within KMC for the year 2000 and 2016 (September)

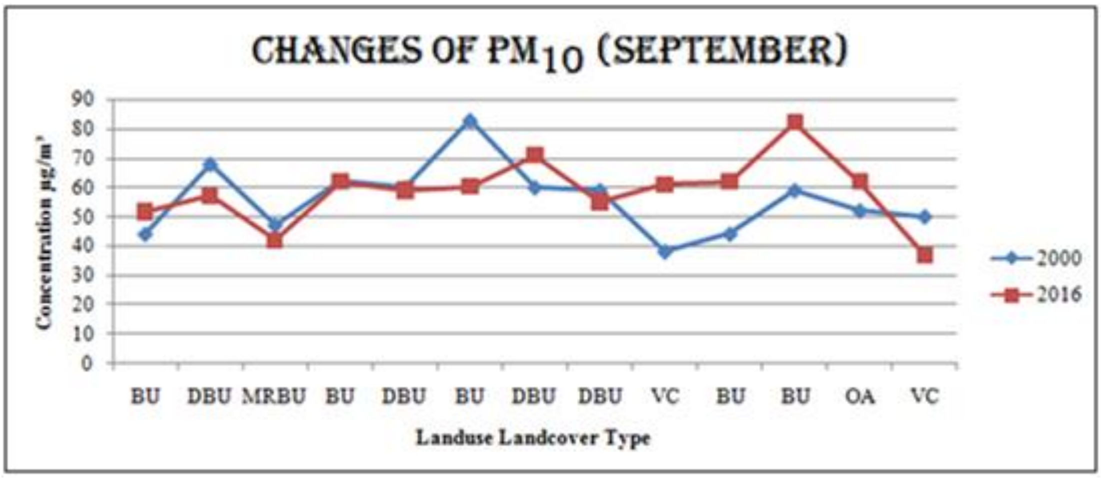


Figure 6.6.2.4: Changes of $PM_{10}$for the year 2000 and 2016 (September)

Respirable Particulate Matter (PM_{10}) and Surface Temperature range was low in rainy season due to the aerosol particles which get bounded with the water droplets and fall in the form of rain. In the month of September 2000, the maximum PM_{10} and temperature range were from 81µgm/m³ to 77µgm/m³ and 22˚C to 24˚C respectively. But in the year 2016, this range was from 88µgm/m³ to 80µgm/m³, 23˚C to 25˚C in different land use area.

The monthly arithmetic averages of PM_{10} levels showed that they were greater throughout the winter (November through March). In figure 6.6.2.2, the changes of PM_{10} have shown within the Kolkata Metropolitan area from 2000 to 2016 of 2 years interval.

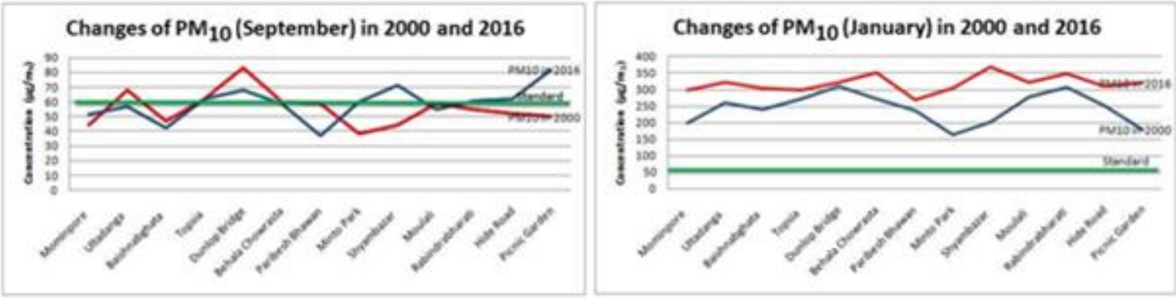


Figure 6.6.2.3: Changes of PM_{10} in the month of September & January for the year 2000 and 2016

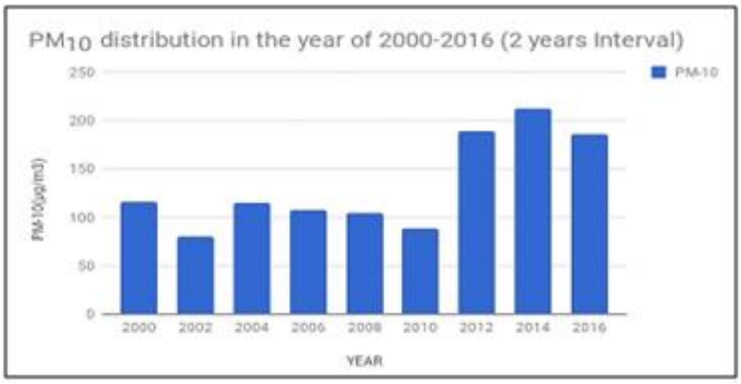


Figure 6.6.2.4: Distribution of PM_{10} within the year of 2000 – 2016

Data Source: West Bengal Pollution Control Board (Kolkata)

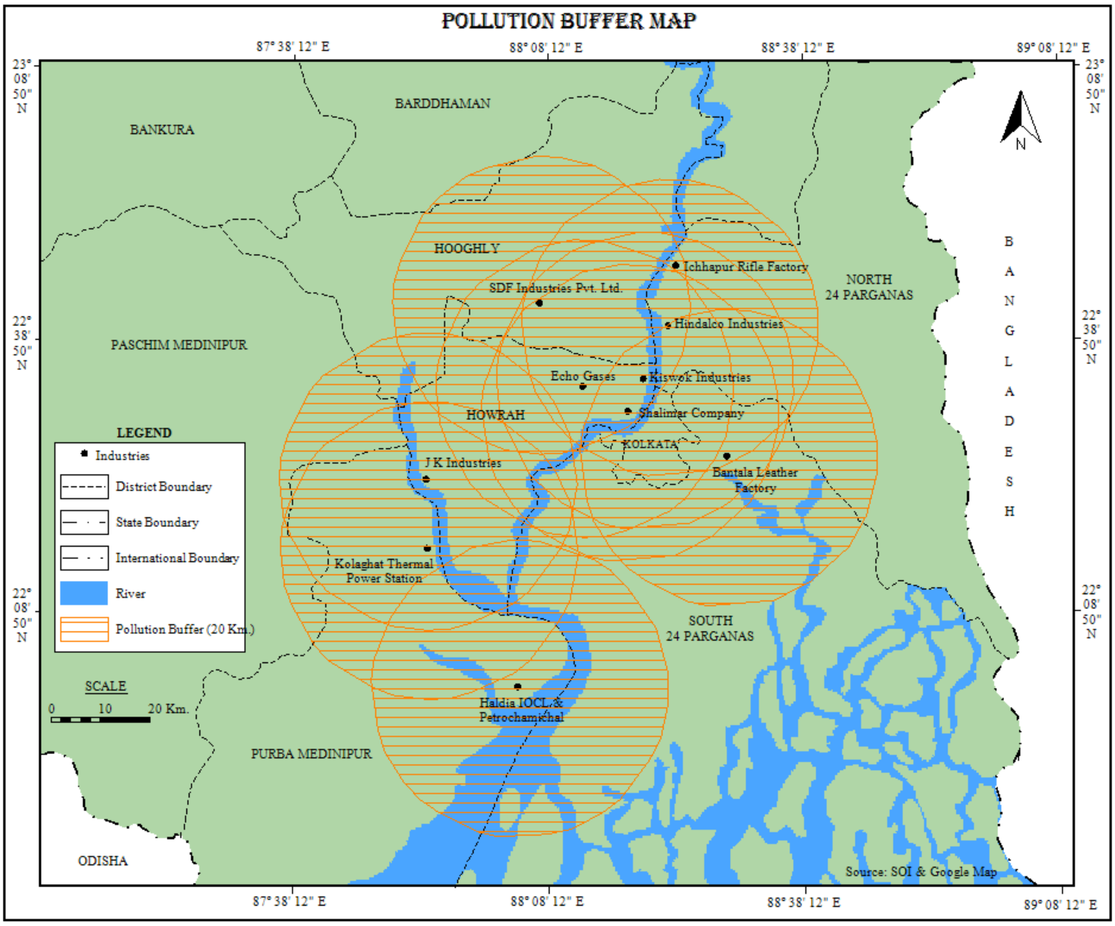


Figure 6.6.2.5: Pollution Buffer **Source: Prepared by the Author**

Buffer zones are created by the surroundings of sensitive or significant areas. There are three basic ways that pollution buffers can impact local and regional air quality: by lowering temperatures, by removing air pollutants and by having an impact on how energy-efficient buildings are. In the 6.6.2.5 figure, the KMC buffer zones have been depicted.

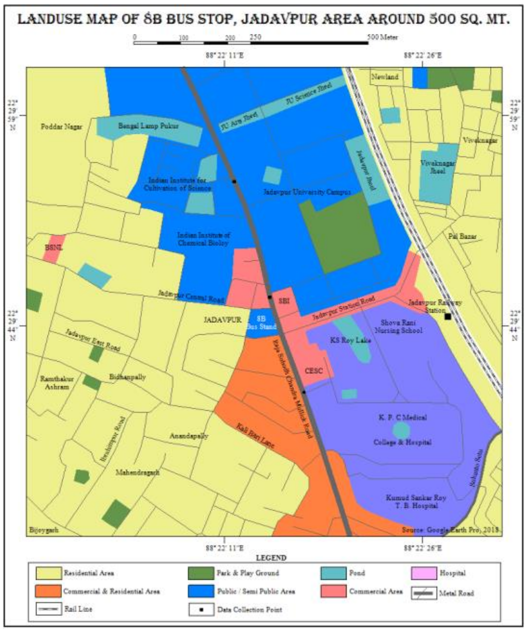


Figure 6.6.2.6: Land use map of Jadavpur 8B Bus Stop

Figure 6.6.2.7: Land use map of Baghajatin More

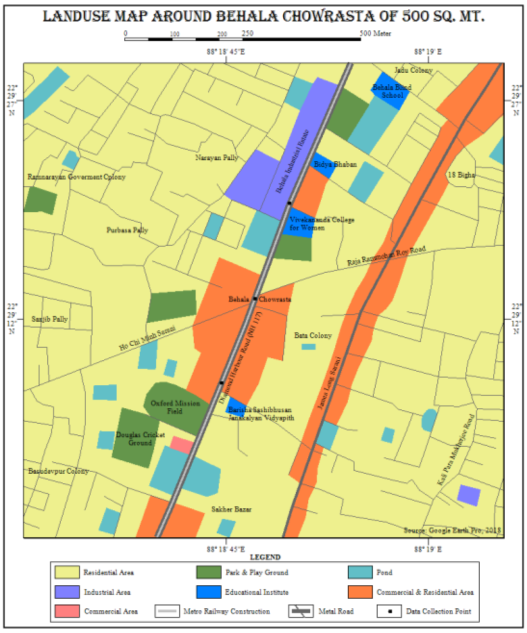


Figure 6.6.2.8: Land use map of Behala Chowrasta

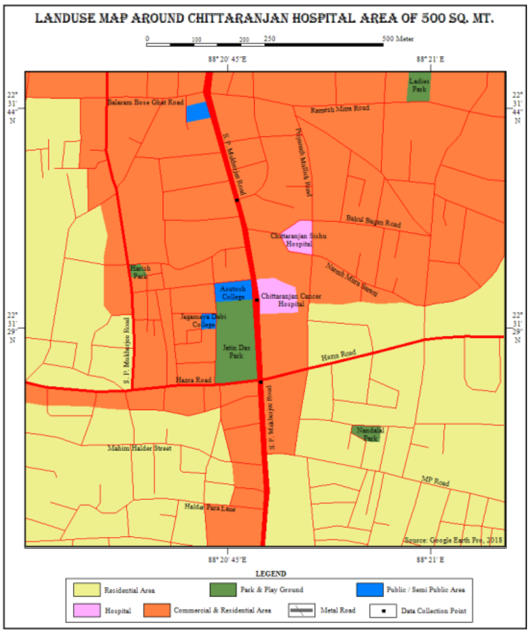


Figure 6.6.2.9: Land use map of Chittaranjan Hospital

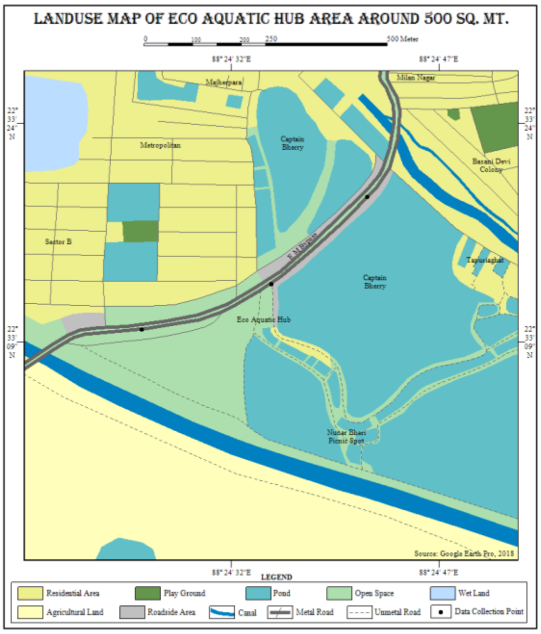


Figure 6.6.2.10: Land use map of Eco Aquatic Hub

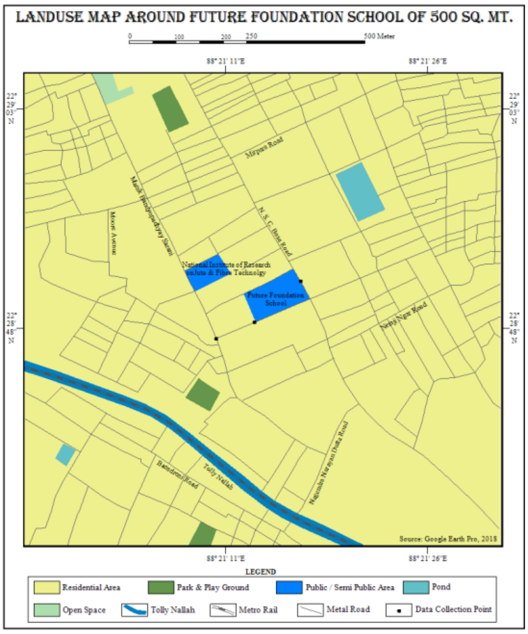


Figure 6.6.2.11: Land use map of Future Foundation

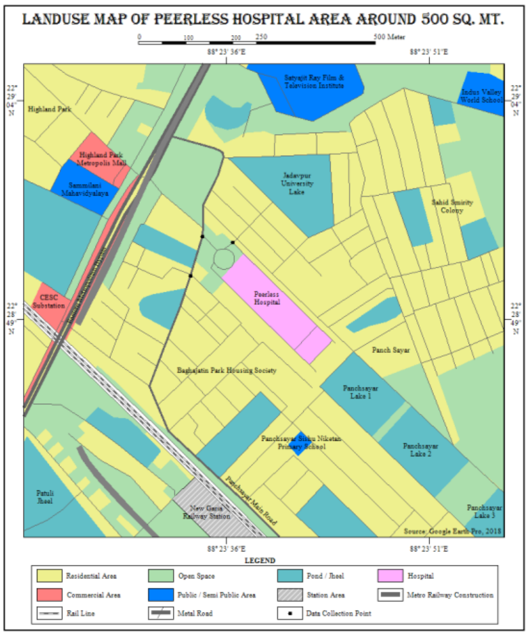


Figure 6.6.2.12: Land use map of Peerless Hospital

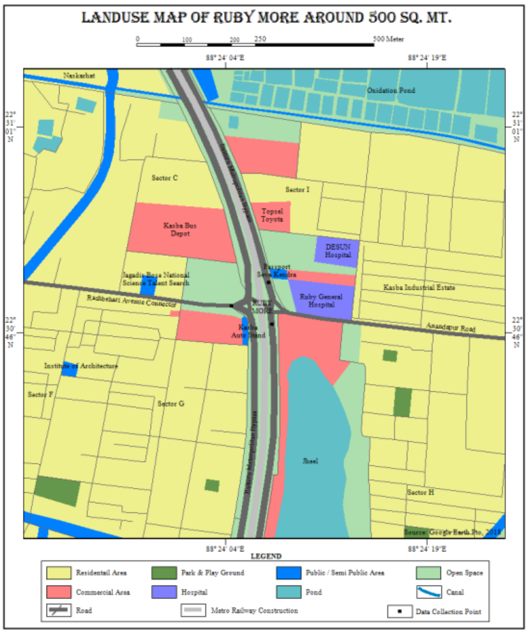


Figure 6.6.2.13: Land use map of Ruby More

6.6.3 Comparative analysis of urban Land Use pattern, PM_{10}& LST

Choropleth maps were produced to show the spatial distribution of PM_{10} and temperature variation for the year 2000 and 2016. Every metropolitan or built-up region has a temperature that is comparatively high. There are some easily discernible "hot patches" (the highest temperature class). The largest hot spot was discovered in 2000 in the northern and western Kolkata metropolitan area, which was a densely populated and busy area of the city. Other noticeable hot spots were detected in the western corner of the proper city, which were Mominpur, Behala Chowrasta having dense built up with high traffic zone.

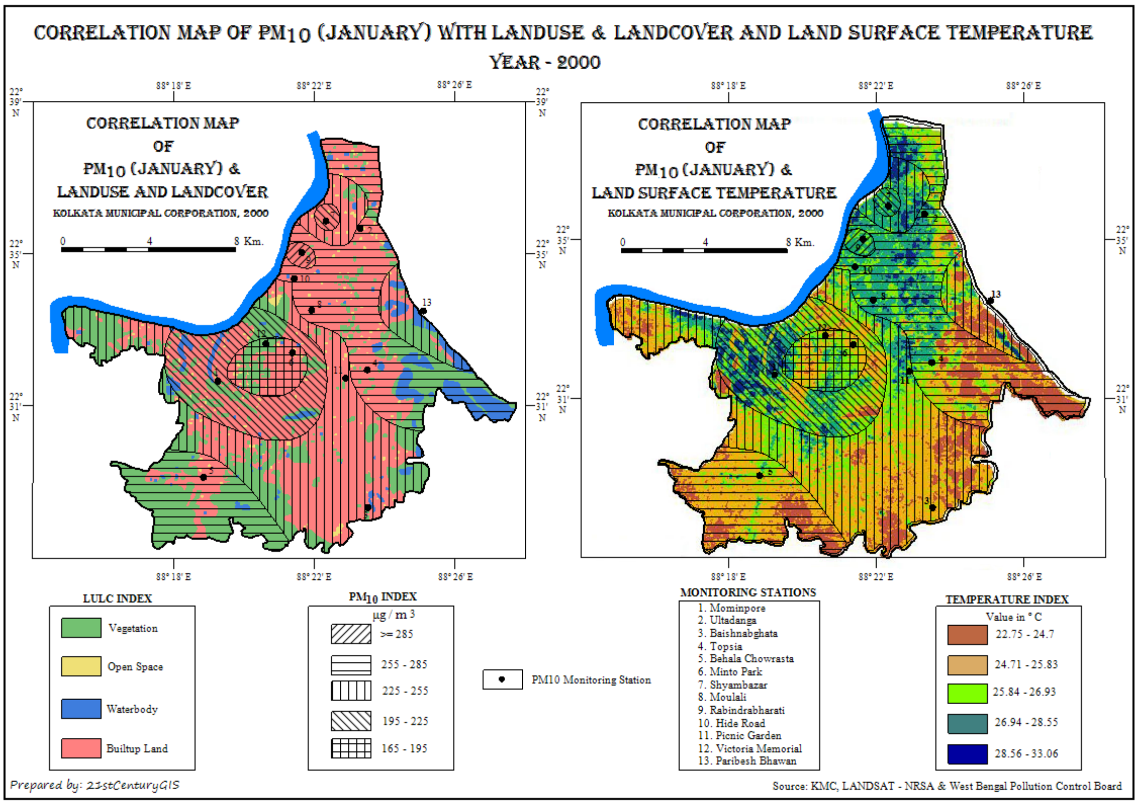


Figure 6.6.3.1: Correlation map of PM_{10} (January, 2000) with LULC and LST

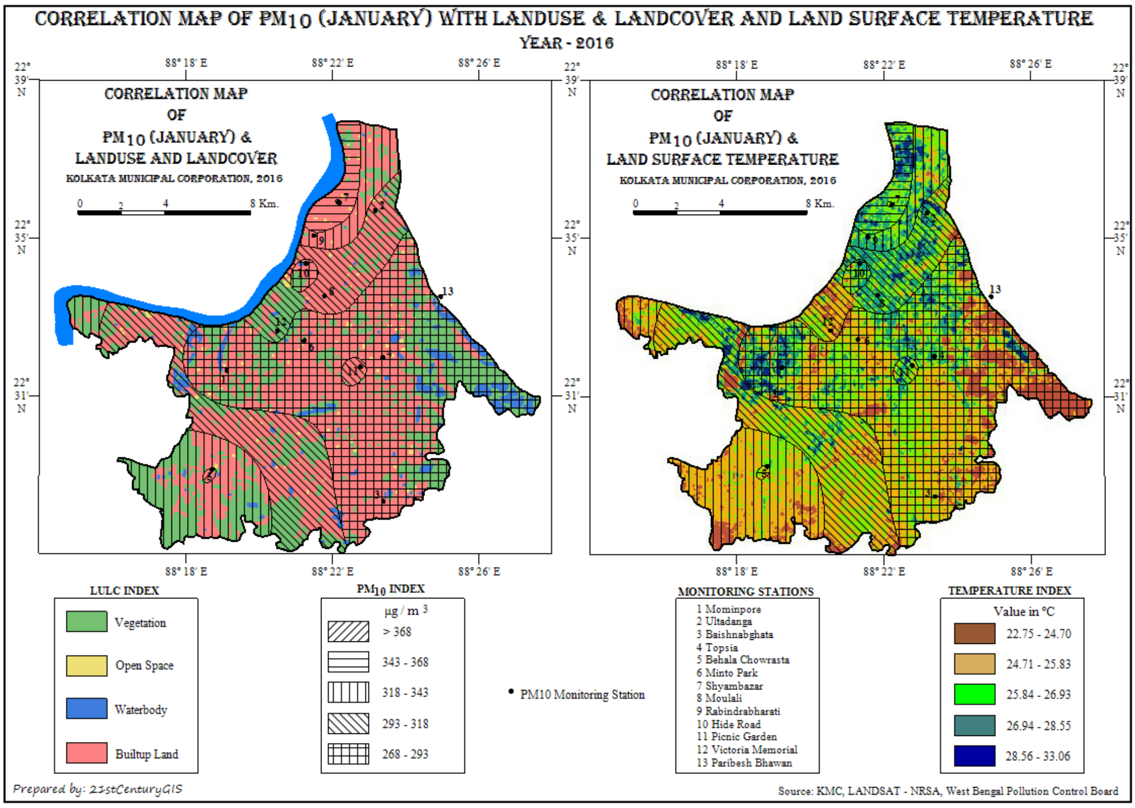


Figure 6.6.3.2: Correlation map of PM_{10} (January, 2016) with LULC and LST

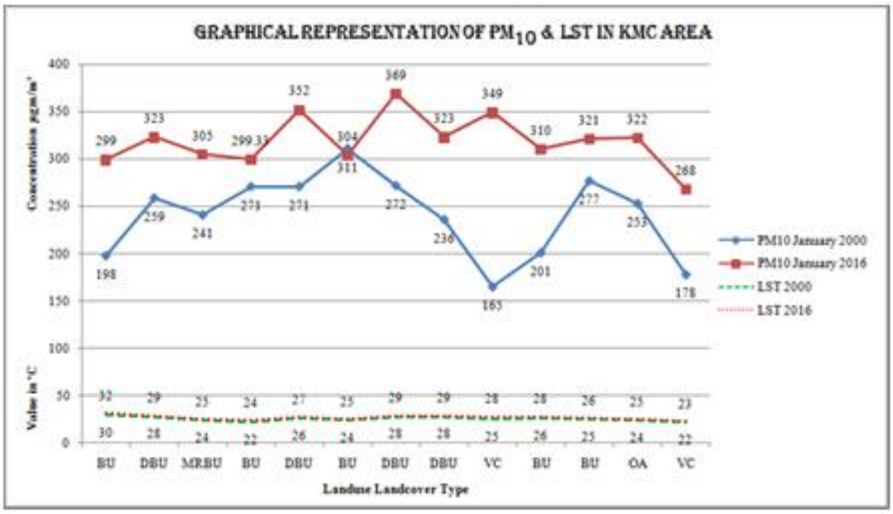


Figure 6.6.3.3: Graphical representation of PM_{10} with LST of KMC for the year 2000 and 2016

Form the above graphical chart (figure 6.6.3.3), it can be concluded that the high density areas experienced an increase in temperature from minimum value of 22˚C and maximum value of 30˚C (in January, 2000) to 23˚C minimum and 32˚C maximum (in January, 2016). Also in the same way, PM_{10} range is high in built up area and its respectively high traffic zone experienced an increase in PM_{10} from minimum value of 165µg/m³ and a maximum value of 311µg/m³ (in 2000) to 299µg/m³ minimum and 369µg/m³ maximum (in 2016). The above data shows increased in surface temperature and PM_{10} has a positive relationship with Builtup area. The study can conclude that there is a positive relationship among builtup area, PM_{10} and Land Surface Temperature.

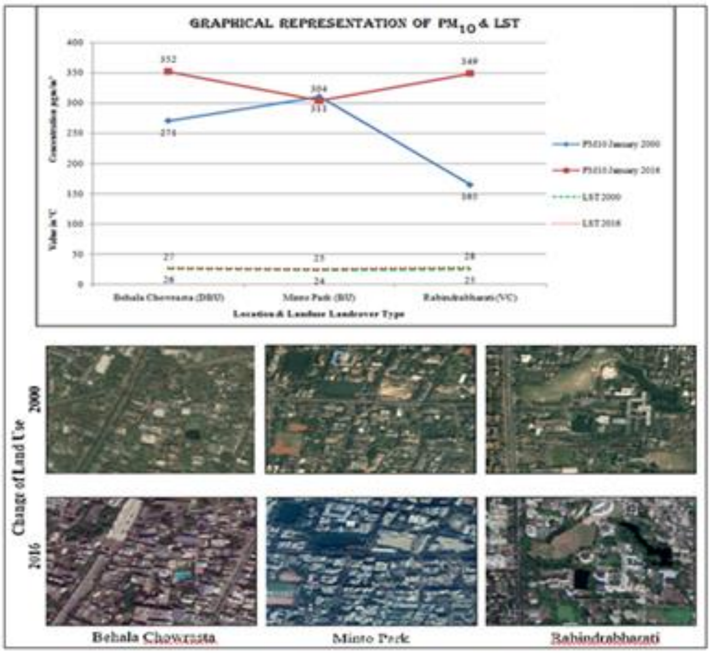


Figure 6.6.3.4: Graphical Representation of PM_{10}& LST at Behala Chowrasta, Minto Park and Rabindrabharati
Data Source: Google Earth and West Bengal Pollution Control Board

This graphical representation (figure 6.6.3.4) includes 3 main highlighted spots of city Kolkata, namely Behala Chowrasta, Minto Park and Rabindrabharati, which indicate the rapid changes of Land Use Land Cover Over and as well as urbanization scenario. A gap of 16 years as calculated from 2000, it also signifies the remarkable difference in Land Surface Temperature during this period.

Relationship between Land Use pattern and respirable Particulate Matter /PM_{10} (Air Pollutant)

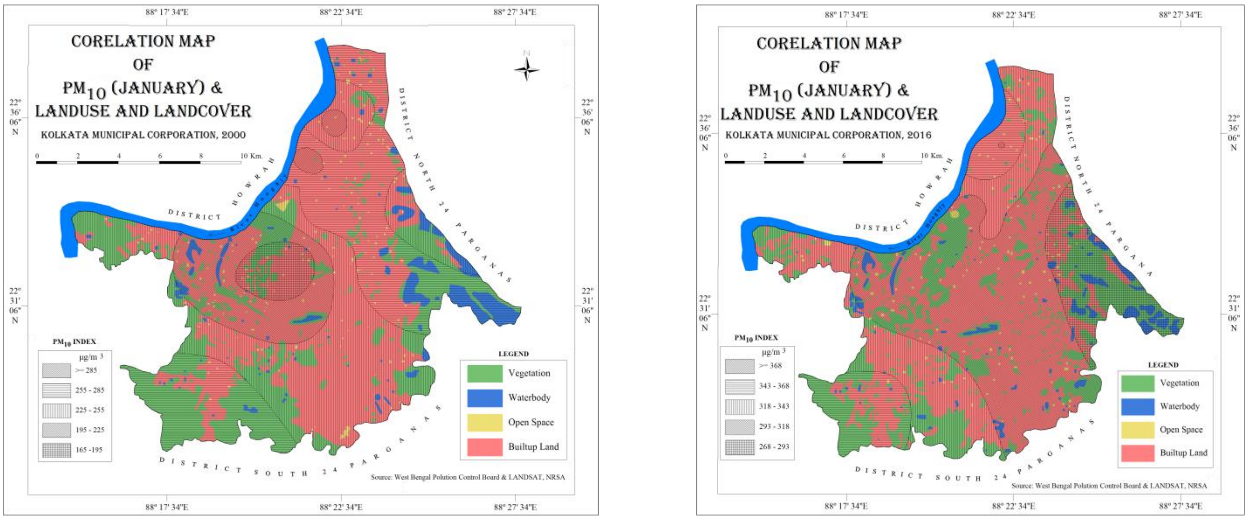


Figure 6.6.3.5: Correlation between Land use and PM_{10} for the year 2000 and 2016

6.7 Conclusion

Particulate pollution and four types of main land use pattern were extracted in representative metropolitan of 2000 - 2016. In order to investigate and describe how particle pollution reacts to LULC in the three characteristics listed below, a correlation between LULC and particulate pollution was also computed:

- The time-lag impact of LULC on particle pollution, the fluctuation trend of particulate pollution with LULC, and the main factor changes affecting urban Air Quality.
- In Victoria Memorial, which is obviously impacted by the plant cover, the link between LULC and particle pollution is quite modest. Due to high-speed urban growth and heavy traffic areas, urban land has a strong link with particulate pollution in Mominpur, Topsia, Moulali, and Shyambazar. High traffic zones show obvious effects on the Air Quality in the city of Kolkata. Water bodies and Open Space are significantly related to particulate pollution in different part of Kolkata.

Chapter 7: Analysis and Observation on Urban Heat Island effects with respect to Air Quality in the special occasion of Diwali, LST and LULC change

This part of the work has been published in -

1. *Sohini Sen, Debashish Das, Anupam Deb Sarkar, Raja Ghosh "Investigating Real-Time Ambient Air Quality Status and Land Surface Temperature during Kalipuja / Diwali Festival in different Land use types – Case study Kolkata", International Journal of Advances in Mechanical and Civil Engineering (IJAMCE), Volume-7, Issue-1, pp. 21-27), ISSN (P): 2394- 2817, International Journal of Advances in Mechanical and Civil Engineering (IJAMCE) December 2019. Peer Reviewed Journal.*
2. *Sohini Sen, Ashwini Kumar Singh, Debashish Das, Anupam Deb Sarkar, Raja Ghosh, "A Study of the Spatio-temporal Variations in PM_{10} and $PM_{2.5}$ with Air Temperature, Traffic Volume and Different Land Use Types during the Diwali Festival Period: A case study of Kolkata, India", ISSN: 0046- 9017 (Print), ISSN : 2456 – 6519 The Indian Journal of Spatial Science, 2021.*

7.1 Introduction

In the metropolitan cities of India, it is generally observed that very small sized particles, i.e., Particulate Matter (PM) are deposited in vegetation ecosystems and industrial areas with high pollution and a high density of buildings and vehicular activities. PM is a complex mixture of various elemental and organic substances such as carbon, ammonium nitrates and sulphates. Singh *et al.*, (2009) studied the temporal variation in ambient air quality during the Diwali festival in India (including pre Diwali, Diwali and post Diwali) and on a foggy day.

Air Quality in metropolitan cities and other developed urban centers is a serious problem due to the high pollutant concentrations and associated health-related issues. The causes of lung cancer and cardiopulmonary mortality are particulate and Sulphur-oxide pollution sources from various combustion-related fine particulate emissions and long exposure to them (Pope *et al.*, 2002). During the Diwali festival, extensive burning of firecrackers is the most common source of short-term anthropogenic pollution and causes serious health issues. Specifically, air quality degradation due to firecrackers has been reported during the Diwali festival in India (Kulshestha *et al.*, 2004, Mandal *et al.*, 2011).

The energy balance and atmospheric heating rates can be impacted by extensive land cover change and air pollution emissions, which may then have an impact on the intensity of UHI. The development of smog and contaminated air is accelerated by high temperatures in urban areas

(Yang *et al*., 2011).Urban and suburban areas have varied loads of particulate matter, which results in different radiative forces and variations in surface temperatures (Wu *et al*., 2017).A city's ambient air warms up because air pollutants including particulate matter, water vapour, and carbon dioxide absorb heat energy from the surface and reemit it into the atmosphere. The intensity of UHI is increased by airborne pollutants, while the dispersion of the pollutants is hampered by temperature increases (Peterson, 1969).

The aerosols in the atmosphere exhibit different spatial distribution and concentration pattern. Although they are not necessarily the source and sink of aerosols, meteorological factors such wind speed, wind direction, air temperature, and surface temperature have a significant impact on aerosol concentration and dispersion. Natural aerosols, which have anthropogenic origins and are important at the regional level, also have a significant influence on a global scale (Coakley *et al.*, 1983, Kaufman and Fraser, 1983, Coakley and Cess 1985, Ramachandran *et al.*, 2012). Another significant source of particulate matter is the smoke from the burning incense in the temples surrounding Kanpur, India, where PM_{10}mass concentrations of more than 2100 µg/m3 have been seen inside the temples (Goel *et al.*, 2017). It is vital to undertake studies at the micro scale because, according to a comparison of the lives of aerosols and greenhouse gases, aerosols have a short life span. As a result, their influence at the micro or regional size is greater than at larger scales.

The gases from roadside tea and food vendors, vehicle emissions, and building activity are some of the most significant causes of air pollution above Kolkata. The WHO's air quality requirements are far stricter (WHO, 2006) than the National Ambient Air Quality Standards of India, which call for an annual average PM_{10} value of 60µg/m^3 (The Gazette of India, 2009).In 2015, a number of locations in Kolkata had yearly average PM_{10} readings greater than 80 g/m^3, and several locations greater than 100 g/m^3.

The city of Kolkata, where industrial growth is moderate and commercial and residential growths are high, is located in the southeastern part of India. The city has 4496694 residents as per the 2011 Census. In the West Bengal state's Ganga basin, this major metropolis also holds enormous potential as a hub for business, education, housing, transportation, and agricultural endeavors. The large metropolis observes the Diwali celebration, during which different kinds of firecrackers are let off, seriously polluting the air. This sporadic increase in atmospheric PM_{10} and $PM_{2.5}$ has a negative impact on local visibility, the global climate, and human health, particularly respiratory health. However, during a pandemic, pollution levels in the nation's cities drop significantly within a short period of time. The findings show that the air quality dramatically improved during lockdown. In comparison to the (Susanta Mahato *et al.*) pre lockup period, PM_{10} and $PM_{2.5}$ concentrations have shown the greatest reduction among the studied pollutants. The reduction in PM_{10} and $PM_{2.5}$ throughout the specified time period was significantly greater than 60% and 39%, respectively, when compared to the year 2019.

Diwali was celebrated throughout India on 7thNovember in the year of 2018, and people in West Bengal celebrated Kalipuja on 6th November 2018 also. On the night of Diwali (7th November), after lighting diya (typically, clay lamps with cotton wicks that have been soaked in ghee or oil), fireworks have been started and continued for two days from 6thto 7th November, 2018.

Kolkata has been considered as study area to understand the effect of short term anthropogenic pollution due to extensive burning of firecrackers during Diwali days. The effect was more pronounced because of its high population density. The climate of Kolkata is characterized by dry winters and warm summers. In Kolkata, there is 1582 mm (62.3 inches) of rainfall each year on average of which 95% occurs during the monsoon season. The southeastern monsoon brings moisture to the state during the period from middle of June to middle of September. The annual mean temperature and monthly mean temperature range are 24.8°C (80°F) and 15°C to 30°C (59°F to 86°F), respectively. Summers are hot and muggy, with lows of 30°C (86°F) and highs that frequently approach 40°C (104°F) in May and June. Winter typically lasts just around two and a half months, with seasonal lows between December and January falling between 9°C to 11°C (48.2°F to 51.8°F). In the mornings, the humidity is around 96%, while in the afternoons, it is 67%.

7.2 Study Area

Eight distinct land use patterns and traffic zone locations in southern Kolkata were the sites of the study. The first site,8B Bus Stop is situated beside the institute campus (Jadavpur University) at Jadavpur and others are Baghajatin Crossing, The Future Foundation School, Hazra Crossing (Chittaranjan Cancer Hospital), Ruby Hospital Crossing, Eco Aquatic Hub, Peerless Hospital and Behala Chowrasta.

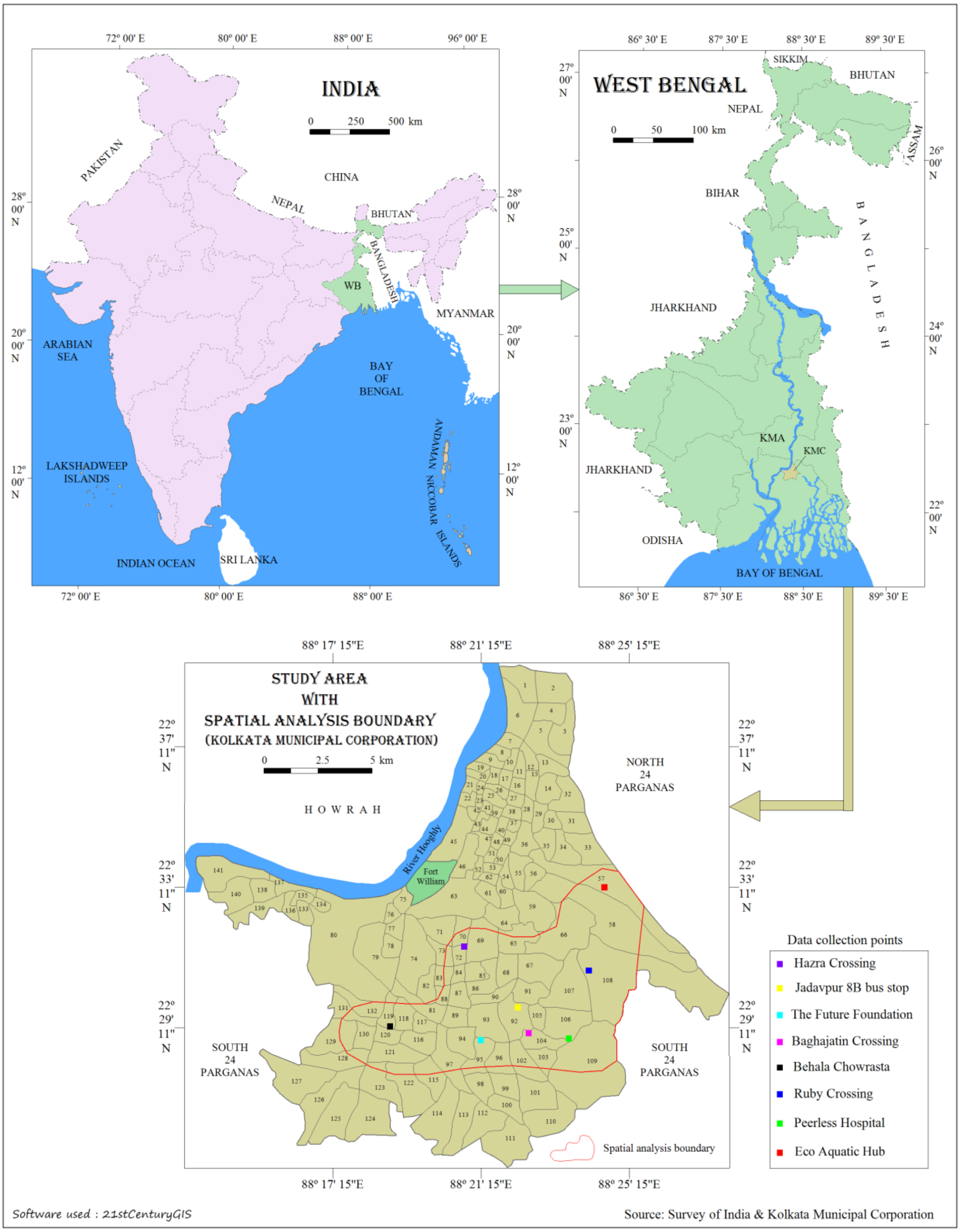


Fig 7.2.1: Location map of study area

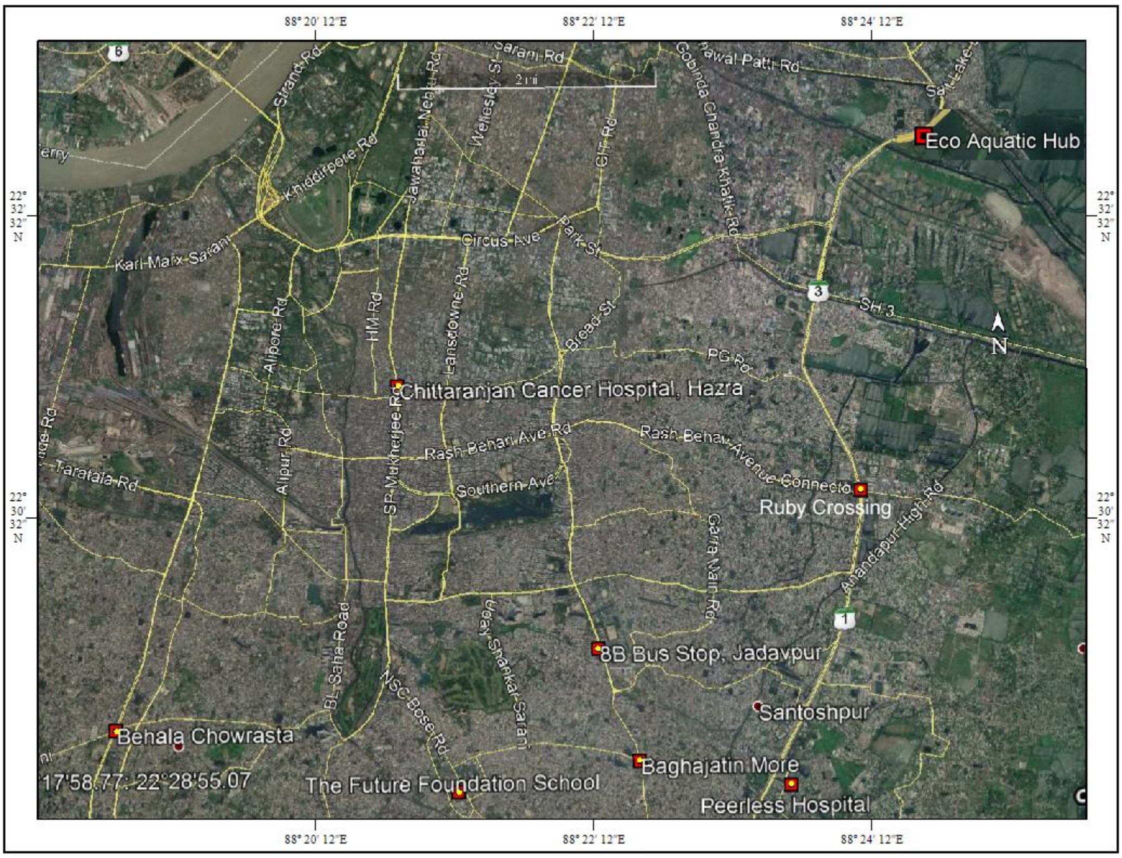


Figure 7.2.2: Google image showing eight surveyed stations

7.3 Land use map of eight stations

Eight stations were selected for the study and land use map of 500 square kilometre surrounding area of these station have been plotted. It seems that all these stations lie in the areas having mixed land use of different type of land use categories. Monitoring was conducted near traffic intersections at all these stations namely Jadavpur 8B Bus Stop (mixed land use and high traffic zone, figure 7.3.1), Baghajatin More (mixed commercial / residential and traffic zone, figure 7.3.2), Eco Aquatic Hub (water bodies, mixed residential, commercial and traffic zone, figure 7.3.3), Ruby Crossing (mixed land use and high traffic zone, figure 7.3.4), Behala Chowrasta(mixed land use and high traffic zone, figure 7.3.5), Chittaranjan Cancer Hospital-Hazra Crossing (mixed land use and high traffic zone, figure 7.3.6), The Future Foundation (mixed residential and traffic zone, figure 7.3.7), Peerless Hospital (open area, water bodies, mixed residential and traffic zone, figure 7.3.8).

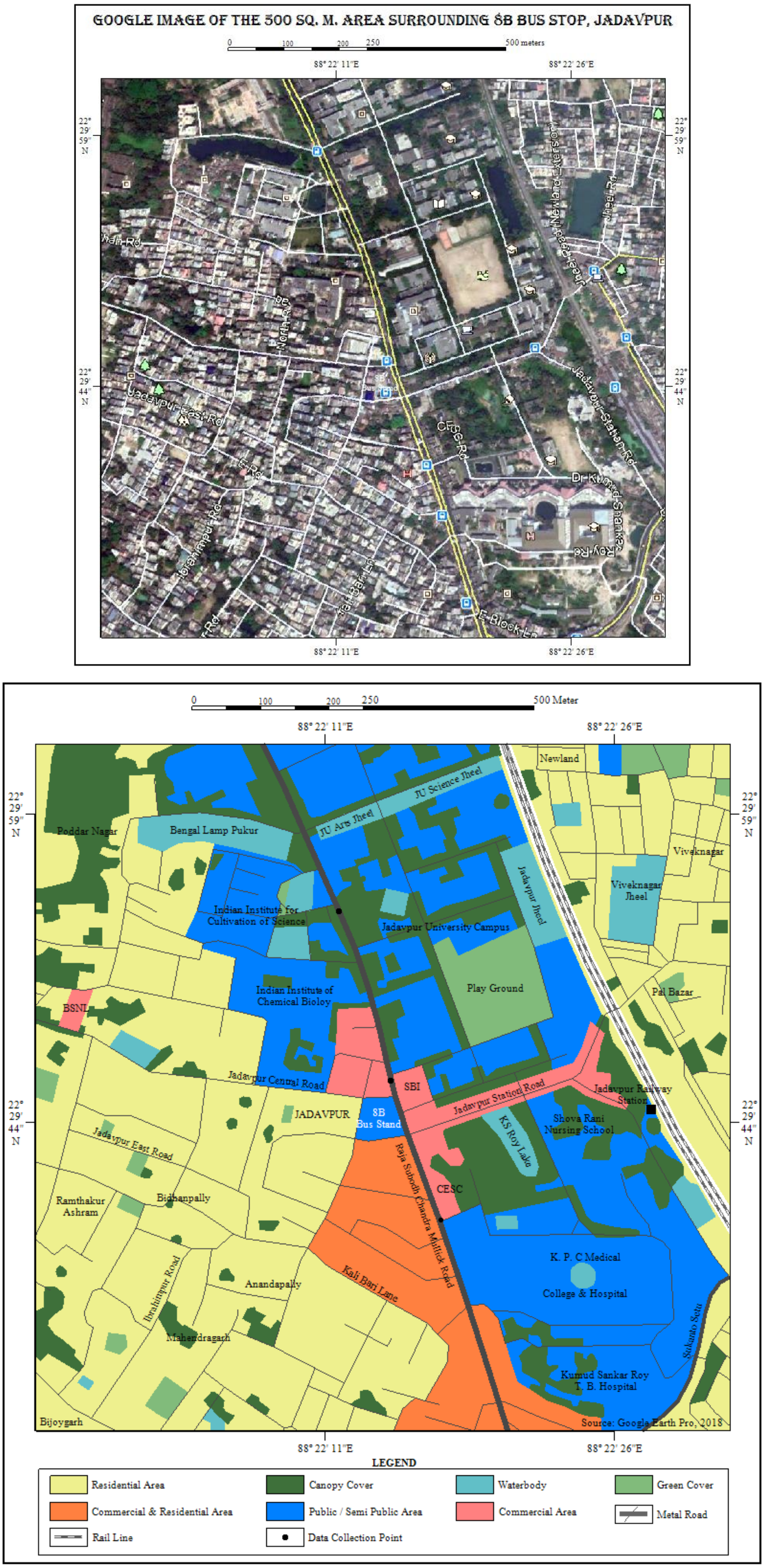


Figure 7.3.1: Google image and land use map of 8B Bus Stop, Jadavpur area

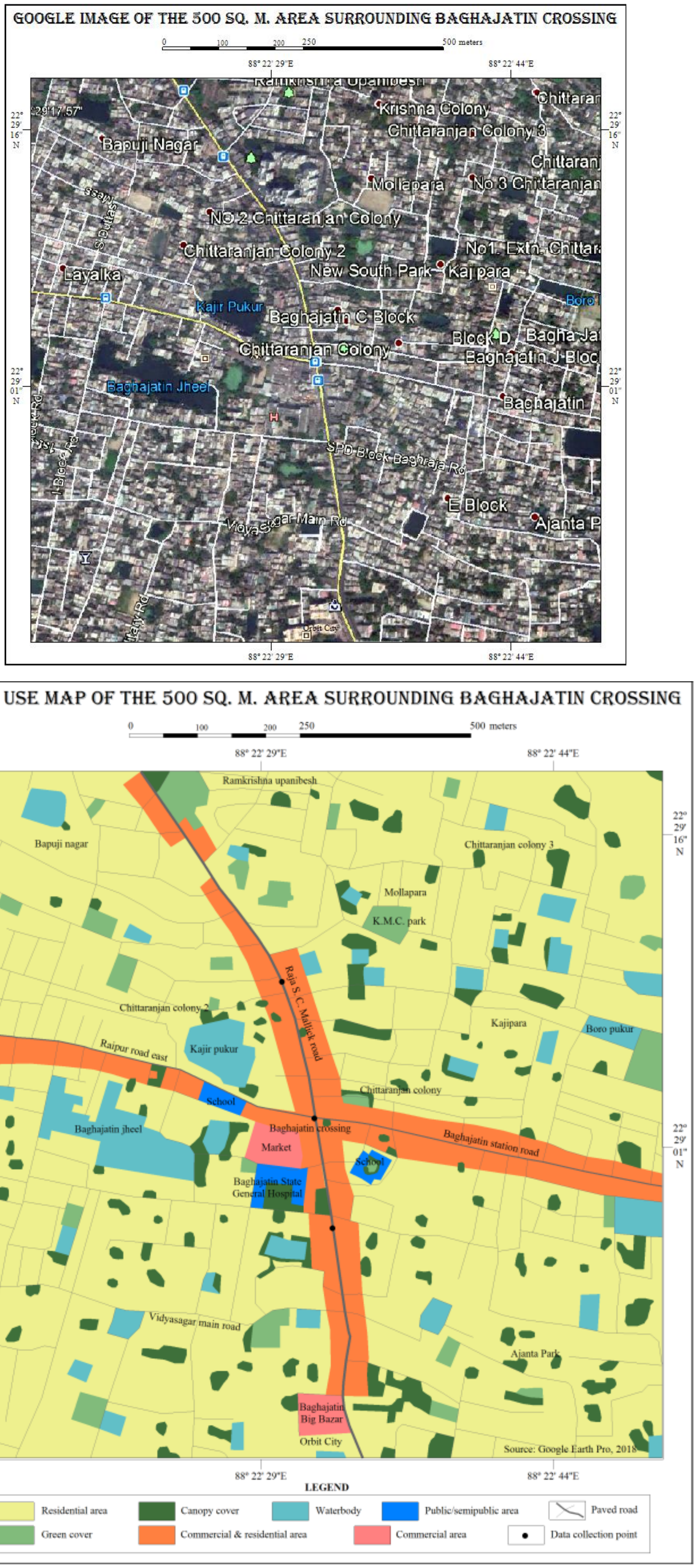


Figure 7.3.2: Google image and land use map of Baghajatin Crossing area

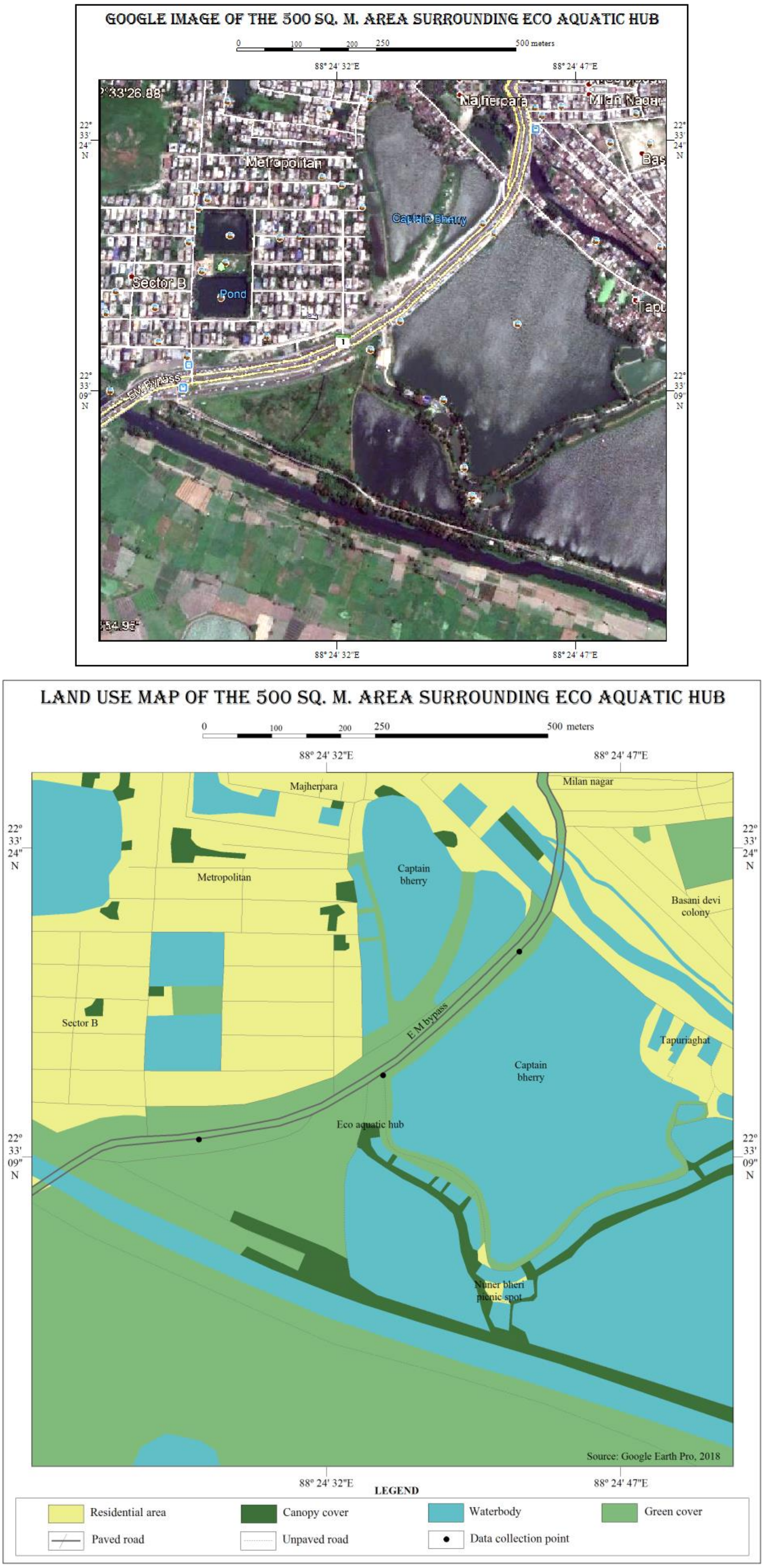


Figure 7.3.3: Google image and land use map of Eco Aquatic Hub area

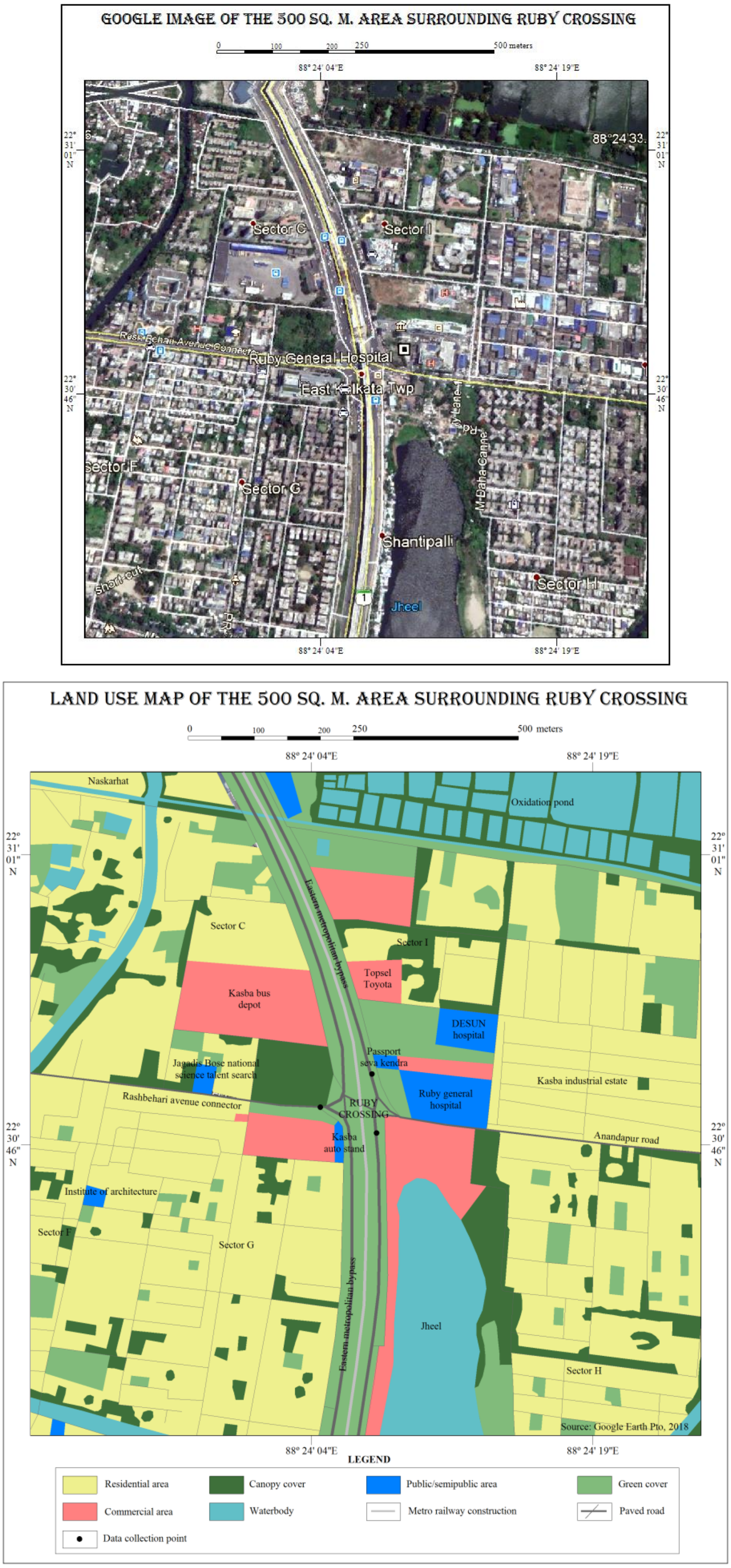


Figure 7.3.4: Google image and land use map of Ruby Crossing area

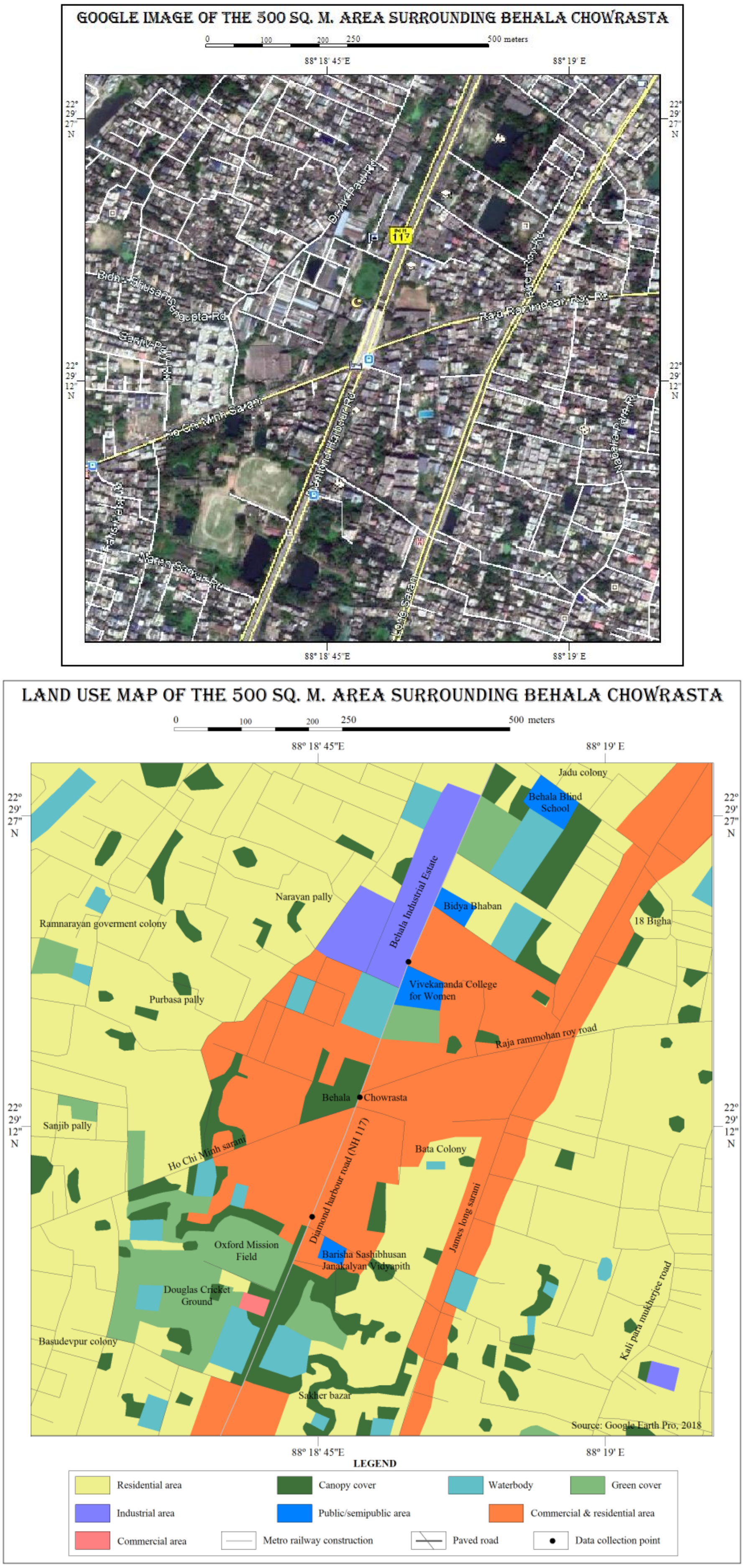


Figure 7.3.5: Google image and land use map of Behala Chowrasta area

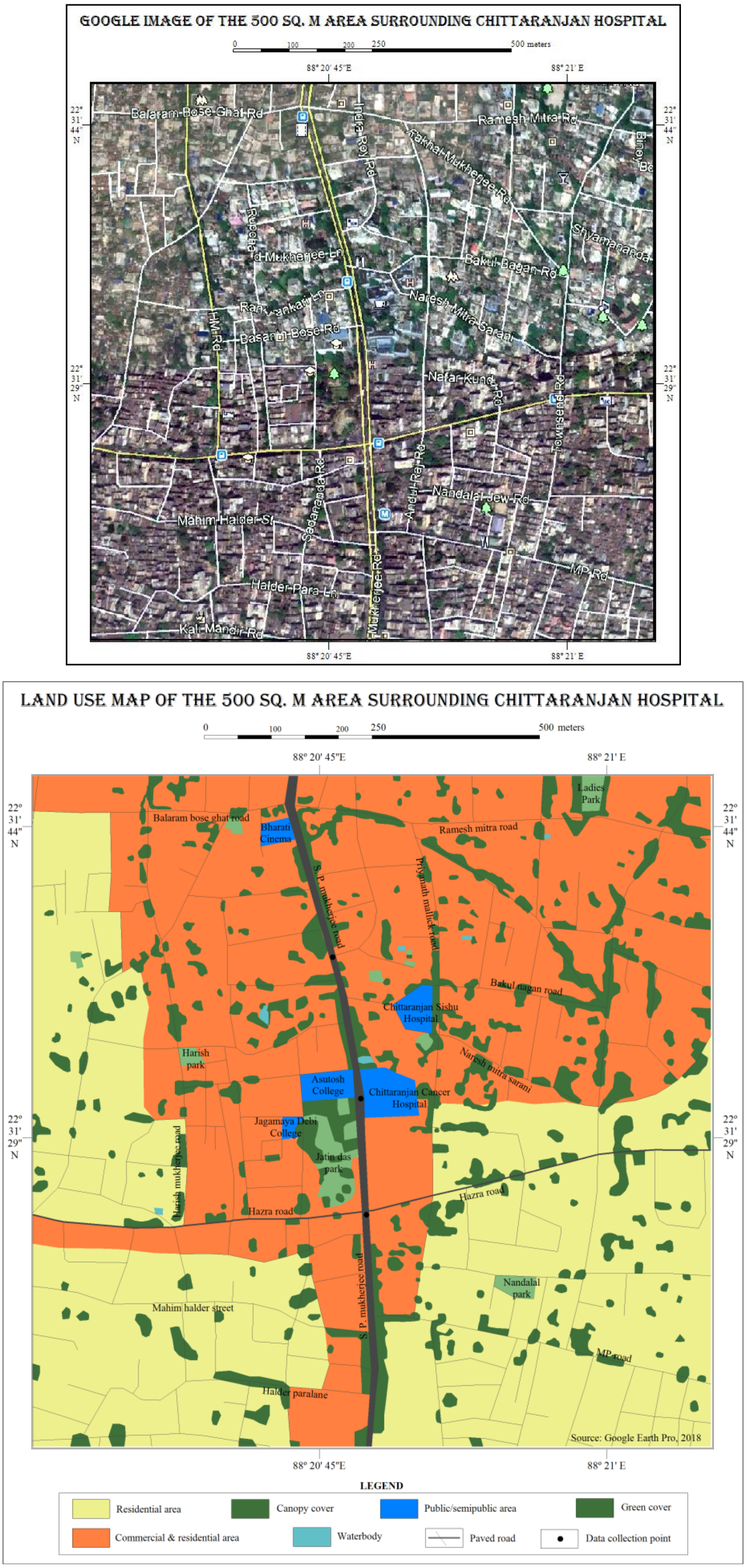


Figure 7.3.6: Google image and land use map of Chittaranjan Hospital area

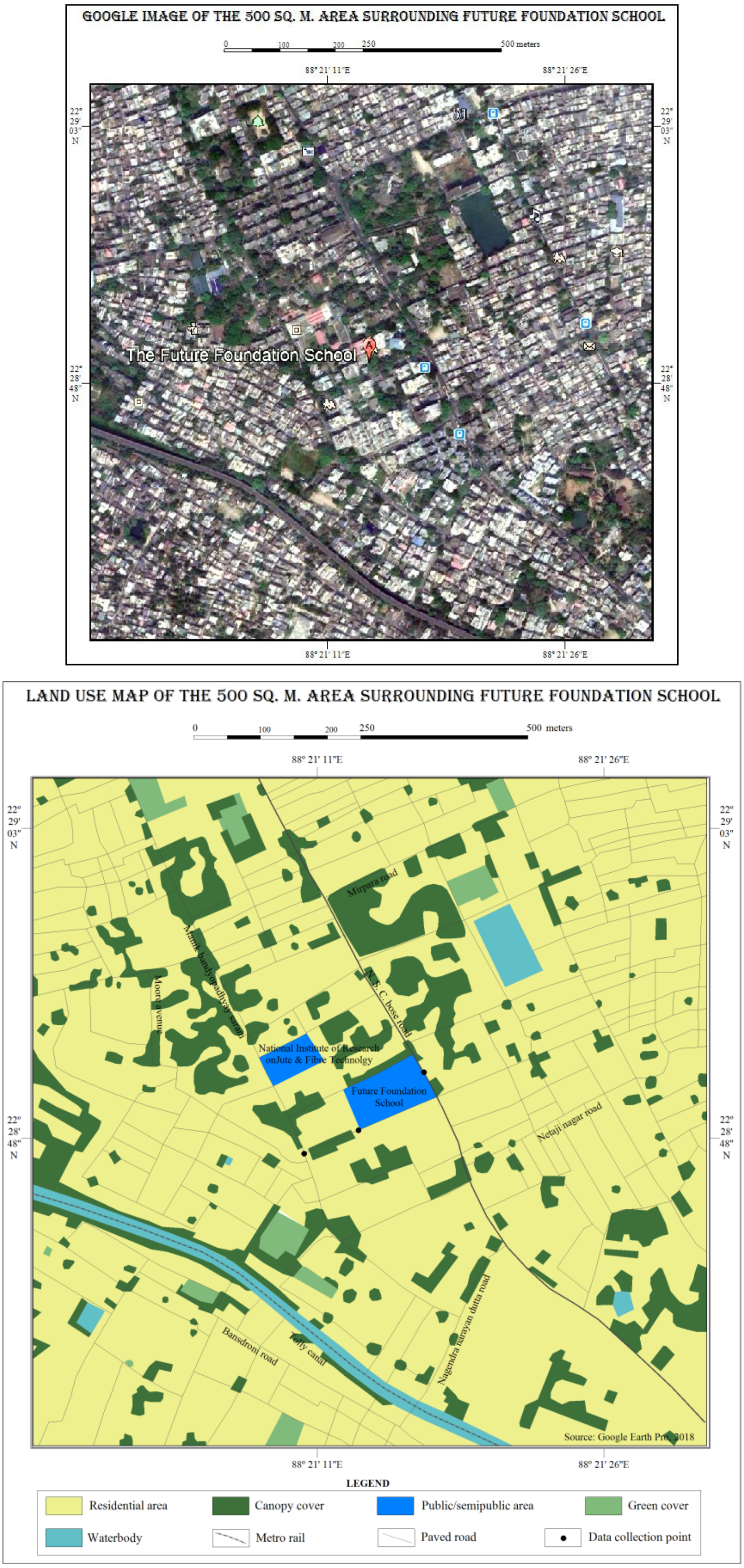


Figure 7.3.7: Google image and land use map of The Future Foundation School area

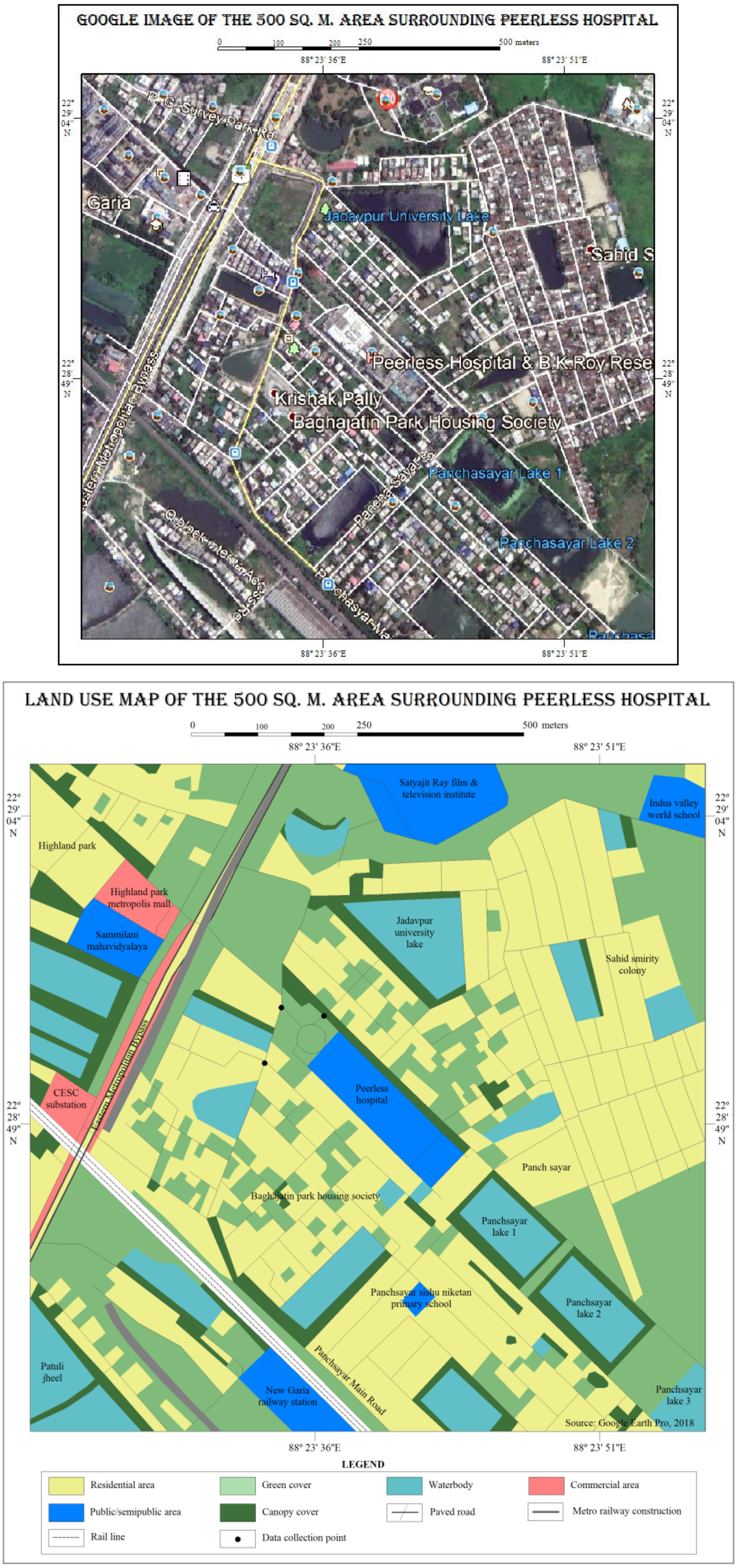


Figure 7.3.8: Google image and land use map of Peerless Hospital area

Table 7.3.1: The percentage of area covered by the different land uses

Sl. No	Location	Mixed Residential	Com &Residential	Green Cover	Public /Semi Public	Canopy Cover	Waterbody	Commercial	Industrial
1	Hazra Crossing	39.27	46.09	1.11	1.39	12.03	0.12	0.00	0.00
2	Jadavpur8B Bus Stop	43.48	6.18	3.09	23.98	15.34	4.84	3.10	0.00
3	Future Foundation	79.47	0.00	1.60	1.21	15.24	2.48	0.00	0.00
4	Baghajatin Crossing	75.07	9.38	2.89	0.20	5.71	5.93	0.81	0.00
5	Behala Chowrasta	65.69	12.42	5.58	0.95	8.21	4.41	0.10	2.63
6	Ruby Crossing	50.95	0.00	15.82	2.03	12.54	11.71	6.94	0.00
7	Peerless Hospital	44.42	0.00	26.87	6.54	7.55	12.67	1.96	0.00
8	Eco Aquatic Hub	25.98	0.00	32.25	0.00	3.96	37.81	0.00	0.00

7.4 Graphical analysis forVariation of $PM_{2.5}$, PM_{10} with Temperature and Traffic Volume (PCU) during the three days of Diwali (2018) period

Table 7.4.1: Variations in $PM_{2.5}$ and $PM_{10}$with Temperature and volume of traffic inthepre Diwali period

Station	Geographical Coordinates	Land Use	Time	$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	Temperature (°C)	Traffic Volume (PCU)
Hazra Crossing	22.52298	COM & RES	Day	72.55	111.00	28.00	3054
	88.35248		Night	88.00	138.50	27.00	3848
Jadavpur 8B Bus Stop	22.4957604	COM	Day	65.25	110.50	27.00	3243
	88.3682580		Night	85.75	142.20	26.00	4001
Future Foundation	22.4805049	RES	Day	39.85	59.15	27.00	1184
	88.3516915		Night	56.60	95.40	25.00	929
Baghajatin Crossing	22.4851196	COM & RES	Day	141.00	178.50	27.00	2987
	88.3785494		Night	171.00	248.50	26.00	3840
Behala Chowrasta	22.4864666	COM & RES	Day	156.50	190.50	28.00	4294
	88.3115481		Night	217.65	219.15	26.00	4820
Ruby Crossing	22.510620	COM	Day	283.20	365.60	26.00	7542
	88.382347		Night	398.50	482.35	27.00	9316
Peerless Hospital	22.4806837	RES, OS & WB	Day	55.15	67.50	26.00	1239
	88.3919835		Night	73.55	98.10	24.00	1350
Eco Aquatic Hub	22.5527682	WB	Day	89.00	138.35	27.00	3462
	88.4071480		Night	133.75	187.75	26.00	4275

**** COM – Commercial, RES – Mixed Residential, OS – Open Space, WB – Waterbody**

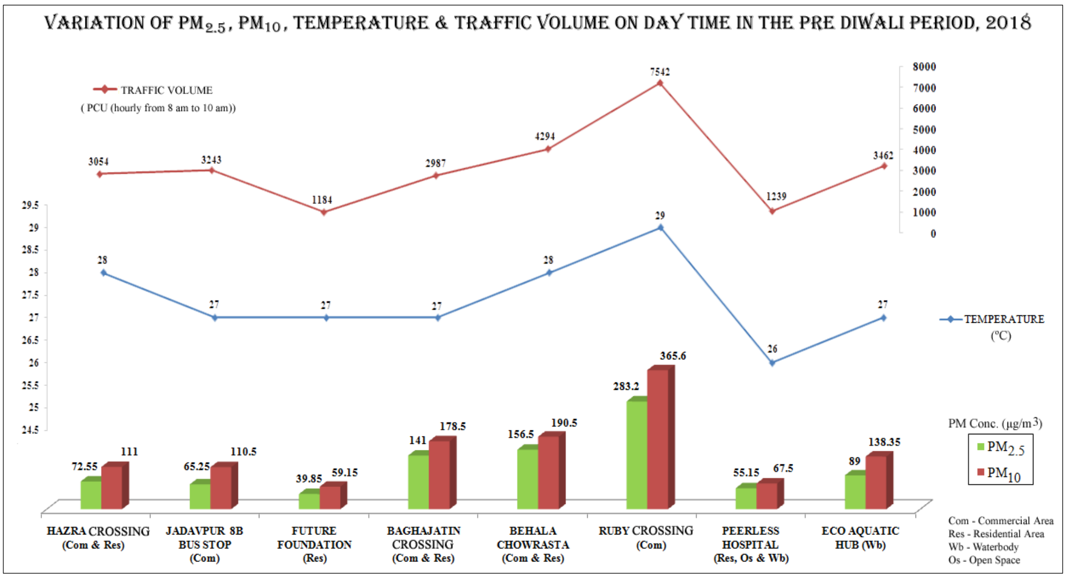


Figure 7.4.1: Graph of Pre Diwali (Day)

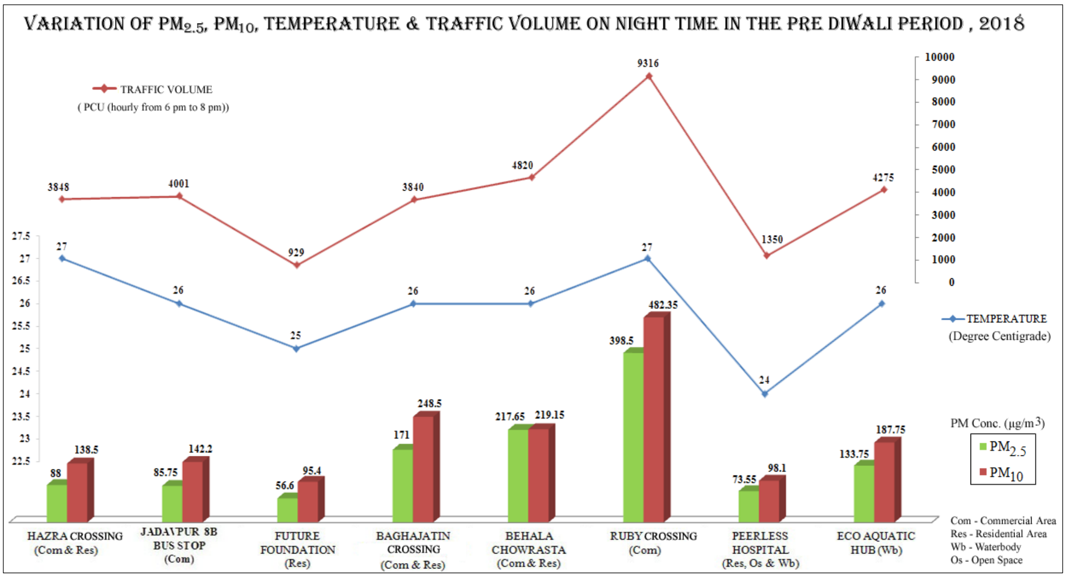


Figure 7.4.2: : Graph showing the variation of $PM_{2.5}$, PM_{10}, Temperature& Traffic volume on the day time of Pre Diwali (Night)

Table 7.4.2: Variations in $PM_{2.5}$ and $PM_{10}$with Temperature and Traffic Volume in the Diwali period

Place	Land Use	Time	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	Temperature (°C)	Traffic Volume (PCU)
Hazra Crossing	COM & RES	Day	153.45	194.17	26.67	3054
		Night	959.00	1460.00	28.67	3464
Jadavpur 8B Bus Stop	COM	Day	146.68	237.92	26.00	3243
		Night	958.00	1438.50	28.00	2987
Future Foundation	RES	Day	107.73	134.20	25.67	1184
		Night	738.50	1183.50	27.33	592
Baghajatin Crossing	COM & RES	Day	158.45	204.58	26.67	2987
		Night	860.00	1349.50	28.33	2419
Behala Chowrasta	COM &RES	Day	222.58	297.97	27.33	4294

		Night	951.00	1442.50	29.33	3612
Ruby Crossing	COM	Day	287.20	373.27	28.00	7542
		Night	1052.00	1687.50	30.67	8231
Peerless Hospital	RES, OS & WB	Day	121.58	158.52	24.67	1239
		Night	393.20	517.10	26.67	1193
Eco Aquatic Hub	WB	Day	159.58	272.33	25.33	3462
		Night	472.10	529.85	27.00	3612

**** COM – Commercial, RES – Mixed Residential, OS – Open Space, WB – Waterbody**

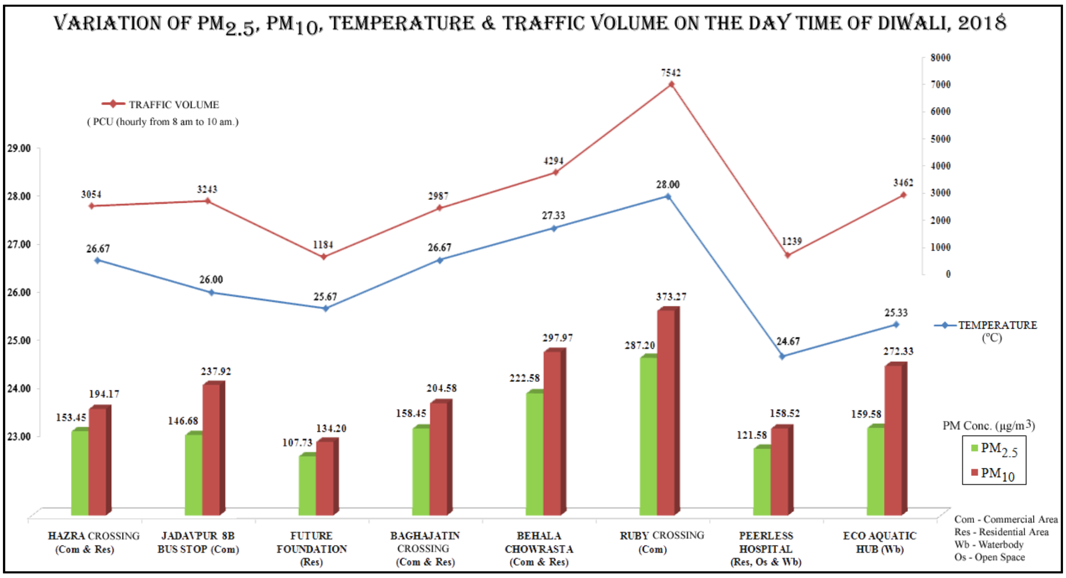


Figure 7.4.3: : Graph showing the variation of $PM_{2.5}$, PM_{10}, Temperature& Traffic volume on the day time of Diwali (Day)

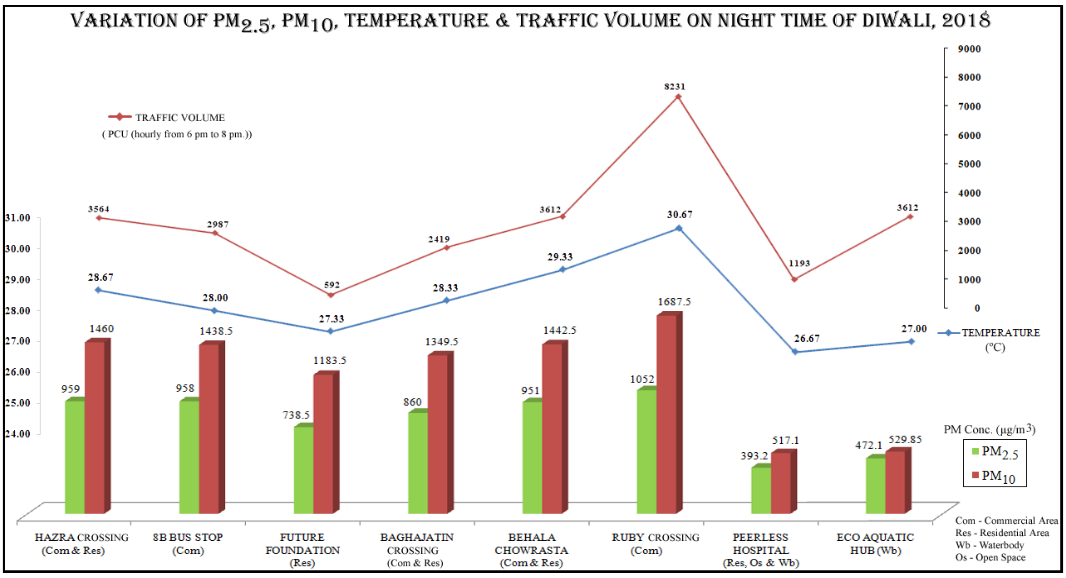


Figure 7.4.4: : Graph showing the variation of $PM_{2.5}$, PM_{10}, Temperature& Traffic volume on the day time of Diwali (Night)

Table 7.4.3: Variations in $PM_{2.5}$ and PM_{10}withTemperature and Traffic Volume in the post Diwali period

Station	Land Use	Time	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	Temperature (°C)	Traffic Volume (PCU)
Hazra Crossing	COM &RES	Day	235.00	315.00	30.00	2986
		Night	226.50	332.50	26.00	3794
Jadavpur 8B Bus Stop	COM	Day	237.65	309.85	29.00	3176
		Night	250.40	310.75	26.00	3819
Future Foundation	RES	Day	188.35	216.50	28.00	1025
		Night	233.25	259.90	26.00	874
Baghajatin Crossing	COM & RES	Day	207.50	234.75	30.00	2843
		Night	288.30	356.00	27.00	3764
Behala Chowrasta	COM & RES	Day	350.35	353.80	30.00	4120
		Night	382.55	443.05	28.00	4795
Ruby Crossing	COM	Day	362.85	408.45	31.00	7348
		Night	406.00	477.75	29.00	9216
Peerless Hospital	RES, OS & WB	Day	201.00	204.10	27.00	3247
		Night	259.85	249.35	25.00	4181
Eco Aquatic Hub	WB	Day	251.00	275.55	27.00	3364
		Night	280.40	299.85	25.00	3854

**** COM – Commercial, RES – Mixed Residential, OS – Open Space, WB – Waterbody**

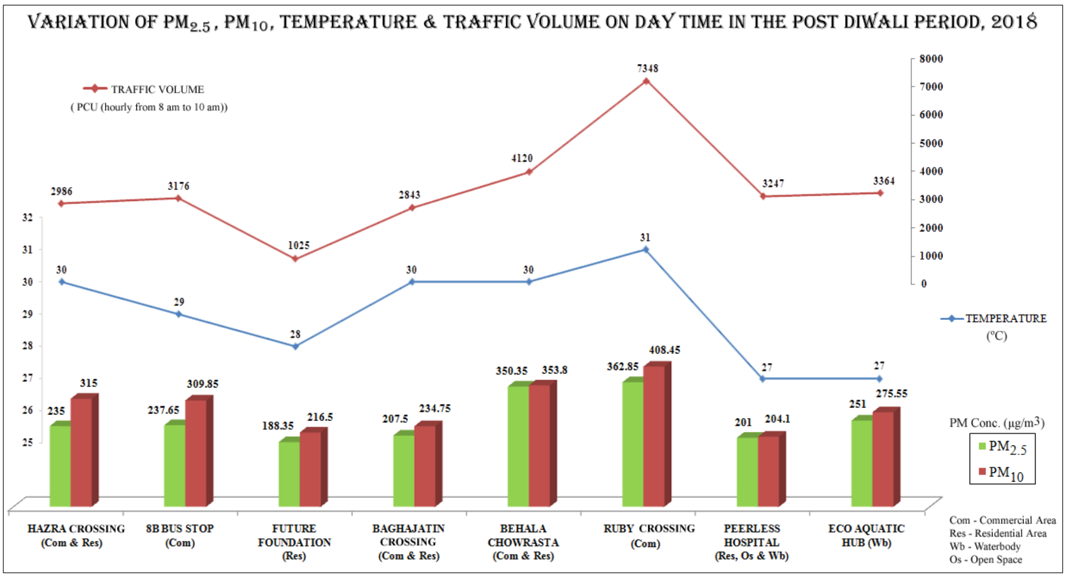


Figure 7.4.5: Graph showing the variation of $PM_{2.5}$, $PM_{10,}$ Temperature& Traffic volume on the day time of Post Diwali (Day)

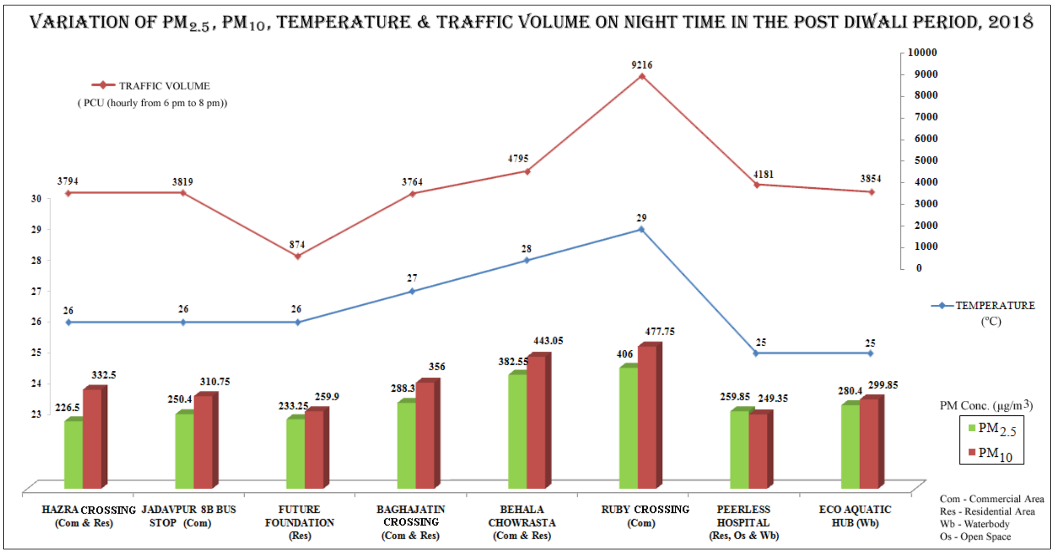


Figure 7.4.6: Graph showing the variation of $PM_{2.5}$, PM_{10}, Temperature and Traffic volume on the day time of Post Diwali (Night)

7.5 Findings

* The highest levels of temperature, $PM_{2.5}$ and PM_{10} were seen in regions with a lot of building activity and traffic. On the days leading up to, during, and following Diwali, the reverse was observed in locations with a relatively high number of water bodies, open space, greenery, and little traffic.
* Among all the land use types studied, the mixed residential, commercial and heavy traffic areas showed the highest average temperature on the day of Diwali compared with that on the pre and post Diwali days. The daytime mean Air Temperature of the In the metropolitan region, LULC types shift away from industrial mixed high-density residential and commercial areas, paved roads, and vegetation toward mixed low-density residential and commercial areas, water bodies, and open areas.
* When compared to the days before and after Diwali, the day of Diwali has heavier traffic and is associated with high air temperature centers (above 28°C to 30°C). On the day of Diwali, the Air Temperature was lowest over water body wide spaces and plant cover come next. Due to construction, traffic pollutants, and pyrotechnics during Diwali, mixed residential and commercial areas experience increased temperatures significantly more quickly than other land use categories.
* The increasing temperature and range of $PM_{2.5}$ and PM_{10} levels observed in certain of the land use categories were represented by a sharp rising curve (i.e., dense mixed residential and commercial areas, areas with high traffic emissions and with substantial use of Diwali firecrackers in Kolkata).

7.6 Relation between LULC change and Air Temperature pattern in the special occasion of Diwali

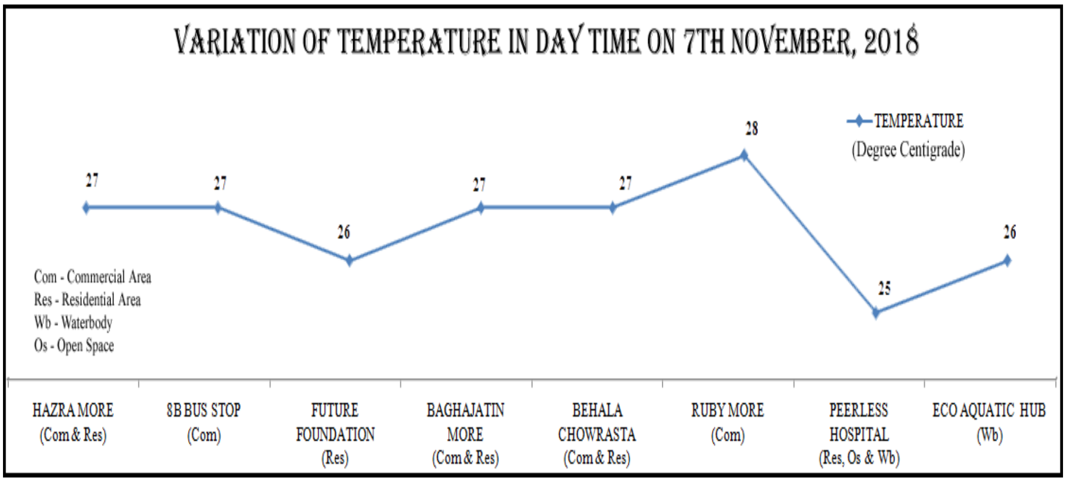


Figure7.6.1: Graph showing the variation of Temperature in different types of land use for 8 stations during the day time on Diwali (7th November 2018)

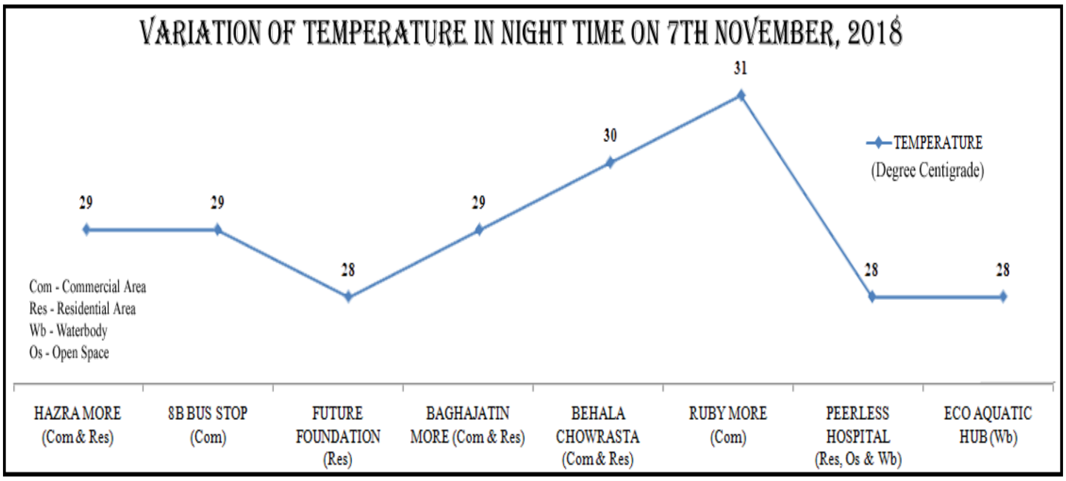


Figure 7.6.2: Graph showing the variation of Temperature in different types of land use for 8 stations during the night time on Diwali (7th November 2018)

During the daytime (8am to11am), there was rain on the Diwali day (7th Nov) which reduces the Air Temperature to a significant level and also supports results obtained during day time. Whereas in the evening there was a formation of smoke in the air which was one of the reason for increased air temperature and the maximum concentrations of Particulate Matter on Diwali night (6pm to11pm) indicating maximum firework activities in this period.

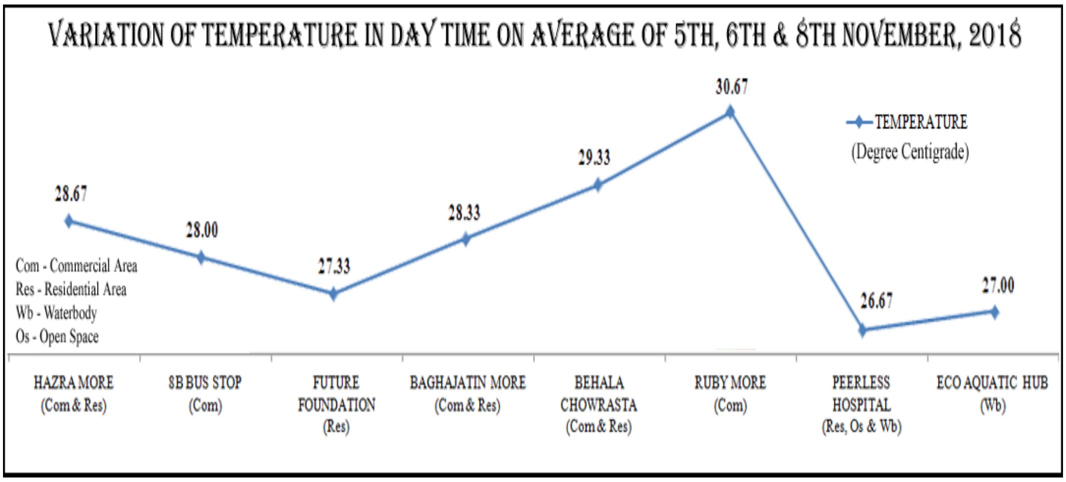


Figure 7.6.3: Graph showing the variation of Temperature in different types of land use for 8 stations during the day time on pre and post Diwali (7th November 2018)

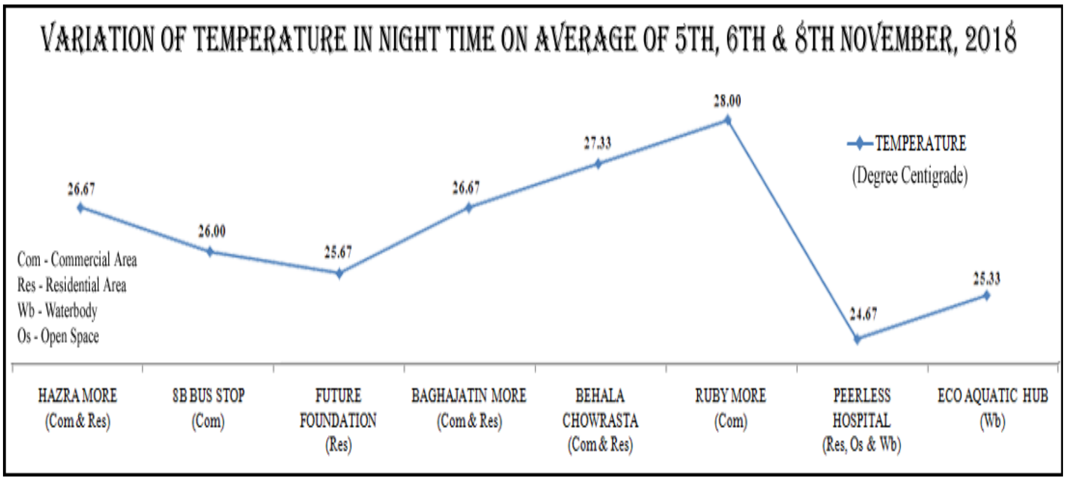


Figure 7.6.4: Graph showing the variation of Temperature in different types of land use for 8 stations during the night time on pre and post Diwali (7th November 2018)

Table 7.6.1: Relationship between daytime and nighttime$PM_{2.5}$ and $PM_{10}$with different land use categories

Place	$PM_{2.5}$ (Day)	$PM_{2.5}$ (Night)	PM_{10} (Day)	PM_{10} (Night)
Hazra Crossing (RC & MXD/HT)	183.76	498.79	228.47	713.25
The Future Foundation (R/T)	140.38	374.35	174.20	564.90
Eco Aquatic Hub (WG/HT)	160.79	307.44	243.09	400.49
Ruby Crossing (R & MXD/HT)	287.74	638.50	357.21	863.04

**** RC – Mixed Residential & Commercial, MXD – Mixed Residential, Commercial& Others, R – Mixed Residential, WG – Water body and Green Cover, HT – High Traffic Zone, T – Normal Traffic Zone**

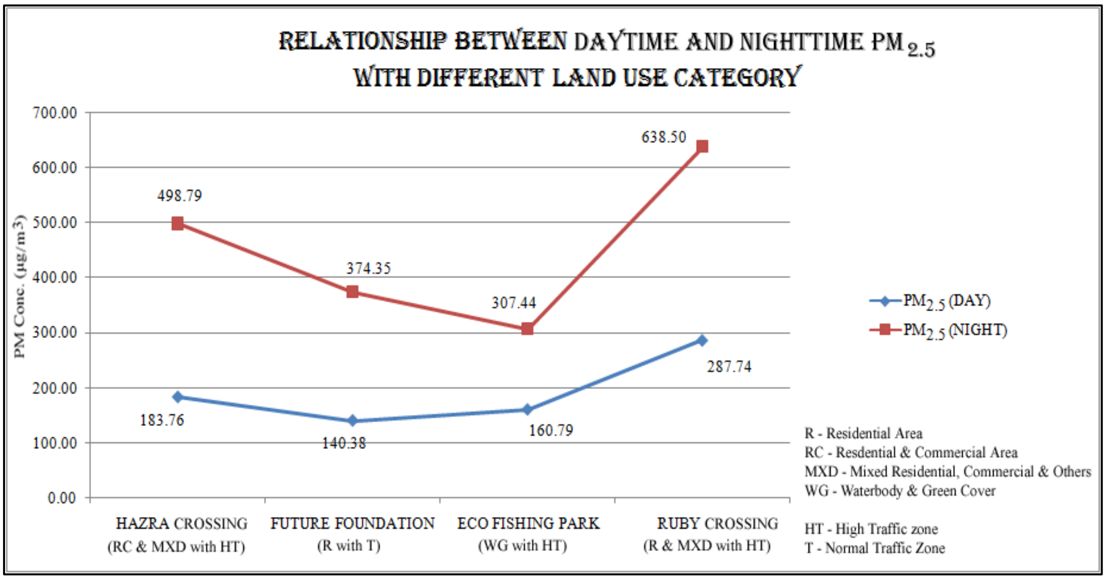


Figure 7.6.5: Relationship between the daytime and nighttime of $PM_{2.5}$with different Land Use category

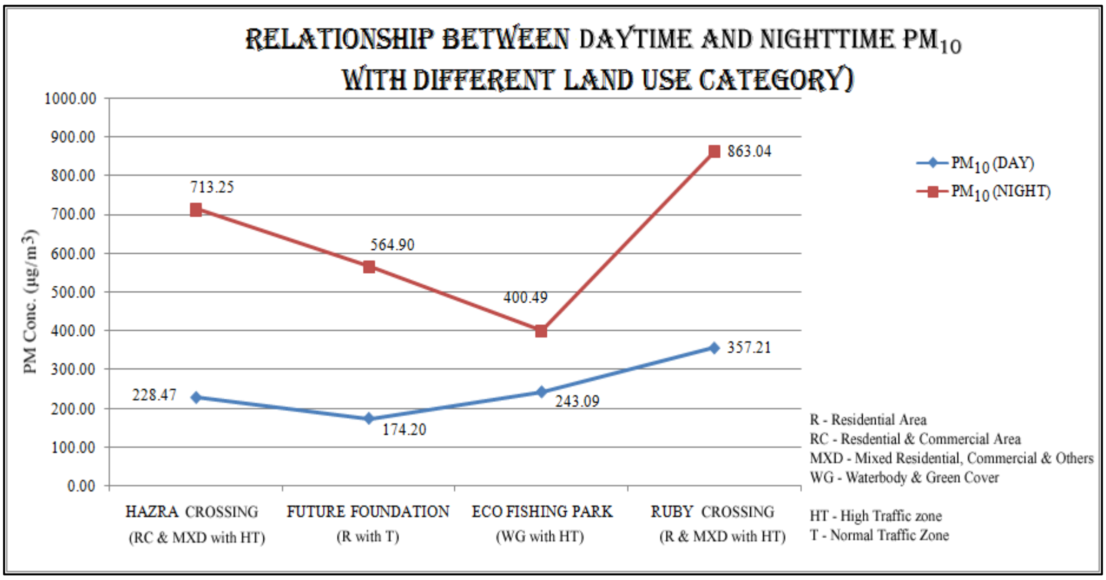


Figure 7.6.6: Relationship between the daytime and nighttime of PM_{10} with different Land Use category

Statistical analyses were executed to assess the differences in the day and night time $PM_{2.5}$ and PM_{10} within the different land use categories during the Diwali period. The correlation between LULC and PM is relatively low in Echo Aquatic Hub area, which is covered by Water body along with High Traffic. This pattern is also observed in the area of The Future Foundation School, which is categorized by Green Cover and Canopy Cover. Due to the rapid urban sprawl, concentration of commercial, public and semi-public land uses and heavy traffic, particularly during the Diwali season, there is a strong correlation between urban land use and particulate matter in the Ruby Crossing and Hazra Crossing (Chittaranjan Cancer Hospital) areas.

7.7 $PM_{2.5}$ and PM_{10}variation in Southern Kolkata

Table 7.7.1: Monitoring data from different stations

Monitoring Station	Morning			Evening		
	$PM_{2.5}$	PM_{10}	$PM_{2.5}/PM_{10}$	$PM_{2.5}$	PM_{10}	$PM_{2.5}/PM_{10}$
Hazra Crossing	153.57	206.37	0.74	424.5	643.67	0.66
Jadavpur 8B Bus Stop	148.86	214.17	0.7	431.38	622.13	0.69
Future Foundation School	111.98	129.1	0.87	342.78	506.7	0.68
Baghajatin Crossing	168.98	176.14	0.96	438.1	602.17	0.73
Behala Chowrasta	243.14	267.84	0.91	483.73	711.12	0.68
Ruby Crossing	311.08	325.52	0.96	618.83	804.35	0.77
Peerless Hospital	125.91	134.16	0.94	242.2	281.13	0.86
Eco Aquatic Hub	166.53	231.63	0.72	295.42	327.23	0.9

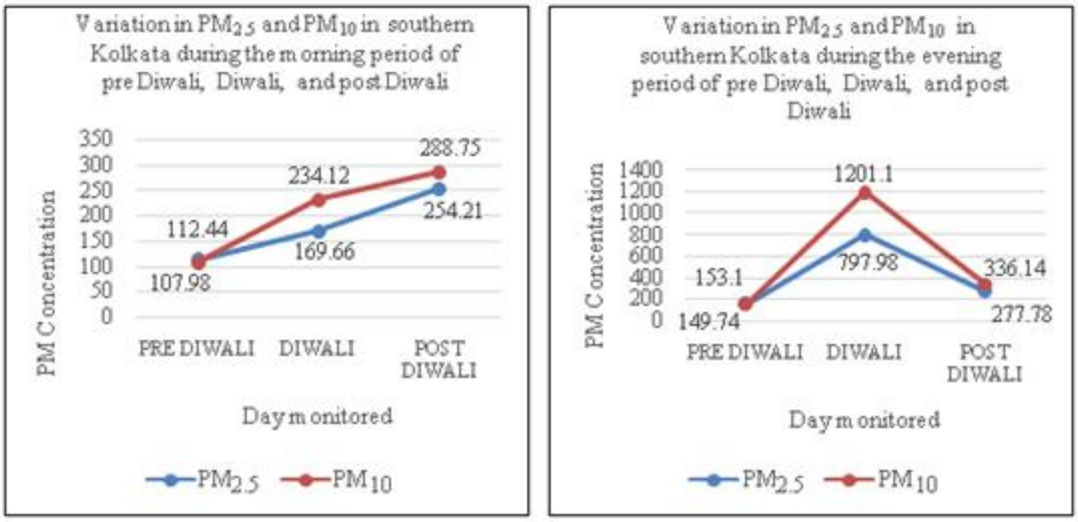


Figure 7.7.1: Variations in $PM_{2.5}$and $PM_{10}$for the morning and evening time during the pre Diwali, Diwali and post Diwali periods in Southern Kolkata

The findings indicated that the $PM_{2.5}$ and PM_{10} concentrations ranged from 0.66 to 0.96 across the three days of the Diwali season. During the Diwali period, the ambient $PM_{2.5}$ and PM_{10} concentrations in the morning increased from pre Diwali to post Diwali. For the evenings, a single peak was observed, with the maximum concentrations of $PM_{2.5}$ and PM_{10} occurring during the evening time of Diwali.

7.8 Spatial & Graphical Analysis of surveyed data

The below figures indicate that during the morning time (8am to 11am), dispersion is concentrated mainly in the Ruby Crossing area (high traffic zone) whereas the concentration is remarkably low in other areas due to the heavy rain across the city which reduced the concentration of pollutants but due to high traffic at Ruby Crossing, the pollution was high even after rain. The night time (6pm to 11pm), it was observed that study of dispersion across all area can be explained by high pollutants area due to fire crackers burning which trapped in the air due to smoke formation in the sky.

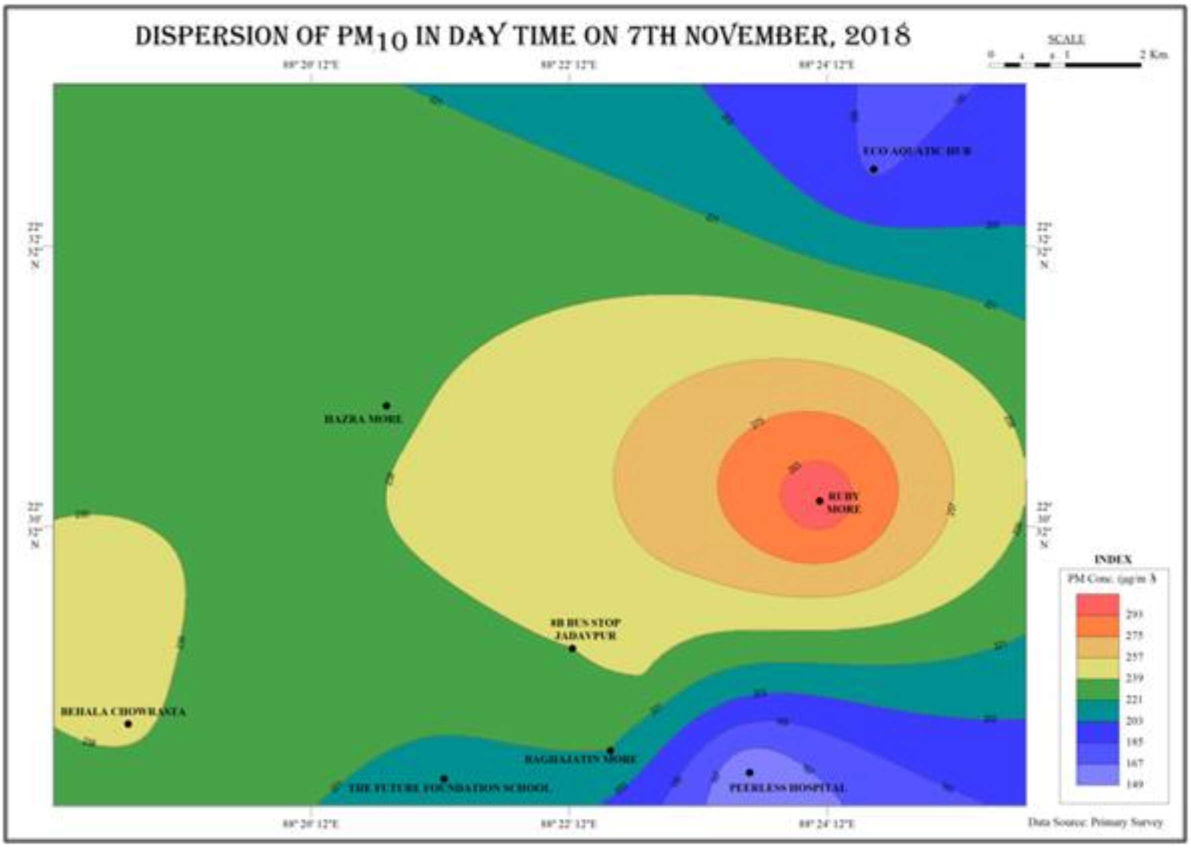


Figure 7.8.1: PM_{10} concentration zone in the day time on Diwali

Table 7.8.1: Dispersion data of $PM_{2.5}$, PM_{10}concentration and Temperature in the day time of Diwali

DATA COLLECTION POINTS	$PM_{2.5}$	PM_{10}	TEMPERATURE
PEERLESS HOSPITAL	81.95	149.45	25
ECHO AQUATIC HUB	117.5	183	25
THE FUTURE FOUNDATION	120.95	166	26
8B BUS STOP, JADAVPUR	166.9	243	26
HAZRA MORE	191	237.5	27
BAGHAJATIN MORE	130.5	201.5	27
BEHALA CHOWRASTA	184	215.5	27
RUBY HOSPITAL MORE	251	307.5	28

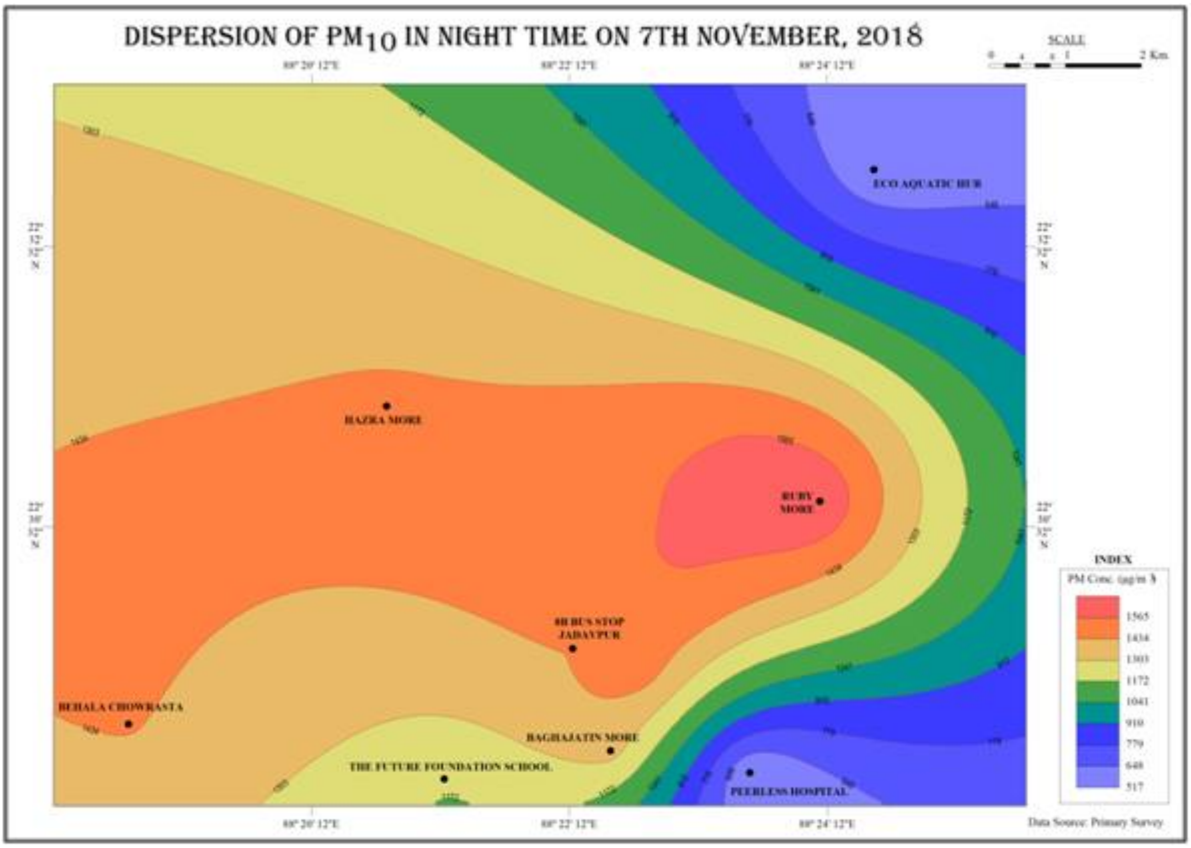


Figure 7.8.2: PM_{10} concentration zone in the night time on Diwali

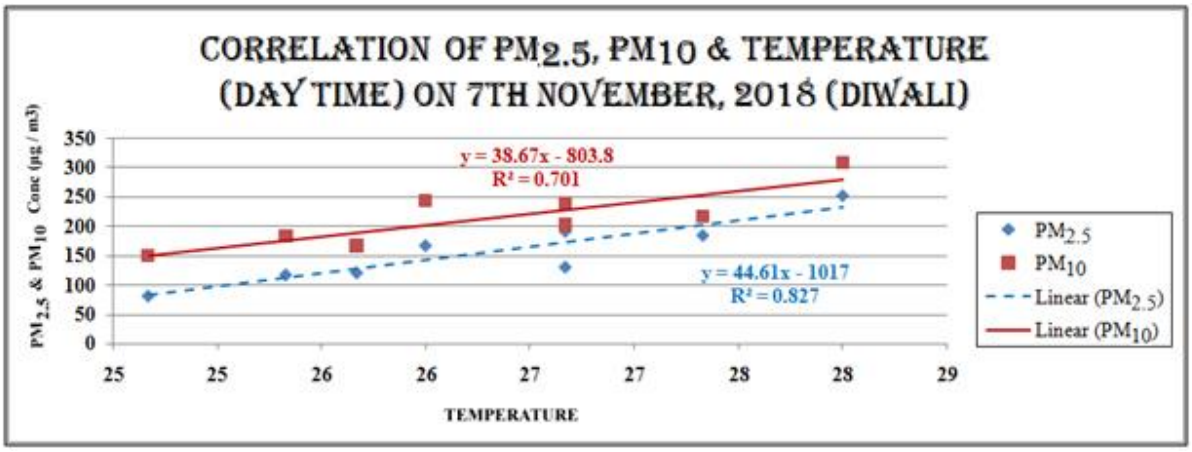


Figure 7.8.3: Correlation of PM_{10} and $PM_{2.5}$ concentration and Temperature in the Day (during 8am to 11am), on Diwali (7th November 2018)

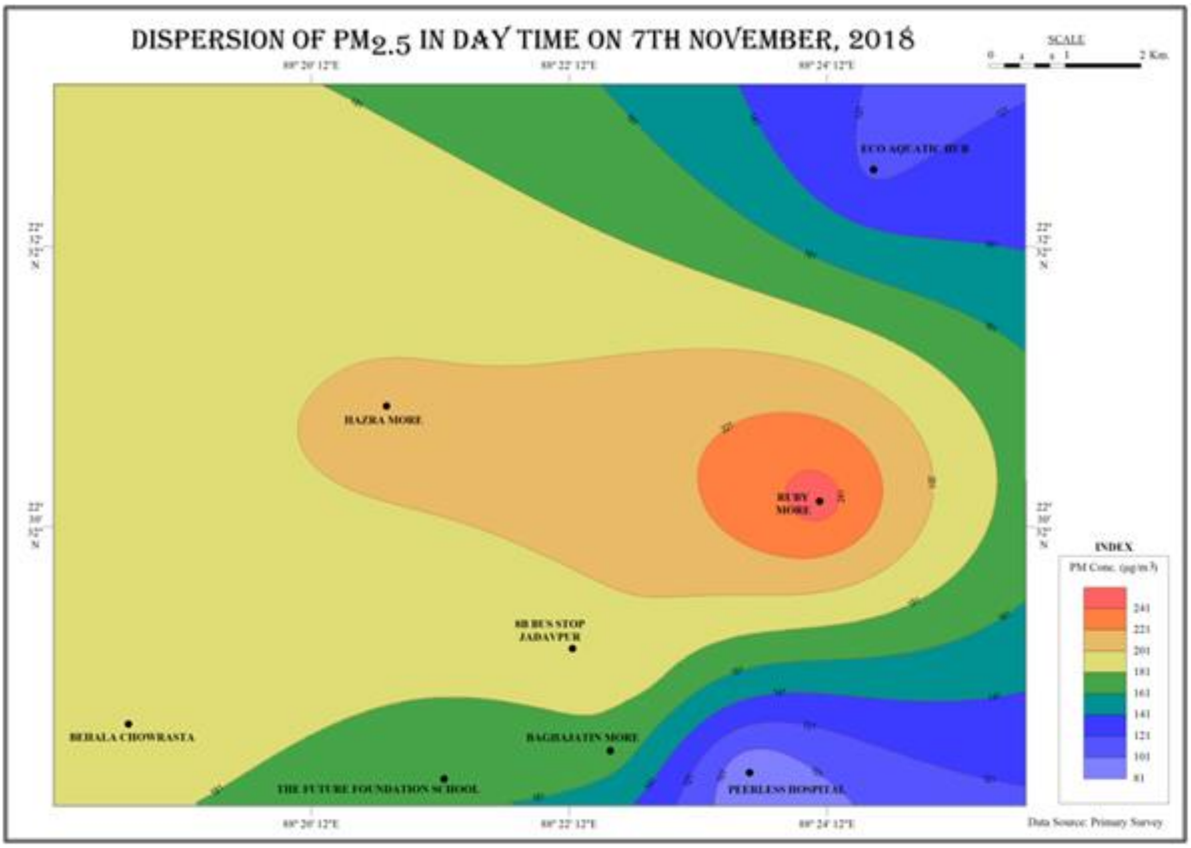


Figure 7.8.4: $PM_{2.5}$ concentration zone in the day time on Diwali

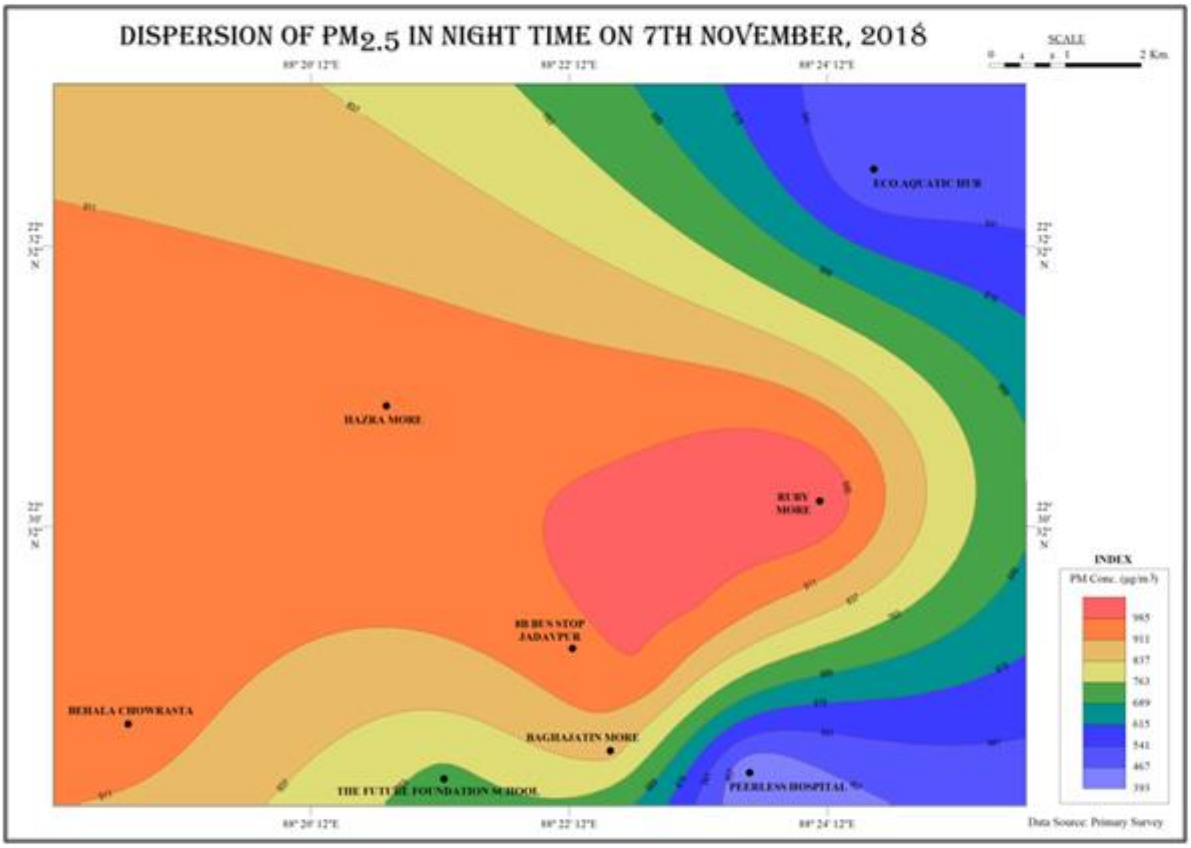


Figure 7.8.5: $PM_{2.5}$ concentration zone in the night time on Diwali

Table 7.8.2: Dispersion data of $PM_{2.5}$, PM_{10}concentration and Temperature in the night time of Diwali

LOCATION	$PM_{2.5}$	PM_{10}	TEMPERATURE
PEERLESS HOSPITAL	393.2	517.1	27
ECHO AQUATIC HUB	472.1	529	27
THE FUTURE FOUNDATION	738	1183.5	27
8B BUS STOP, JADAVPUR	958	1438.5	28
BAGHAJATIN MORE	860	1299	28
HAZRA MORE	959	1353.5	29
BEHALA CHOWRASTA	951	1297	29
RUBY HOSPITAL MORE	1052	1477	31

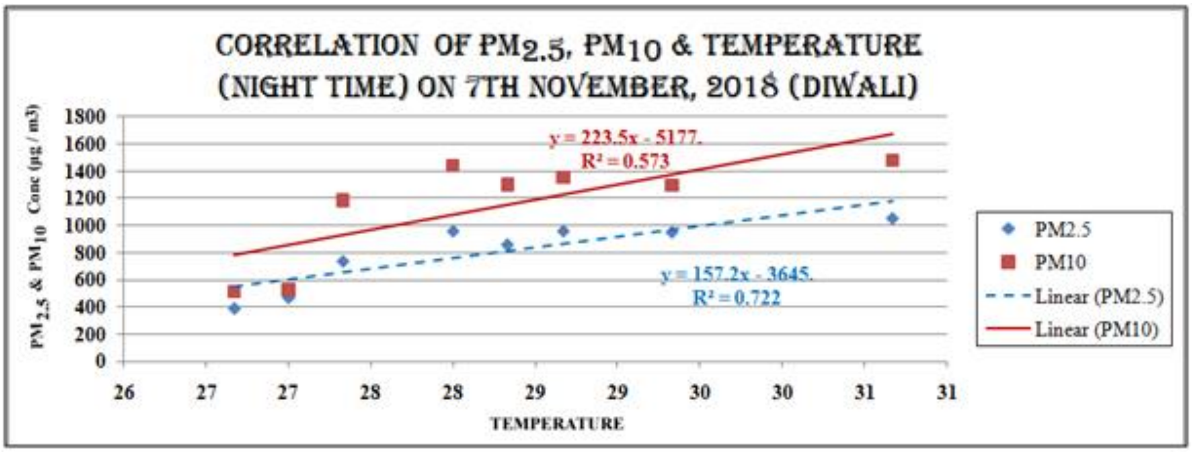


Figure 7.8.6: Correlation of PM_{10} and $PM_{2.5}$ concentration and Temperature in the Night (during 8am to 11am), on Diwali (7th November 2018)

The statistical analyses, linear regressions were performed between $PM_{2.5}$,PM_{10} and temperature, during Diwali day (figure 7.8.3) and night (figure 7.8.6).It was observed that linear regressions of $PM_{2.5}$andPM_{10} on temperature have a very similar relationship in day time R^2 >0.701 and R^2> 0.827 and in night time R^2>0.573 and R^2 >0.722 respectively. These statistical analyses also confirm the assumptions explained during the result of dispersion, seen on the day of Diwali.

7.9 Spatial Variation in terms of Air Quality Index (AQI)

The AQI fluctuated between the poor and severe categories throughout the day and between the very poor and severe categories during the night. Typically, firecrackers are set off at night in residential neighborhoods. This led to "bad" daytime Air Quality and "severe" nighttime Air Pollution in the vicinity of the Future Foundation School.

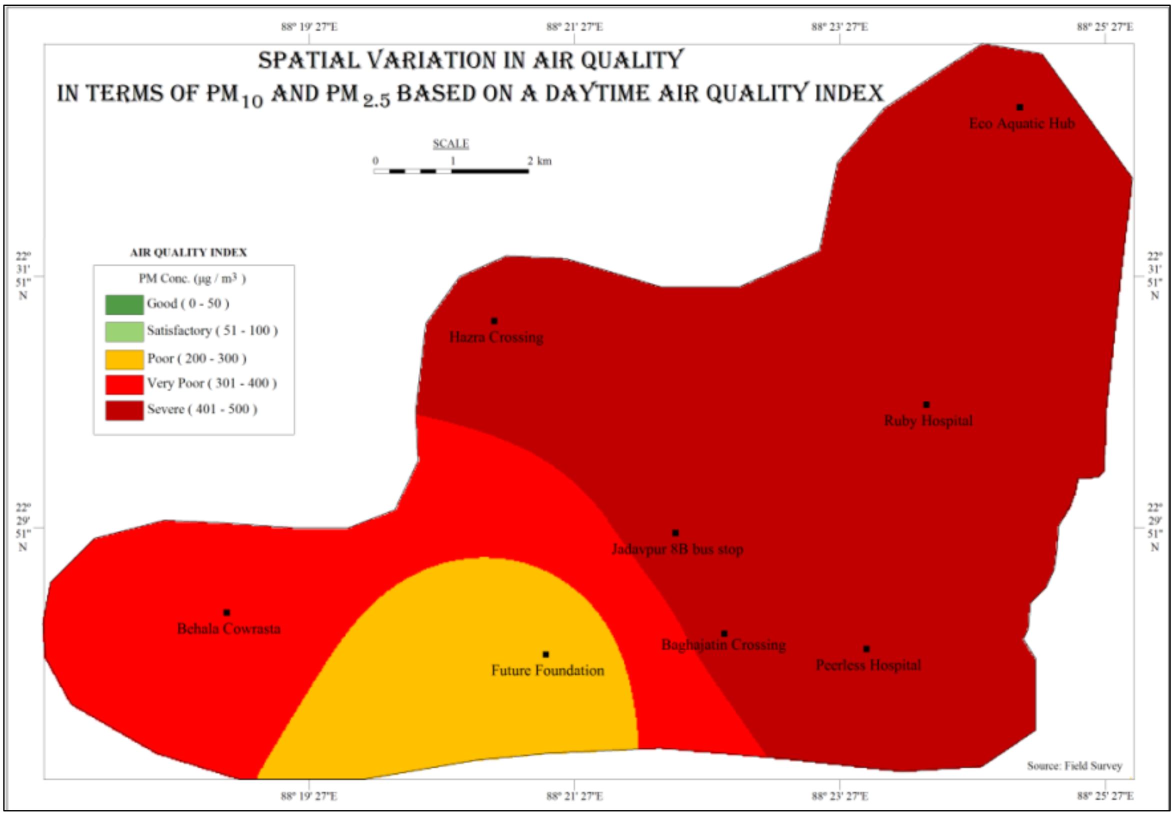


Figure 7.9.1: Spatial variation in Air Quality in terms of PM_{10} and $PM_{2.5}$ during the Diwali day time AQI

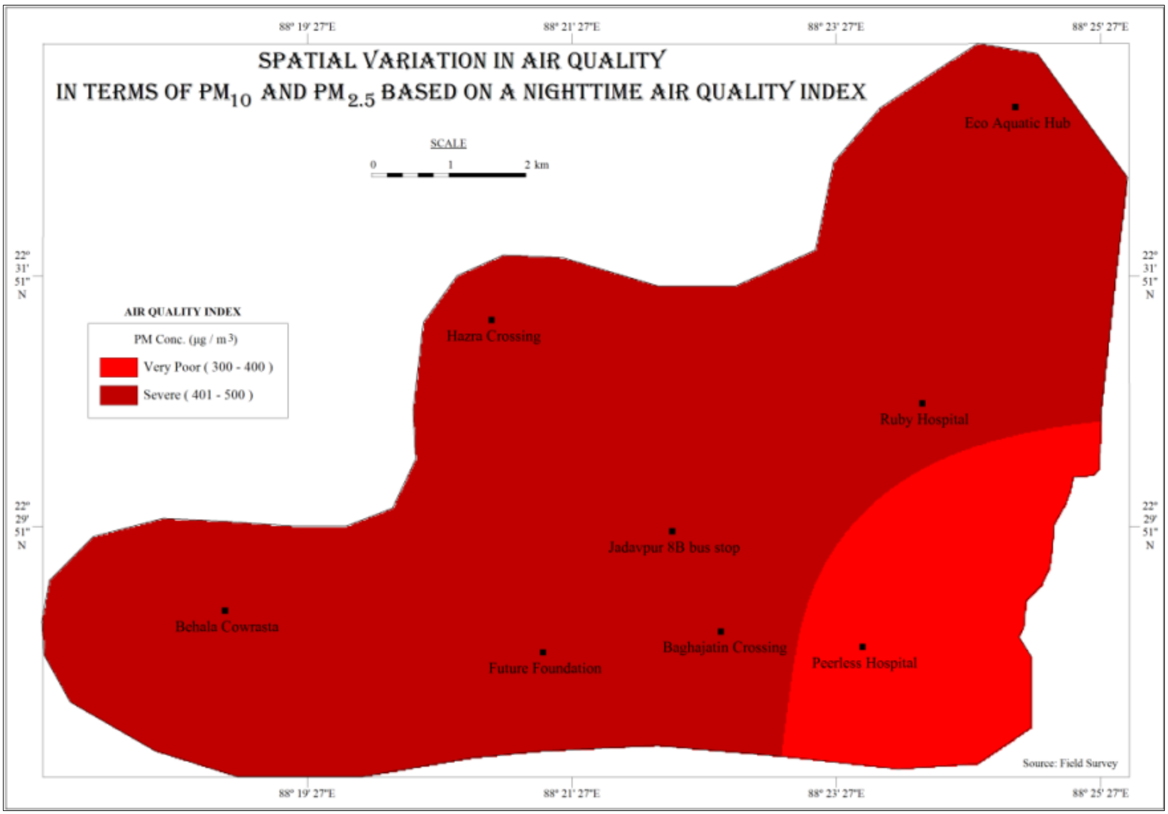


Figure 7.9.2: Spatial variation in air quality in terms of PM_{10} and $PM_{2.5}$ during the Diwali night time AQI

7.10 Diurnal Variation

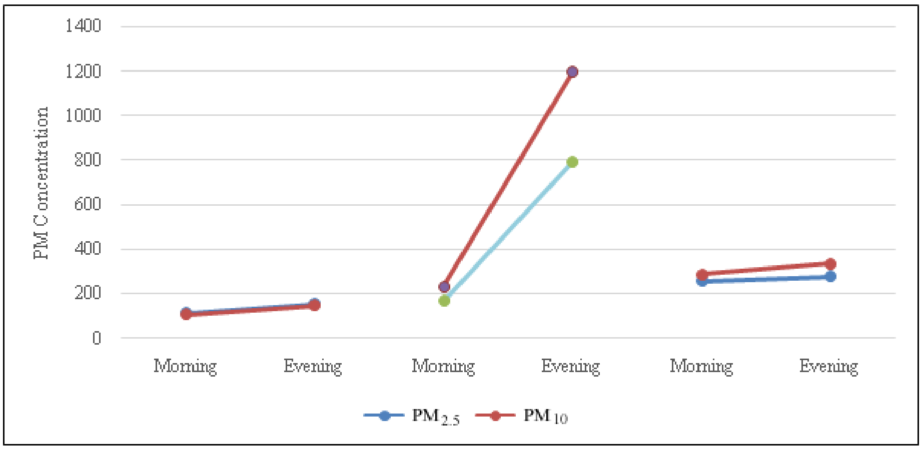


Figure 7.10.1: Diurnal variations in $PM_{2.5}$ and PM_{10}

During the Diwali period, the concentrations of both $PM_{2.5}$and PM_{10}were higher in the evening than in the morning, and there were huge increase in the concentrations of $PM_{2.5}$and $PM_{10}$from the morning to the evening of Diwali compared to the increase observed during pre Diwali and post Diwali. Additionally, given that more firecrackers were lit on Diwali night than on the evenings before and after Diwali, higher $PM_{2.5}$and PM_{10}concentrations were recorded on the night of Diwali than on the pre Diwali and post Diwali nights.

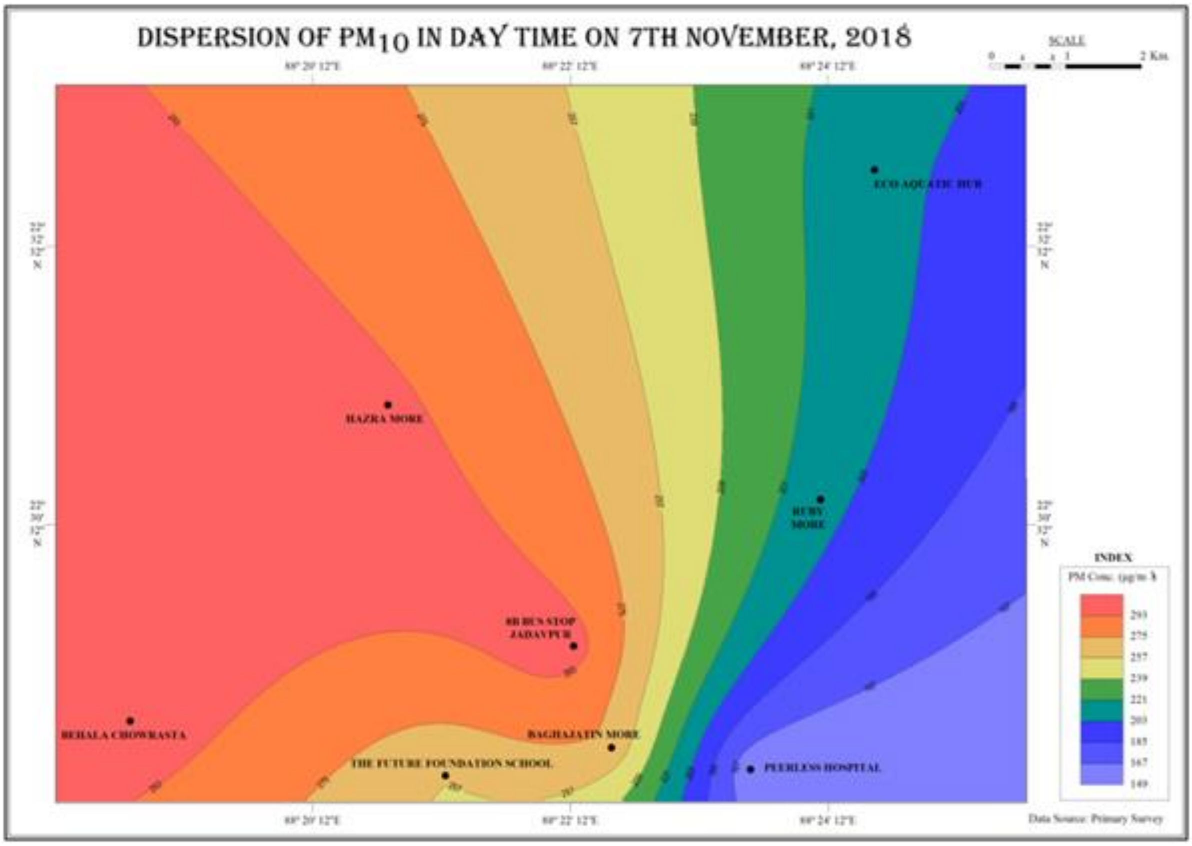


Figure 7.10.2: Dispersion of PM_{10} in day time on Diwali (7^{th} November 2018)

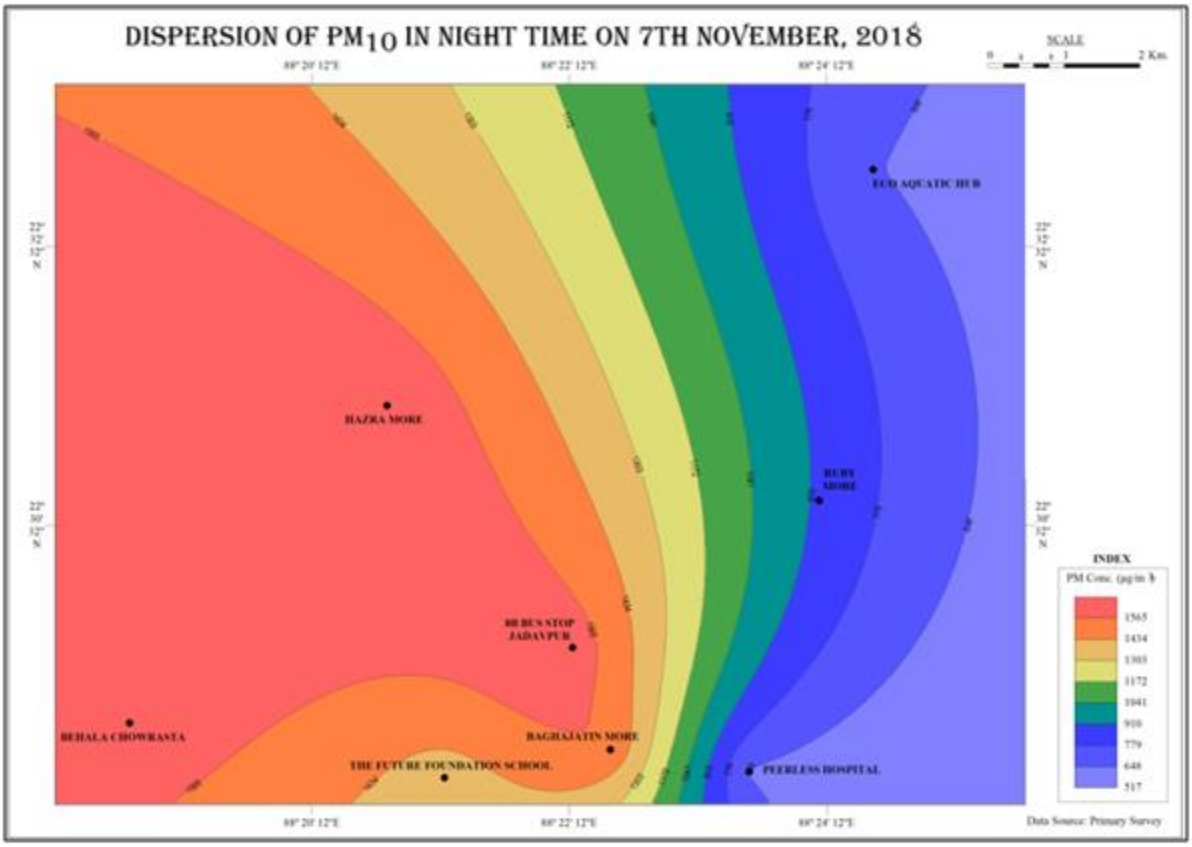


Figure 7.10.3: Dispersion of PM_{10} in night time on Diwali (7th November 2018)

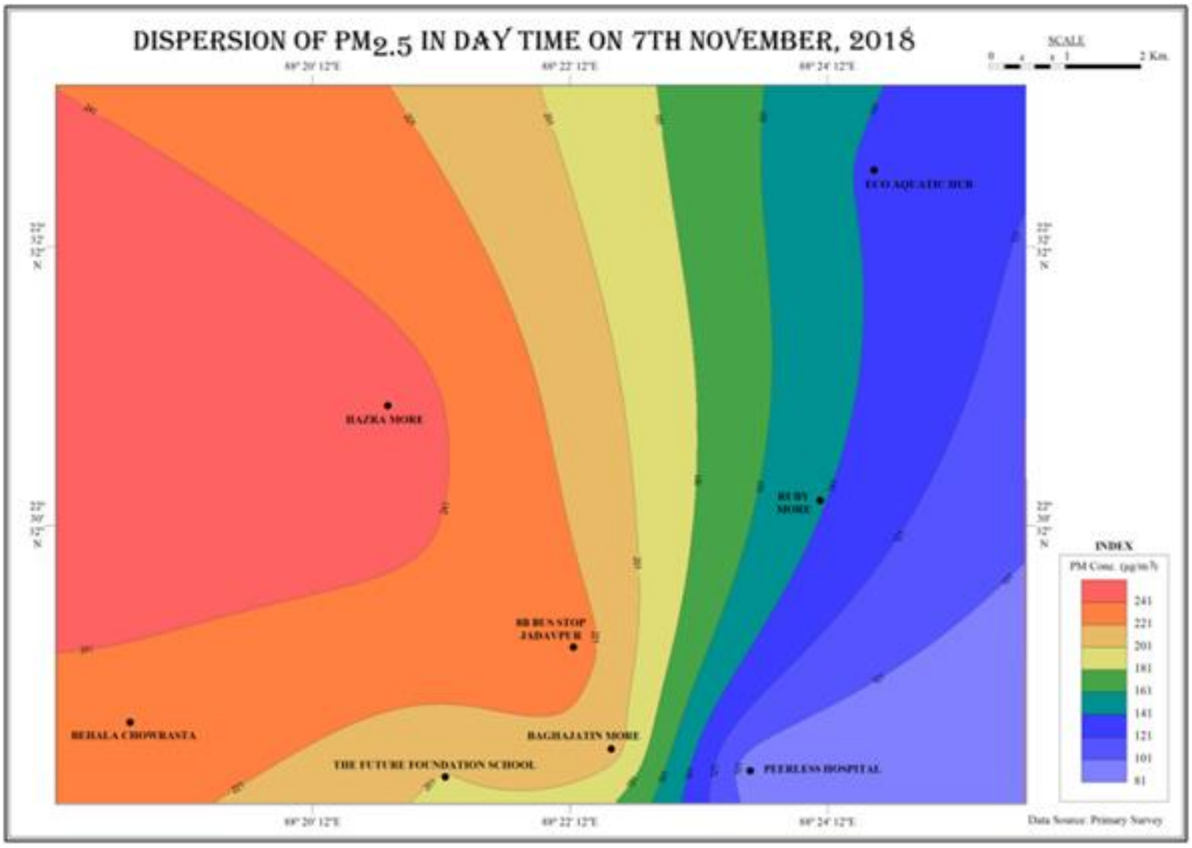


Figure 7.10.4: Dispersion of $PM_{2.5}$ in day time on Diwali (7th November 2018)

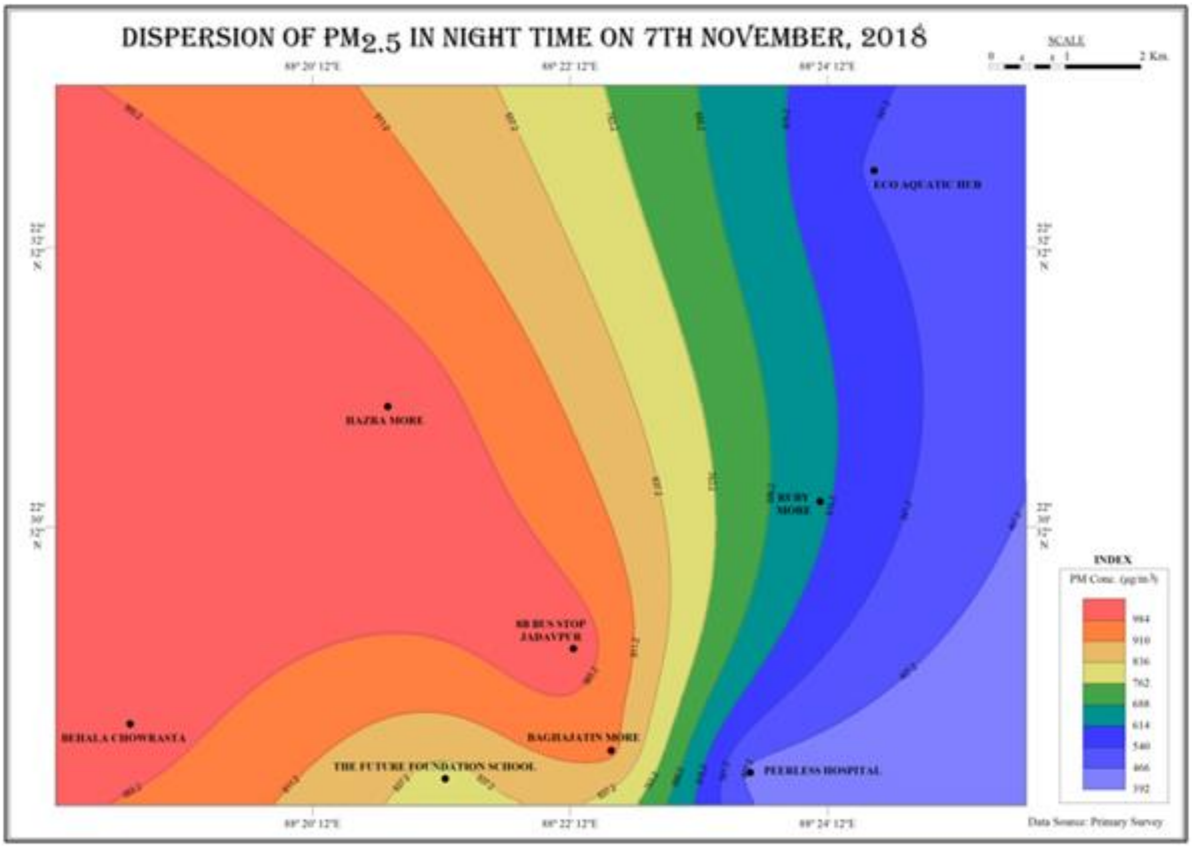


Figure 7.10.5: Dispersion of $PM_{2.5}$ in night time on Diwali (7th November 2018)

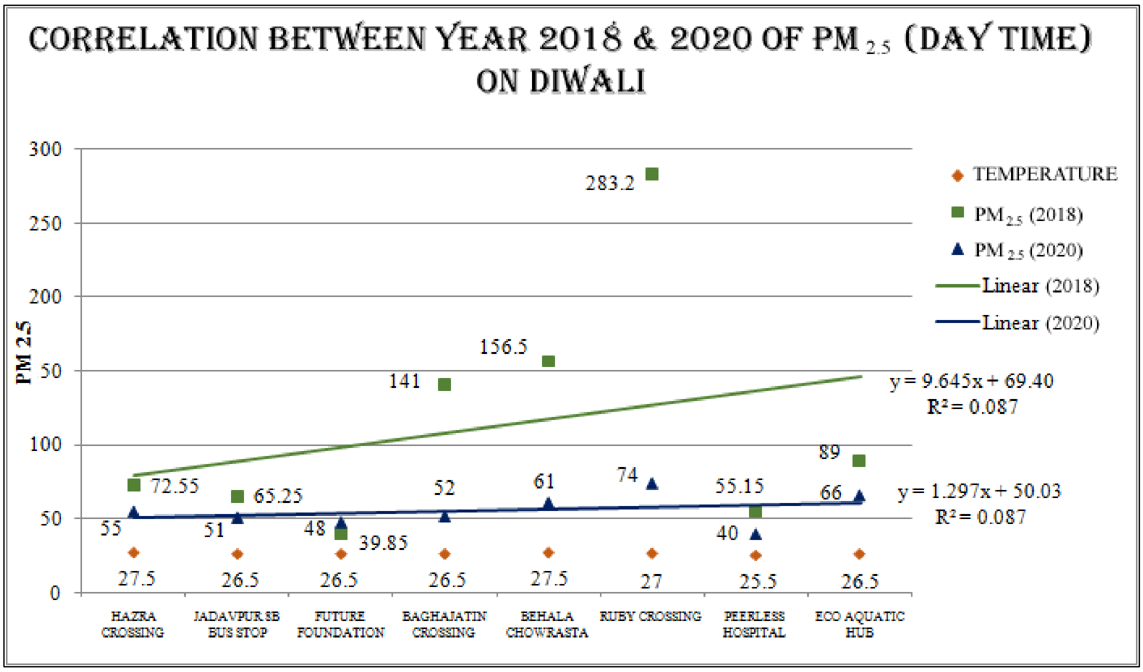


Figure 7.10.6: Correlation between 2018 and 2020 of $PM_{2.5}$ in day time

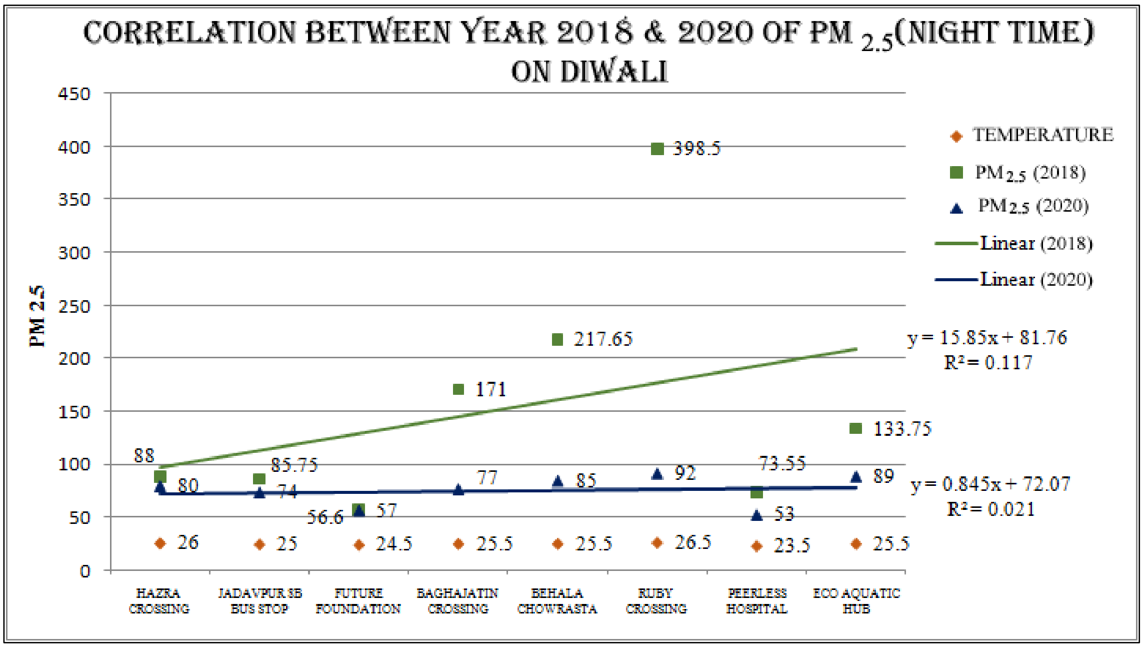


Figure 7.10.7: Correlation between 2018 and 2020 of $PM_{2.5}$ in night time

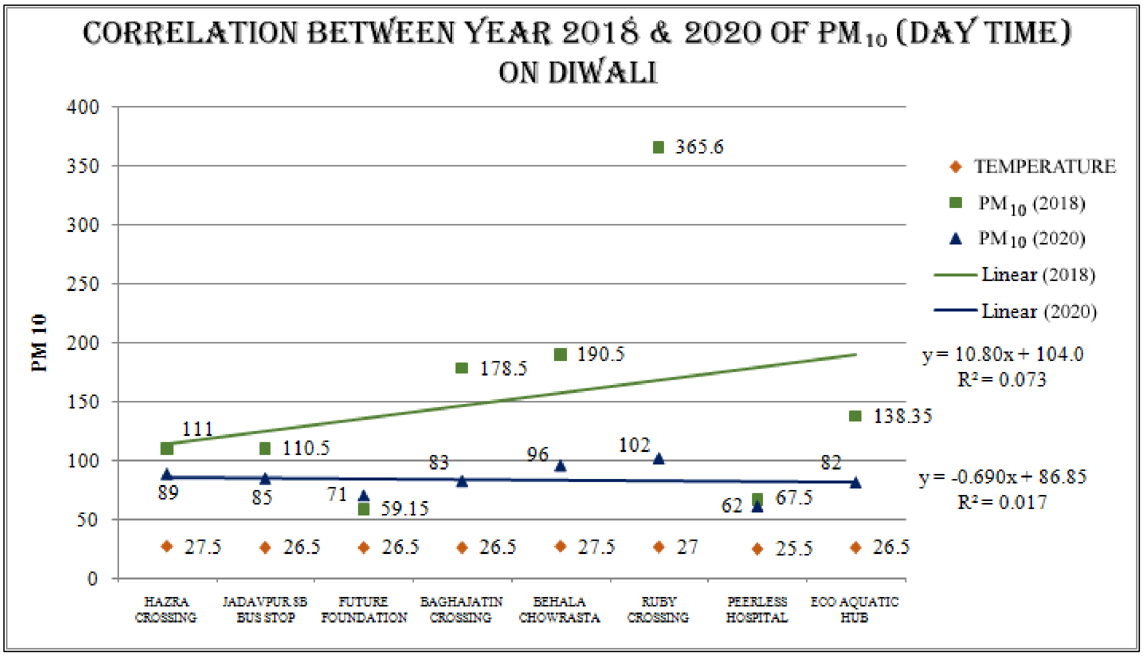


Figure 7.10.8: Correlation between 2018 and 2020 of PM_{10} in day time

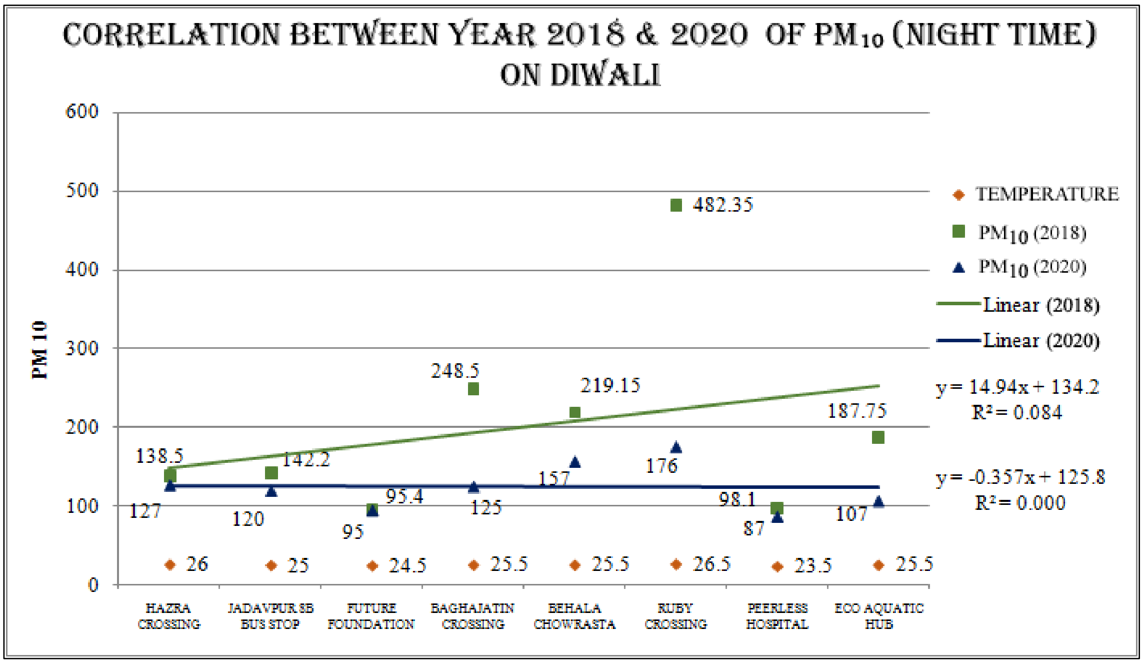


Figure 7.10.9: Correlation between 2018 and 2020 of PM_{10} in night time

The above statistical analyses, bivariate linear regressions by least square method were performed between the year 2018 and 2020 for $PM_{2.5}$and $PM_{10}$with temperature, during the day(figure 7.9.6 and 7.9.7) and night (figure 7.9.8 and 7.9.9) of Diwali, respectively. It was observed that linear regressions between the year 2018 and 2020 of $PM_{2.5}$ and temperature has normal relationship in day time R^2=0.087 and R^2=0.087 respectively and in night time R^2=0.117 and R^2=0.021respectively. This statistical analysis (figure7.10.6, 7.10.7, 7.10.8 and 7.10.9) also confirms the assumptions explained above during the discussion on result of dispersion seen on the day.

The R^2valuesof PM_{10}at the day time have normal relationship in 2018 and 2020, whereas the value of PM_{10}in the night of 2018 is higher than 2020,which confirms the assumptions that PM value was higher due to the burning of fire cracker. Celebration of Diwali along with fire crackers in the year 2020 was called off due to Covid-19 pandemic so the air pollution level was very negligible.

7.11 Conclusion

The results confirm a positive correlation among Land Use, Air Temperature, Air Quality and Traffic Zones for the year 2018 during Diwali period, which has already been demonstrated by many other studies. It was observed that Air Temperature responded extremely delicately to the various Land Use categories and Air Quality metrics, particularly on the day of Diwali, which was one of the study's goals. In this study, vehicle emissions and the firing of fireworks and sparklers rank as the two main sources of Air Pollution in each of the eight studied locations. The late-night entry of big diesel-powered interstate cars into the city also added to the elevated level of air pollution.

The land use types and traffic zones with the lowest Air Temperatures included water bodies and open areas with significant vegetative cover (such as the Peerless Hospital and Eco Aquatic Hub areas), which had the Air Temperatures ranging between 26.67°C and 27°C. In contrast, mixed residential and commercial areas, where traffic is high and construction activity is going on along with Diwali fireworks, had high Air Temperatures. However, in the southern part of Kolkata city, Within the high traffic zones of mixed business and residential districts, two high temperature zones (about 27.33°C to 28.67°C and 29.33°C to 30.67°C) were found (such as Behala Chowrasta and Ruby Crossing). This established the second objective that PM concentration has impact on Air Temperature in the study area.

Chapter 8: Conclusion

8.1 Introduction

The results confirm a positive correlation among land use, air temperature, air quality and traffic zones, which have already been demonstrated by many other studies. It was discovered that air temperature responded extremely delicately to the various land use categories and air quality metrics, particularly on the day of Diwali, which was one of the study's goals.

In this research work, in all eight research regions, burning fireworks and sparklers together with vehicle emissions are the main contributors of Air Pollution. The late-night arrival of large, interstate diesel-powered cars into the city also contributed to the elevated level of air pollution.

The land use types and traffic zones with the lowest air temperatures included water bodies and open areas with significant vegetative cover (such as the Peerless Hospital and Eco Aquatic Hub areas), which had the air temperatures ranging between 26.67°C and 27.00°C. In contrast, mixed residential and commercial areas, where traffic is high and construction activity is going on along with Diwali fireworks, had high air temperatures. However, in the southern part of Kolkata city, Within the high traffic zones of mixed business and residential districts, two high temperature zones (about 27.33°C to 28.67°C and 29.33°C to 30.67°C) were found.(such as Behala Chowrasta and Ruby Crossing). This established the second objective that PM concentration has impact on air temperature in the study area.

IGBC has been a driving force behind the Green Building Movement in India since 2001 by raising awareness among the key players. 2.23 billion square feet of green buildings have been made possible across the nation thanks in part to the Council. The Council's initiatives have helped the market change in terms of green building products and technology. IGBC works tirelessly to offer resources that make it easier for India to embrace green building principles. Another significant achievement in this approach is the creation of the IGBC Green New Buildings grading system (Abridged Reference Guide, Indian Green Building Council, September, 2014).

8.2 Research Conclusion

8.2.1 Objectives 1

Study of Urban Heat Island (UHI) intensity with respect to different LULC change

The study reveals that the average temperature was 26ºC in the year 2000, 22.95ºC for 2010, 24.44ºC for 2015and by the year 2020 it had become 20.75ºC. It seems there were huge variations in average temperature within the Kolkata Municipal Corporation area in that stipulated period. Variations in temperature are mainly due to the increase of dense built up areas, decrease of water body, open space area, depletion of vegetation cover and the different kind of activities like accumulation of high traffic zones on the roads for a long period of time during day night.

Table 8.2.1.1: Percentage of LULC and Average LST within KMC from the year 2000 to 2020

	2000	2010	2015	2020
Built up	63.13	53.77	64.84	58.46
Vegetation	30.7	37.78	28.73	31.21
Waterbody	5.45	5.72	4.75	9.12
Open Space	0.72	2.73	1.68	1.21
Average Temperature	26	22.955	24.435	20.75

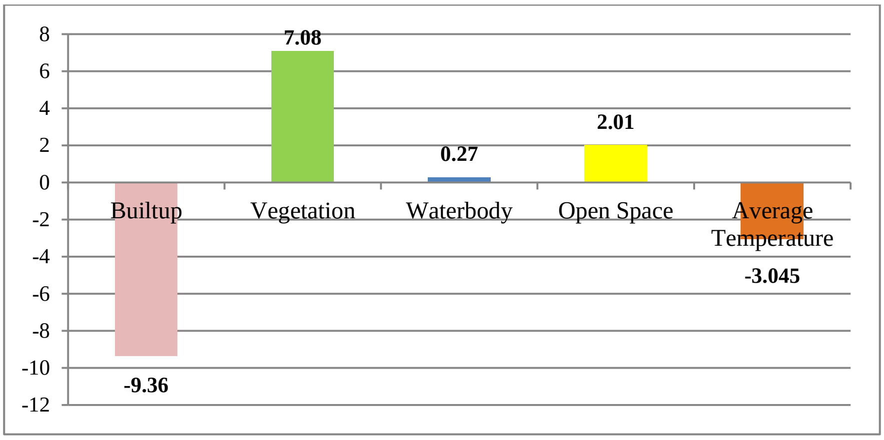


Figure 8.2.1.1: Bar diagram showing percentage of LULC and Average Temperature changes in KMC area from 2000 to 2010

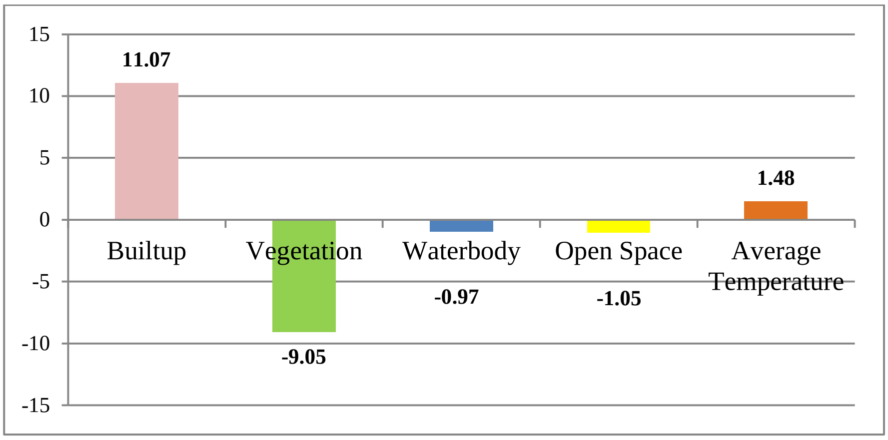


Figure 8.2.1.2: Bar diagram showing percentage of LULC and Average Temperature changes in KMC area from 2010 to 2015

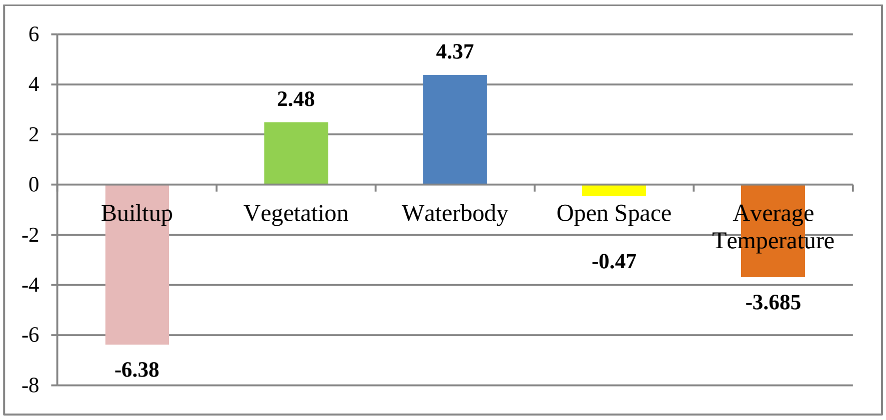


Figure 8.2.1.3: Bar diagram showing percentage of LULC and Average Temperature changes in KMC area from 2015 to 2020

From the above diagram, it can be conclude that seizing in expansion of dense builtup area, average temperature can be controlled. Due to super cyclone 'Aila' in the year 2009, it has been observed that the augmentation of water body area (0.27%) and depletion of average temperature (3.045ºC) along with the increase in percentage of vegetation (7.08) and open space (2.01) area compare to the year 2000, were also the causes.

By the year 2015, the amplification of dense built up (11.07%), reduced the percentage of vegetation (9.05), water body (9.05) and open space (1.05).

The scenario got changed by the year 2020 and the super cyclone 'Fani' along with 'Bulbul' during the month of April and November 2019 merged with the lockdown (complete and partial) period due to Covid-19 pandemic situation, had also a vital role for changing the weather conditions. The non-activity of human being during the lockdown period dwindle the dense built up area to 6.38% along with open space 0.47%, average temperature up to 3.685ºC. On the other hand, vegetation area had increased 2.48%, water body 4.37%. These are significant causes of healthy environment with the sustainable average temperature for further ecological balance.

In 2020, the Land Surface Temperature (LST) in Kolkata has been decreased to the minimum (17.40ºC) and maximum (24.10ºC) to the tune of 1.62ºC as minimum and 5.75ºC as maximum which is the sign of improvement.

The correlation map of Land Use Land Cover (LULC) and Land Surface Temperature (LST)for the year 2015 shows that the built up areas of north and port area of Kolkata Municipal Corporation exhibits the maximum Land Surface Temperature (LST), compare to the other regions. The East Kolkata Wetland and southern part of KMC having the vegetation and water body areas experienced the lowest LST. As a special case on COVID-19 pandemic time in 2020, The NDWI and NDVI analysis maps of KMC signified that the index values of this region were high where as the LST values were comparatively low compare to the previous years.

Table 8.2.1.2: Variations of LST related with the LULC types within KMC

Areas (Sq. Km) within five LST (in ºC) categories of different LULC types					
LULC	**VERY HIGH**	**HIGH**	**MODERATE**	**LOW**	**VERY LOW**
2010	**23.91 - 28.66**	**22.62 - 23.91**	**21.72 - 22.62**	**20.43 - 21.72**	**17.25 - 20.43**
Waterbody	0.077	0.222	0.571	1.88	4.173
Vegetation	3.933	17.273	32.18	15.035	1.833
Open Space	1.592	2.005	1.037	0.431	0.016
Built up	24.48	45.481	27.287	6.451	0.393
2015	**25.01 - 29.85**	**23.70 - 25.01**	**22.76 - 23.70**	**21.49 - 22.76**	**19.02 - 21.49**
Waterbody	0.018	0.129	0.408	1.968	4.508
Vegetation	0.405	3.409	16.002	27.496	3.216
Open Space	0.903	1.636	1.99	1.002	0.068
Built up	10.643	36.008	57.535	18.776	0.229
2020	**21.23 - 24.10**	**20.36 - 21.23**	**19.71 - 20.36**	**18.97 - 19.71**	**17.40 - 18.97**
Waterbody	0.565	4.053	12.486	14.081	7.661
Vegetation	1.725	6.602	13.646	12.266	1.673
Open Space	0.439	0.919	1.159	0.235	0.02
Built up	10.95	31.393	48.346	17.826	0.305

The table 8.2.1.2 indicates that due to the increased areas of water body and vegetation along with open space, most of the areas under KMC experience moderate to very lowland surface temperature. Huge built up areas were also under moderate category of LST for the year 2020. That is why this year was an iconic in the context of sustainable surface temperature and healthy atmospheric condition within the KMC area.

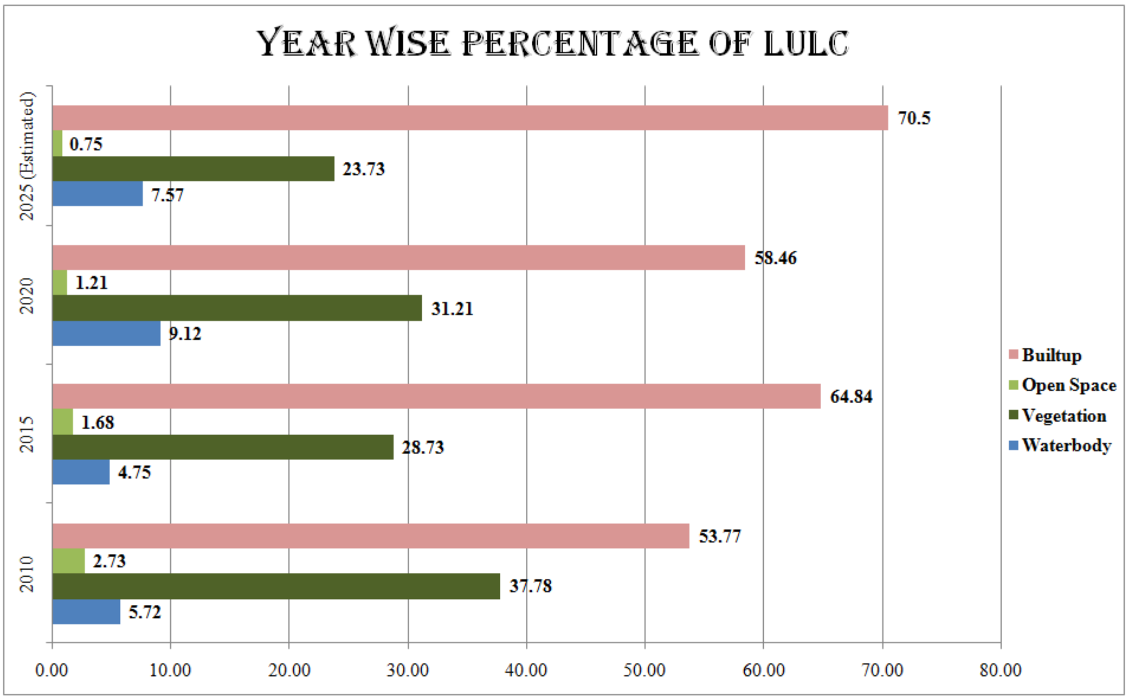


Figure 8.2.1.4: Year wise (2000, 2010, 2015 and 2020) calculated percentage and estimated (2025) of LULC

The estimated value has been calculated by the formula –

Value (2025) = {Value (2015) / Value (2010)} * Value (2020)

It is also examined the variation of values derived from three years of data throughout the study periods to investigate the relationship between biophysical indices (NDVI, NDWI and NDBI) and LST. It is clear that the expansion of urban built-up area in KMC has been significantly influencing the rise in land surface temperature.

8.2.2 Objectives 2

Study the Urban Heat Island (UHI) intensity with respect to Air Quality special emphasize on respirable particulate matter

- From this study data it can deduce that there is variation of concentration of $PM_{2.5}$ and PM_{10} in the day time or night time and in addition, it even varies in different seasonal period, which indicates the changing pattern of Air temperature.

According to the year 2000 study, during the winter time PM_{10} range was 247.11µg/m^3 onwards in the built up area, however in 2016, during the winter time PM_{10} range grew 292µg/m^3 to the level. The constructed area has expanded throughout this 16 year period while the vegetation cover has shrunk.

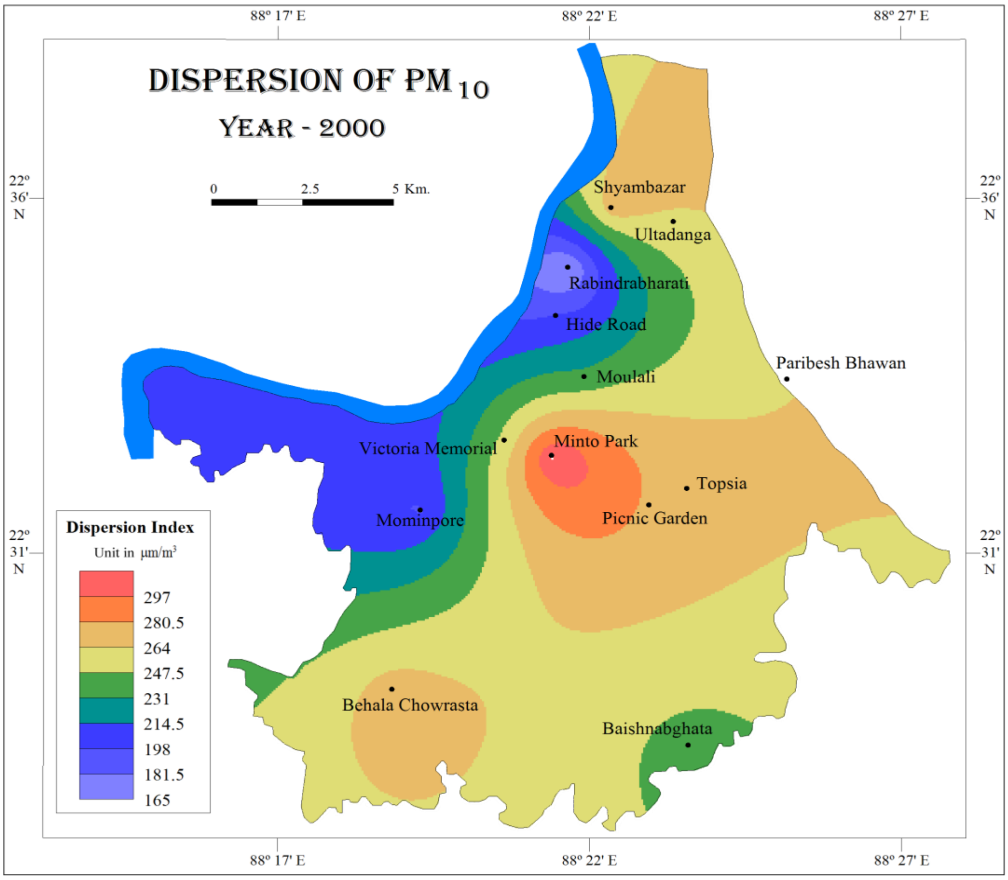


Figure 8.2.2.1: Dispersion Map of PM $_{10}$ of 2010

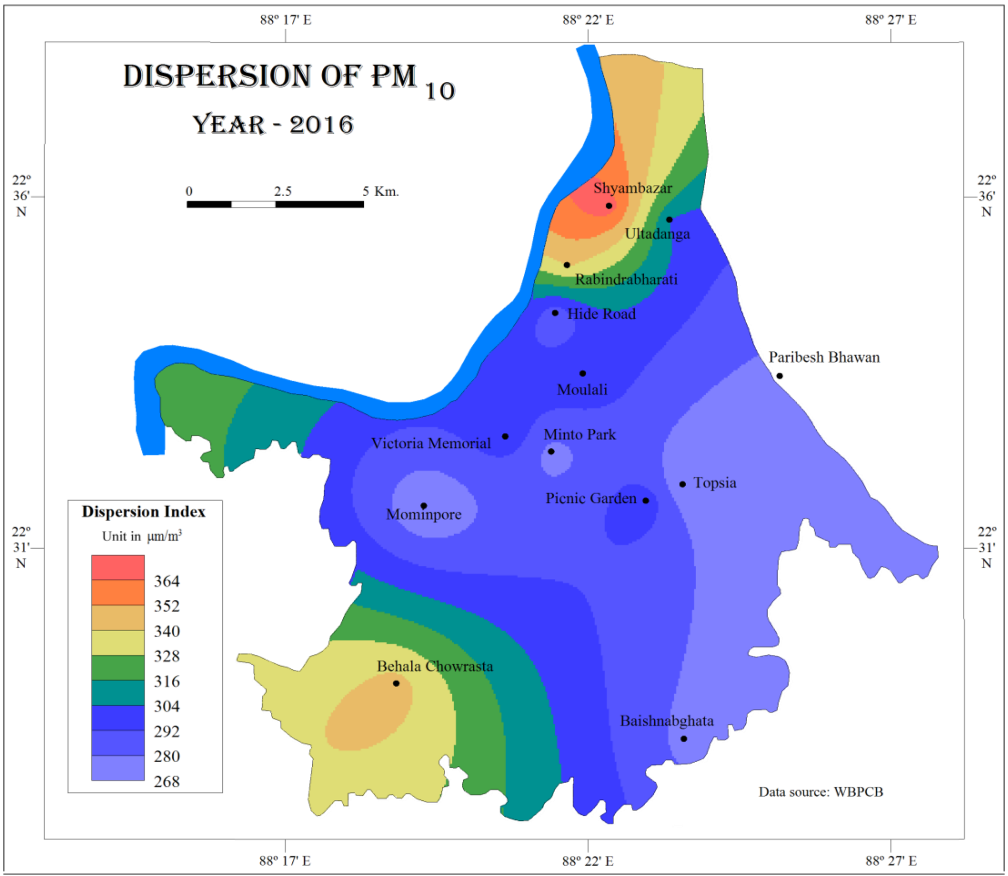


Figure 8.2.2.2: Dispersion Map of PM $_{10}$of 2016

Table 8.2.2.1: Air Quality (PM_{10}) and Average Temperature for the year 2000 and 2016

Type	2000	2016	Change
Air Quality (PM_{10} in mg/m^3)	238	318.5	80.5
Average Temperature (°C)	26	27.5	1.5

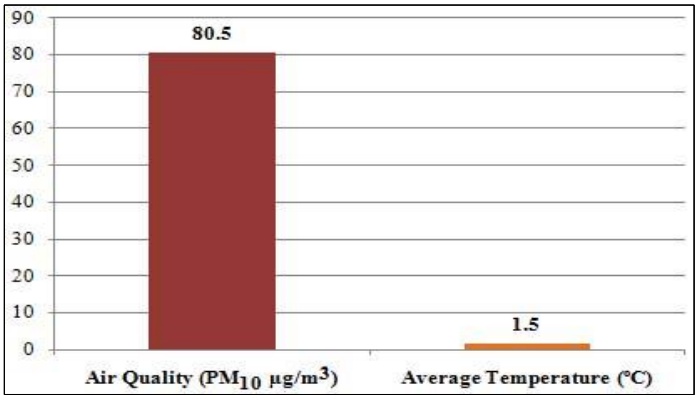


Figure 8.2.2.3: Change of Air Quality (PM_{10}) and Average Temperature

- It is also demonstrated that the increase in Air Temperature and Air Quality pattern due to the fire crackers on the special occasion like Diwali.

Table 8.2.2.2: Air Quality ($PM_{10}$and$PM_{2.5}$) and Average Temperature on Diwali day (07/11/2018)

Type	Diwali Day (7th November 2018)
Air Quality (PM_{10} in $\mu g/m^3$)	665.3875
Air Quality ($PM_{2.5}$ in $\mu g/m^3$)	444.775
Average Temperature	27.5

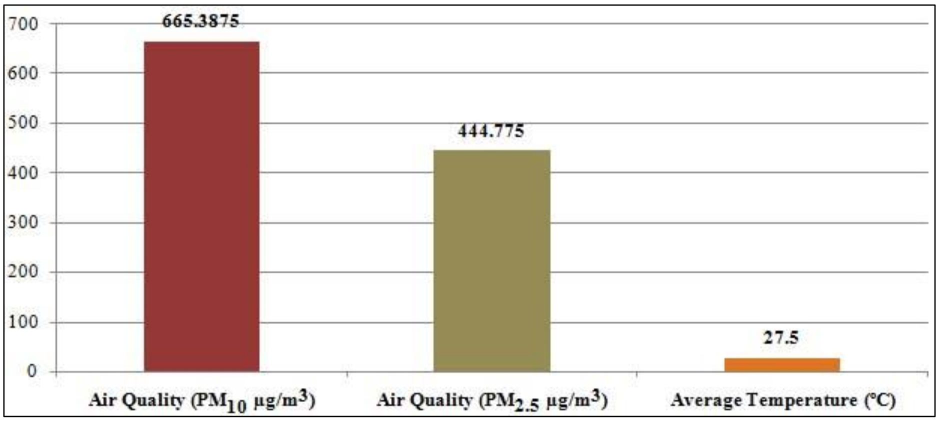


Figure 8.2.2.4: Air Quality (PM_{10} and $PM_{2.5}$) and Average Temperature on Diwali day (07/11/2018)

- High traffic zones and occasion of Diwali has experienced an increase in temperature and also increase in particulate pollutant.

- From the present study data, the variation in $PM_{2.5}$ and PM_{10} in the daytime or night-time can be deduced and, in addition, it even varies in different seasonal periods, which indicates the changing pattern of air temperature.
- It has also been demonstrated that the increase in air temperature and Air Quality pattern is due to the fire crackers on special occasions like Diwali.
- High traffic zones on the occasion of Diwali have experienced a further increase in temperature and also an increase in particulate pollutant.

8.2.3 Objectives 3

Investigation the inter-relationship and co-relationship among the UHI, LULC and Air Quality pattern in Kolkata

Moreover, this observation summarizes the interactions and relationships among Kolkata's UHI, LULC, and Air Quality Pattern. It also presents recent changes.

Table 8.2.3.1: Variation of $PM_{2.5}$, PM_{10} and Temperature (Day & Night time) with respect to LULC

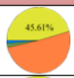
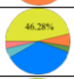
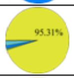
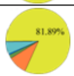
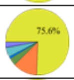
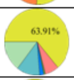
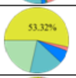
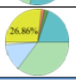
VARIATION OF $PM_{2.5}$, PM_{10} AND TEMPERATURE WITH RESPECT TO LAND USE									
LOCATION	LAND USE	LATITUDE	LONGITUDE	DAY TIME			NIGHT TIME		
				$PM_{2.5}$	PM_{10}	TEMPETURE	$PM_{2.5}$	PM_{10}	TEMPETURE
HAZRA MORE		22.52298	88.35248	203.6	236.65	26.67	959.00	1460.00	28.67
8B BUS STOP, JADAVPUR		22.49576	88.368258	188.85	238.75	26.00	958.00	1438.50	28.00
THE FUTURE FOUNDATION		22.480505	88.35162	165.35	165.35	25.67	738.50	1183.50	27.33
BAGHAJATIN MORE		22.48512	88.378549	172.85	220.55	26.67	860.00	1349.50	28.33
BEHALA CHOWRASTA		22.486467	88.311548	191.8	240.80	27.33	951.00	1442.50	29.33
RUBY HOSPITAL MORE		22.51062	88.382347	251	307.50	28.00	1052.00	1687.50	30.67
PEERLESS HOSPITAL		22.480684	88.391984	81.95	149.45	24.67	393.20	517.10	26.67
ECO AQUATIC HUB		22.552768	88.407148	117.5	183.00	25.33	472.10	529.85	27.00

Table 8.2.5 prepared by field data shows the relationship between LULC with Air Quality and Temperature during the day and night time. It concludes that though the Future Foundation, Baghajatin More, Behala Chowrasta areas are covered with mainly dense built up, but due to the fire crackers at night time, the air quality became worst.

8.2.4 Objectives 4

Suggestion and Recommendation for mitigating the UHI and improving the Air Quality for various land use classification.

Suggestion

i) Finding the appropriate method and technology to efficiently lower the ambient air temperature in tropical cities is crucial for the biophysical thermal comfort of city residents.

ii) It has been demonstrated that cool pavements, cool roofs, and urban vegetation are practical and affordable solutions for reducing local air pollutant concentrations in tropical cities like Kolkata and mitigating the impacts of UHI.

iii) The shade provided by the urban tree canopy is a type of green infrastructure that lowers air temperatures and lessens the Heat Island Effect.

iv) The main goal of the upcoming research should be to carry out model-based tests on UHI mitigation techniques.

v) The effectiveness of beneficial Urban Planning and Land Use Land Cover management.

Recommendation

Urban residents experience extreme discomfort as a result of nighttime temperature increases. The need for overall energy usage for cooling, such as refrigeration and air conditioning, has increased as a result. This makes the issue even worse. Therefore, it is crucial to develop solutions for reducing the harmful consequences of UHI. Urban Heat Island mitigation strategies must be economically feasible and suited for wide-scale implementation in order to be successful.

There are three main solutions being used in Kolkata to lessen the Urban Heat Island Effect. The first tactic entails lowering vehicle emissions over Kolkata. The use of high albedo building materials and increasing the amount of greenery in the city's built environment are the other two options for lowering ambient temperatures. The analysis yields the following recommendations in particular:

a) Walking and use of cycle or electric vehicles. Use of pool car and shared riding with friends and co-workers. Smoking should be prohibited.

b) Urban farming, home gardening, urban and community agriculture, organic agriculture is one of the solutions.

c) Delineation of control strategies of fireworks. Fire crackers display should be not promoted as a community entertainment.

d) To improve albedo and lower incoming solar radiation, the roofs and walls of the buildings should be coated with reflecting materials or light-coloured roofing material.

e) Vehicle maintenance should be up-to-date and along with regular basis replacing of air filter.

f) The public transportation system needs to be strengthened even more to deter people from using their own cars as a form of transportation. Less waste heat and air pollutants, especially aerosols, would be emitted if there were fewer cars on Kolkata's roads.

g) The use of prohibited DG (Diesel Generator)sets in legally punishable.

h) In future research, meteorological and point sources emission variables should be incorporated into the model.

i) Development of Decision Support System.

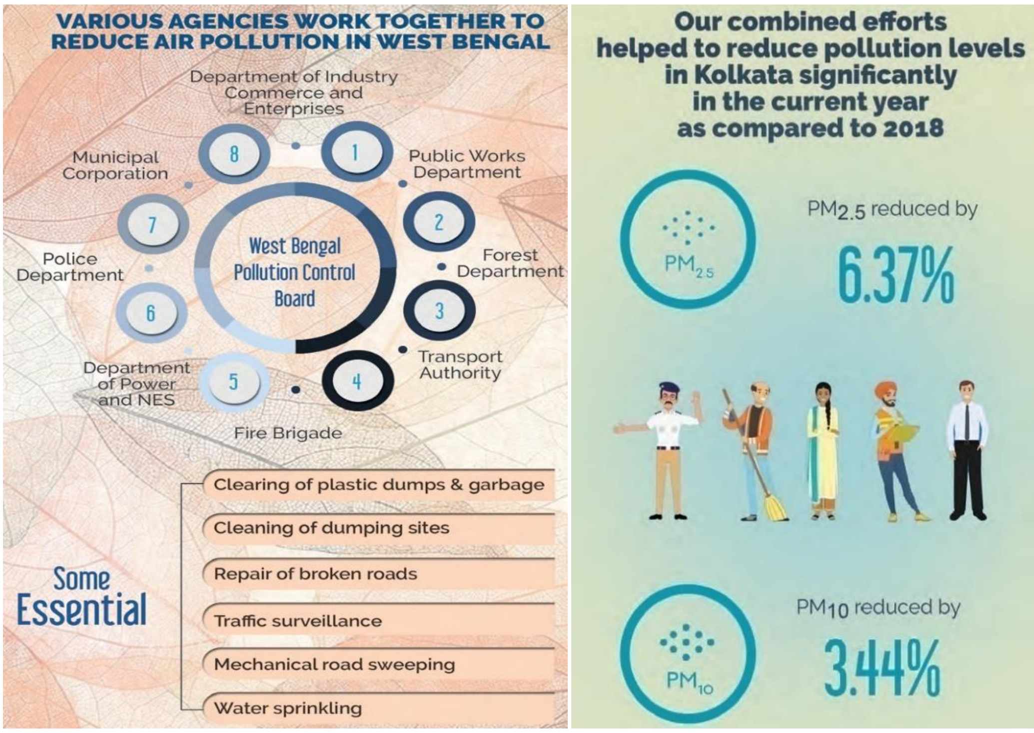


Plate 8.2.4.1: Some Essential steps to reduce air pollutions

Source: A Guide Book of WBPCB Department of Environment, Government of West Bengal

8.3 Future avenues of research

Future fresh and committed attempts must focus on tasks that were only temporarily addressed due to various time, resource, and lack of trustworthy data constraints. This thesis focused more explicitly on how changes in Land Use and Land Cover Patterns affected Air Quality and Urban Heat Islands.The thesis concentrated on how urban land use variations affect surface temperature, air quality, and urban heat islands.Despite the fact that many novel concepts were put out, several topics remain unexplored, opening up fresh possibilities for future researchers. Future scholars need to investigate each of these options. It is believed that the current exercise will make them aware of the proper technique for such studies and assist them in formulating their issue, potential solutions, and instructions for the creation, application, and distribution of knowledge to the next generation.

Future research opportunities abound as a result of this study:
Given the limitations of the current investigation, several markers could not be assessed. Each indication could not be measured, indicating a data and opportunity gap.
Future exploration may address aspects like -

- Quantification of environmental impact of reduced heat gain, mitigation of urban heat island, air quality management, urban bio-diversity etc.
- ***Qualitative findings*** of socio-economic impact on urban growth & human health.
- Mitigating analyses of control strategies for fire crackers on Diwali and other festivals.
- Further research promotes to ***incorporate Model analysis*** for relevant studies.
- Controlling assessment of vehicular emission and promote to eco-friendly vehicles.
- Crop residue burning, wildfires, and mining fires are all identified by WBPCB in various districts.

  By using satellite imagery and providing the district administration with the required guidance, you can reduce air pollution.
- The WBPCB established plans to put solar panels in numerous schools, colleges, and offices throughout the state in order to lessen the effects of global warming.
- In future research, promote the ***required urban farming, rooftop farming and vertical farming*** also.

8.4 Policy Recommendation

The purpose of policy recommendations is to explain to those who must make decisions about a specific issue what the best options are based on study and data. It is about utilising research to address an issue in public policy or to offer proof of how a policy is working. A detailed description of the current state of affairs is also essential. Policymakers will find it extremely helpful if you present an analysis of the problem that explains what approach, law, or government policy is presently in effect and why the research suggests a need for change.

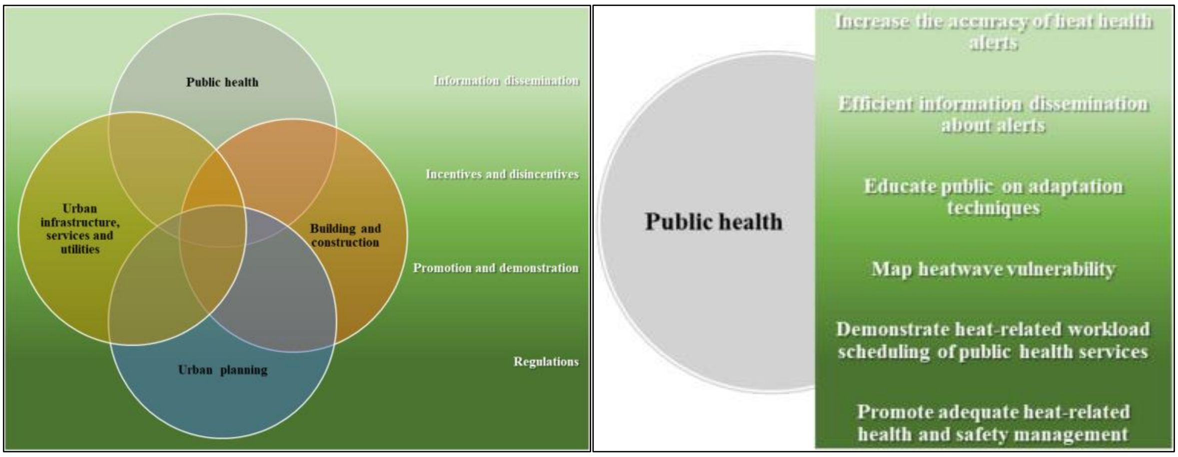


Plate 8.4.1: Public Health

Source: climatecentral.org

Urban ecological security has grown increasingly important and is proving to be the key to limiting the sustainable growth of the urban social economy. The globe has been actively working to protect the environment in recent years, and India in particular has increased its awareness of environmental security and elevated it to the level of national security.

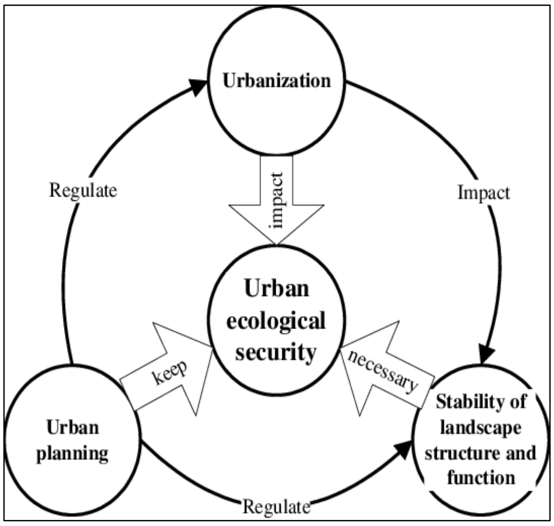


Plate 8.4.2: Policy Recommendation and Urban ecological security

Source: teriin.org.com

Road side Plantation and Water shrinking at Kolkata:

To prevent dust resuspension and maintain control over the skyrocketing air-quality index, the West Bengal Pollution Control Board (WBPCB) began employing water sprinklers. To keep smaller particles grounded, water will be sprayed along roads to combine them into larger ones. Following the use of dust suppressant sprinkling, a study by the central Pollution Control Board (CPCB) demonstrates an increase of over 30% in the airborne particulate content.

Plate 8.4.3: Road side Plantation for dust filtration at New Town

Plate 8.4.4: Road side Water shrinking at Kolkata

Source: A Guide Book of WBPCB Department of Environment, Government of West Bengal

A CPCB study found those 10 minutes after spraying the suppressant, there was an initial drop in dust concentration of 50% to 60%.

Plate 8.4.5: Public health aspects

Air Quality Management Plan (AQMP) :

The fundamental goal of the process for developing an AQMP is to create a solid and reliable foundation for planning and managing the air quality in a particular area. Planning in this way will guarantee that the most cost-effective means of identifying and controlling key sources of impacts are used. Identification of sources and creation of an exhaustive emission inventory are crucial components of the AQMP, as are the creation and administration of an air quality monitoring programme and the creation and use of atmospheric dispersion models. The gathering of the essential input data is a significant undertaking.

Plate 8.4.6: Air Quality Management Plan

The requirements for the Air Quality Management System (AQMS), operational and functional structure, source identification through emission inventories, source reduction alternatives that may be implemented, mechanisms for facilitating interdepartmental cooperation to ensure that actions are being taken, institutional building and training requirements are all factors that will be taken into consideration when developing the AQMP.

'Urban heat is a huge challenge — India has a history of mitigations like city trees'

Vivek Shandas teaches climate adaptation at Portland State University. Speaking to Times Evoke, he discusses why the world's cities are heating up:

THE DIFFERENCE YOU MAKE

HEAT IN THE CITY

TIMES EVOKE

'Climate change is the tipping point driving migration — building local resilience is key'

GLOBAL TO LOCAL

CLIMATE RISK INDEX

Plate 8.4.7: Paper clippings of recommendation (continued)

'Policies can play key role in reducing fossil fuels'

▸Continued from P 1

During a truly unprecedented year where some people who are accustomed to breathing dirty air, experienced clean air, it became acutely apparent the important role policy has played and could play in reducing fossil fuels that contribute both to local air pollution and climate change," said Michael Greenstone, the Milton Friedman Distinguished Service Professor in Economics and creator of the AQLI along with colleagues at the Energy Policy Institute at the University of Chicago (EPIC). "The AQLI demonstrates benefits these policies could bring to improve our health and lengthen our lives," he added.

The AQLI is a pollution index that translates particulate pollution into expected impact on life expectancy. Developed by Greenstone and his team at EPIC, it quantifies the causal relationship between long-term human exposure to air pollution and life expectancy by combining hyper-localised, global particulate measurements. In 2019, India's average particulate matter concentration was 70.3 µg/m³ — the highest in the world and 7 times the WHO's guideline of 10 µg/m³.

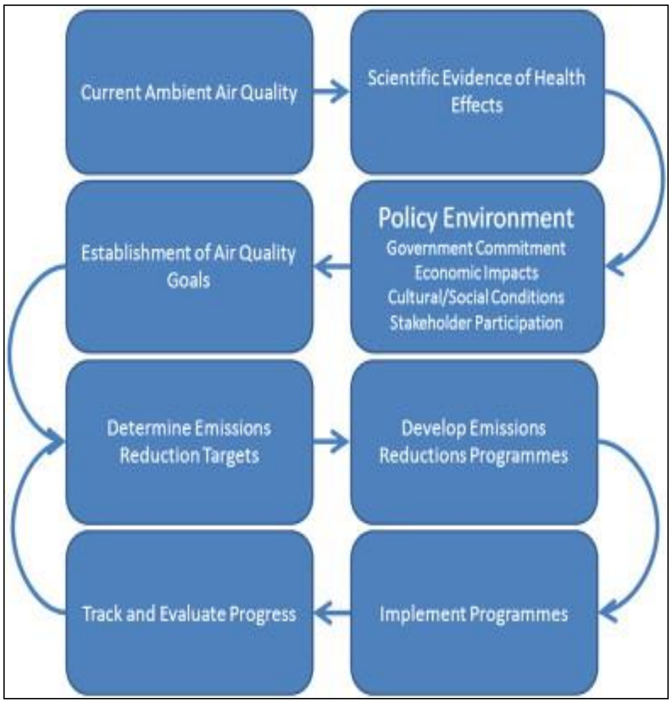


Plate 8.4.8: Paper clippings of recomendation

8.5 Mitigation Strategies of Reducing UHI & Air Pollution

India's cities are particularly susceptible to heat waves, which are predicted to occur more frequently in urban areas than ever before. According to reports, reducing air pollution could lessen the difference in incoming radiation between rural and urban areas, which would lessen the impact of the urban heat island effect**.**

There are several evaluation standards for UHI mitigation tactics that are presented. Not all mitigation strategies should give equal weight to all initiatives. However, given the various conditions and limitations inherent in various urban zones, these requirements must be wisely prioritiseds (Georgescu, *et al.*, 2015).The interplay between air pollution and urban heat should be taken into account by urban authorities when developing mitigation solutions because it is dynamic and complex.

Environmental Temperature :

The most crucial indications for UHI and surface urban heat island (SUHI) are environmental temperatures, including air and surface (and occasionally subsurface) temperatures. Additionally, when developing and putting into practise UHI mitigation techniques, it is important to take into account the extreme vertical variations in air temperature.In comparison to temperatures at higher elevations (> 2 m), street canyon temperatures have a substantially steeper vertical gradient close to the ground.

Although 2-m air temperature is frequently used as a measure of UHI intensity, there is currently no "standard" air temperature to be used for mitigation strategies across all scales and regions. This lack of a "standard" air temperature has led to disagreement on the measure of UHI mitigation for different strategies, especially among modellers.

Energy Consumption / Savings :

When UHI mitigation measures are used to lower environmental temperatures, buildings' cooling loads can be efficiently reduced. This results in significant energy savings during the hotter months (Salamanca, et al., 2013; Santamouris, et al., 2001; Wang, et al., 2016).However, the environmental benefits of these strategies, such as human thermal comfort (such as increased moisture absorption from urban vegetation), the co-benefit of the water-energy trade-off, and potential heating losses during the colder months, must be considered along with the energy-saving benefits.

Out door Air Quality (OAQ)

The literature has a clear understanding of the significance of outdoor air quality (OAQ) and how closely it relates to health issues (Costa, et al., 2014; Godish, Davis, & Fu, 2014; World Health Organization (WHO), 2014). Cities, which require a lot of energy, are often linked to huge power plants and the burning of fossil fuels, which turn out to be the main source of air pollution (Cohen, et al., 2004). As heat speeds up atmospheric chemical reactions, UHI tends to worsen air quality (Walcek & Yuan, 1995). All UHI mitigation techniques can have a direct impact on urban OAQ by lowering ambient temperatures, for example, by delaying the photochemical generation of pollutants like ozone (Taha, 1997).

Green roof studies

The UHI phenomena may be lessened through the use of vertical greenery systems, green façades, and green roofs on the exterior of buildings (Alexandri & Jones, 2008). The use of the green envelope and the reduction of local temperature have been the subject of several studies (Oberndorfer et al., 2007; Sailor et al., 2008; Takebayashi & Moriyama, 2007).According to Akbari, Rose, and Taha (2003), up to 25% of metropolitan areas are often covered by roofs. In particular, green roofs have a number of benefits with regard to reducing adverse UHI impacts (Takebayashi & Moriyama, 2007).

Plate 8.5.1: Wall of water and cascade

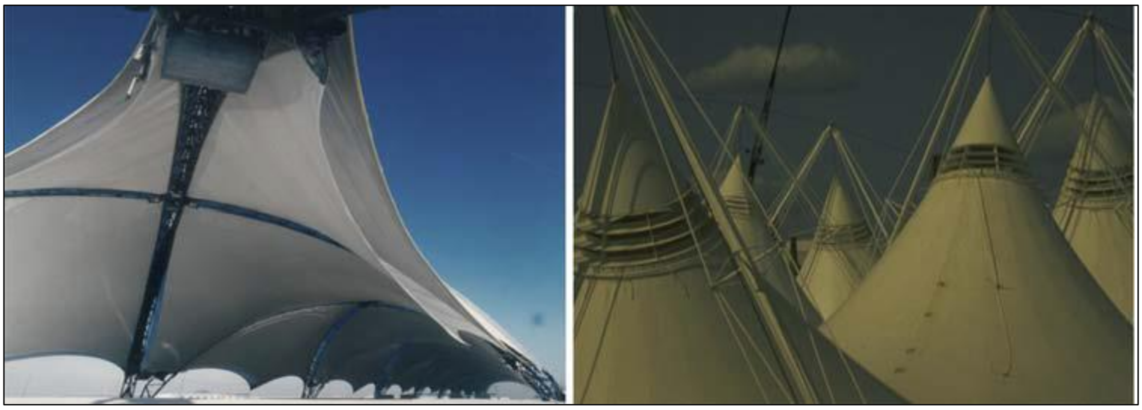
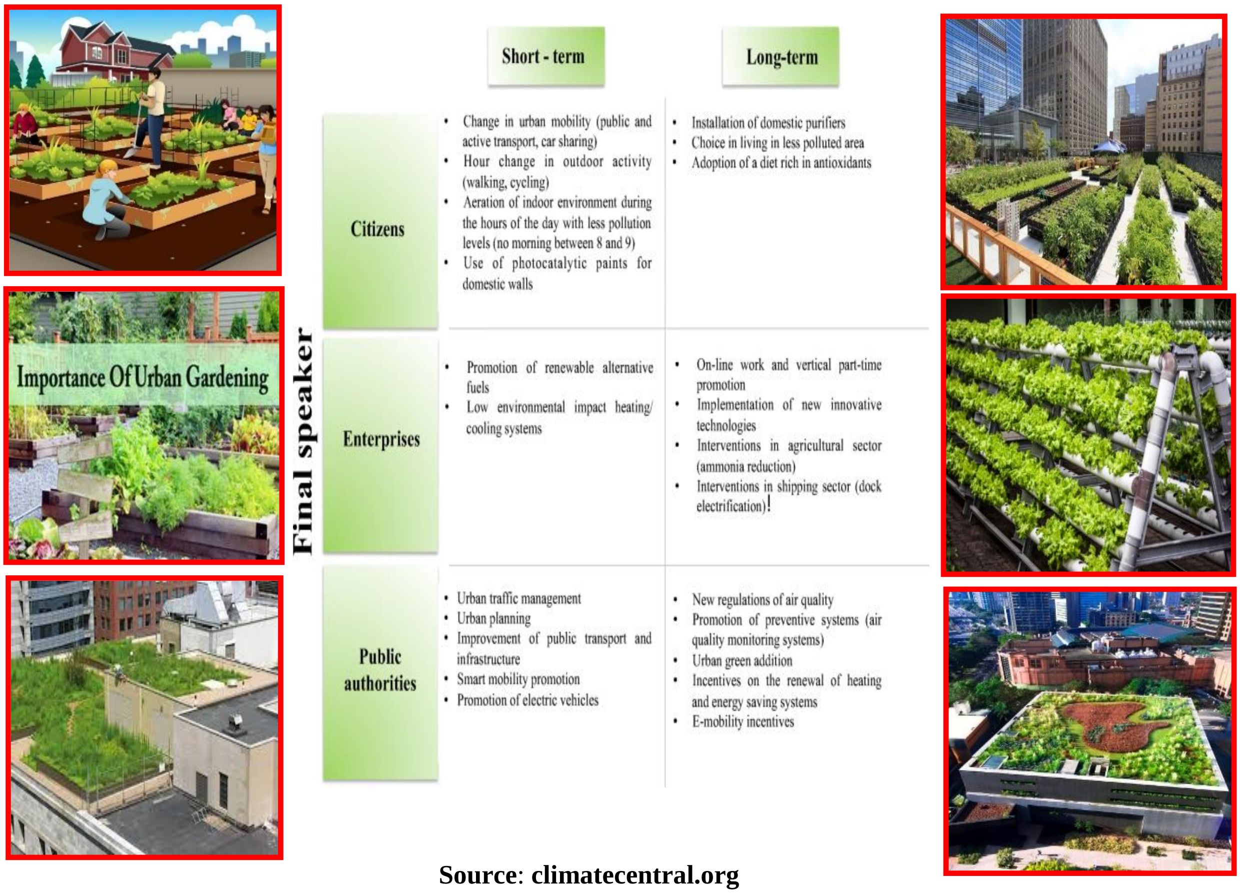


Plate 8.5.2: Double PVC covering and single covering with heat dissipation on the top and surface cooling via irrigation **Source: nature.com**

Studies on vertical greenery

A key component of mitigating UHI effects, particularly in urban areas, is vertical vegetation. In order to determine the effects of employing vegetated walls on the thermal performance of a public housing flat in Hong Kong, Cheng (2010) carried out an experimental investigation. The findings demonstrated that the indoor air temperature decreased as a result of the vertical vegetation acting as a barrier to solar heat transmission. Additionally, when vertical plants were installed on the building exterior in place of bare concrete, the energy consumption of the air conditioner was reduced by up to 30%.



Source: **climatecentral.org**

Plate 8.5.3: Short and Long term planning

Plate 8.5.4: Health impacts of UHI and mitigation

Source: climatecentral.org

8.6 Limitations of the study

- The study has been conducted only in some chosen pocket of Kolkata that is why the collected data as well as observations may not fully reflect whole Kolkata as a whole.
- Data collection was fully dependent on the sensors and sensors have some error in accuracy of (+/-) 2 to 5%as per sensors datasheets.
- Temperature historical data which is collected from a weather website is not possible to validate with actual data as those are not available publicly from IMD.
- Most of the important historical air pollutant data were not available at the pollution control board website and that is why the change in measure was impossible over a period.

8.7 Conclusion

The chapter's conclusion offers a few mitigating strategies to deal with the growing UHI problem. Urban planners, stakeholders, and decision-makers can use the information in this chapter and other research findings as background knowledge and recommendations as they establish new policies for attaining sustainability and reformulate existing ones. The results may provide researchers with a fresh method for obtaining precise urban and land use information from publicly available satellite data. Instead of using the standard two to three urban groups (low, medium, and high density) or one basic urban category as in prior research, this study may analyze the intra urban UHI difference in the two mega urban regions thanks to the different LCZ built kinds. The results can aid in the better understanding of the impact of urban morphology (i.e., LCZ classes) on regional climatic conditions by urban planners and urban climate researchers.

8.8 Overall Conclusion of the study

The findings support numerous previous researches and establish positive correlation among Land Use and Land Cover, Air Temperature, Air Quality, and traffic zones. Contrary to predictions, it has been observed that, especially on the day of Diwali and during different seasons, Air Temperature responded very significantly to the various LULC categories and Air Quality parameters. Finally, few mitigating measures has suggested under the conclusion section in the study in order to solve the growing UHI problem. Urban planners, stakeholders, and decision-makers can use the research findings as background knowledge and recommendations can be incorporated into different sustainability-related policy framework.

List of Abbreviations and Acronyms

AQI	Air Quality Index
AQM	Air Quality Monitoring
AQMP	Air Quality Management Planning
AQMS	Air Quality Management System
AQP	Air Quality Profile
CAAMS	Continuous Ambient Air Quality Monitoring
CiteSeer	An Automatic Citation Indexing System
CNG	Compressed Natural Gas
CPCB	Central Pollution Control Board
CO	Carbon Monoxide
CO_2	Carbon Dioxide
FCC	False Colour Composite
GIS	Geographical Information System
GPS	Global Positioning System
IGBC	Indian Green Building Council
IMD	Indian Meteorological Department
IOT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
KC	Kappa coefficient
KMA	Kolkata Metropolitan Area
KMC	Kolkata Municipal Corporation
KMDA	Kolkata Metropolitan Development Authority
LANDSAT	Land Remote-Sensing Satellite
LCZ	Local Climate Zone
LPG	Liquefied Petroleum Gas
LST	Land Surface Temperature
LULC	Land use Land Cover
LULCC	Land use Land Cover Change
MSS	Multispectral Scanner
MODIS	Moderate resolution Imaging Spectro-radiometer
NAAQS	National Ambient Air Quality Standard
NAMP	National Air Quality Monitoring Programme
NAQI	National Air Quality Index
NASA	National Aeronautics and Space Administration

NATMO	National Atlas and Thematic Mapping Organization
NEERI	National Environmental Engineering Institute
NIR	Near Infrared
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NEERI	National Environmental Engineering Research Institute
NGO	Non-Government Organisation
NH_3	Ammonia
NUHIZ	Non-Urban Heat Island Zone
OAQ	Outdoor Air Quality
OECD	Organization for Economic Co-operation and Development
OLI	Operational Land Imager
PM	Particulate Matter
PM_{10}	Particulate Matter 10
$PM_{2.5}$	Particulate Matter 2.5
RS	Remote Sensing
RH	Relative Humidity
RPM	Respirable Particulate Matter
SARI	Severe Acute Respiratory Infection
SAGA	System for automated geo-scientific analysis
SDS	Space Debris Sensor
SO_2	Sulphur Dioxide
SPM	Suspended Particulate Matter
SQL	Structured Query Language
TERI	Tata Energy and Research Institute
TM	Thematic Mapper
TSP	Total Suspended Particulate
UBL	Urban Boundary Layer
UCL	Urban Canopy Layer
UHI	Urban Heat Island
UA_S	Urban Agglomerations
UHII	Urban heat island intensity
USGS	United State Geological Survey
WBPCB	West Bengal Pollution Control Board

WMO	World Meteorological Organization
WHO	World Health Organization
WIFI	Wireless Fidelity
WOS	Web of Science

Glossary

Air pollutants - They are also known as "air toxins" and are chemical compounds that harmfully impact on human health and also decrease the environmental quality. It can be found in anywhere indoor or outdoor environments, Carbon monoxide is one of the major air pollutants in the urban environment.

Air pollution - It refers to the release of harmful or excessive quantities of substances into the air that decreases the quality of human health and the planet as a whole.

Albedo - It is the reflectance of solar energy from any materials or substance on the earth's surface. Something that appears white reflects maximum light that hits in any material that has high albedo, whereas something that looks dark absorbs maximum light from any material or substance that has low albedo.

Anthropogenic heat - heat generated by human activity, including heat dissipated from buildings, heat given off by vehicles and the metabolic heat of people themselves.

Effective temperature - the temperature at which motionless saturated air would induce the same sensation of comfort as that induced by the actual conditions of temperature, humidity and air movement.

Emissivity - the tendency of a surface to emit radiant energy, compared to a black body at the same temperature. Expressed as a decimal fraction between '0' and '1',

Energy balance - the difference between the total incoming and total outgoing energy of a physical system. If this balance is positive, warming occurs if it is negative, cooling occurs.

Evaporation - the physical process by which a liquid is converted to its gaseous state.

Evapotranspiration (ET) - the total process of water transfer into the atmosphere from vegetated land surfaces, comprising the sum of evaporation and transpiration.

Geographic Information System (GIS) - an information system that integrates, stores, edits, analyses, shares and displays geographic information in a form suitable for a variety of applications such as remote sensing or land surveying.

Latent heat **-** the amount of energy released or absorbed by a substance during a change of phase (e.g. from solid to liquid) that occurs without changing its temperature.

Latent heat of vaporization **-** the amount of energy required to evaporate a unit mass of a liquid.

Long wave radiation **-**is the electromagnetic radiation in the infra-red range with wavelengths of about 3 to 100μm.

Mean radiant temperature - the area-weighted mean temperature of the surfaces surrounding an object.

Microclimate - the climate of a very small space, which differs from that of the surrounding area. Microclimatic conditions such as air temperature, wind flow and the radiation balance within an area that may range in size from a few centimeters to several kilometers are influenced by the physical nature of the immediate surroundings as well as by the climate of the surrounding region.

Suburban - It is a geographical location to mixed-use or residential area, either adjacent to a city or urban area or separate residential community within commuting distance of a city. This area is observed both urban and rural characteristics.

Surface Temperature - the temperature of the air near earth's surface is in variably measured by the thermometer in the instrument shelter. Globally, surface temperature 1s calculated by averaging the temperature at the surface of the sea and air temperature on land.

Surface urban heat island - The relatively warmer surface area than adjacent area exists in urban area due to land cover changes and increasing population density, which is called as surface urban heat island.

Soil-air temperature -is the corresponding outdoor temperature which will cause the same rate of heat flow at a surface and the same temperature distribution throughout the material as results from the actual outdoor air temperature and net radiation exchange between the surface and its environment.

Thermal inertia - the tendency of a material to resist rapid change in its temperature. Thermal inertia is affected by a material's thermal conductivity and by its heat capacity.

Troposphere - the lowest portion of the Earth s atmosphere, in which most weather phenomena take place, and which 1s generally characterized by perceptible water content and a decrease in temperature with increasing height above the ground. The thickness of the troposphere varies between about 10 and 20kilometers.

Urban Boundary Layer (UBL) -is the part of the planetary boundary layer that is affected by the presence of an urban surface. It typically begins at ground level, a short distance upwind of the city, and may extend a substantial distance downwind at higher elevations.

Urban Heat Island (UHI) - a difference in temperature observed between a city and its surrounding rural areas, whereby it isotherms are drawn for the area in question, the city is apparent as a series of concentric, closed lines of increasing temperature towards the centre.

Urban heat island circulation - It consists of the updraft extending temperature over much more urban areas, a compensating downdraft over the rural surroundings. It can be extended horizontally two or three times the diameter of the cities.

Urban climate - The climate of urban areas is the difference from their adjacent rural area because of urbanization. The important features of urban climate area are higher air temperature and surface temperature, lower humidity, lower air quality, and changes in radiation balance.

Urban climatology - It is a specific branch of climatology that is the study of the climatic effect on urban areas and application of knowledge acquired to better planning and urban development.

Urban ecosystem - It is any ecological system located within a city or any setter area; in border sense, it is the greatest ecological system that creates up a whole metropolitan region.

Urban structure - a two-dimensional organization of the ground plan of an urban area, such as the street pattern or the structure of land parcels.

Vapour pressure (of water) - a measure of the moisture content of air, based on the partial pressure exerted by water molecules in the air. Typical values near the surface are less than 4kPa (compared to total atmospheric pressure at sea level of about 100kPa).

Vulnerability - It can be defined as the inability of an individual or group or community to withstand the effect of environmental changes due to different natural or human-made causes. To increase the resilience power of a group or community, that may reduce the vulnerability of that community and survive with that changing environment.

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APPENDICES

APPENDIX: A

(Analytical Formulations)

1. NDVI estimation:

Formula has been used for the Normalized Difference Vegetation Index.

NDVI = (NIR – Red) / (NIR + Red)

For Landsat 5 data, NDVI = (Band 4 – Band 3) / (Band 4 + Band 3)
For Landsat 8 data, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

2. NDBI estimation:

NDBI has been calculated by the following formula –

NDBI = (SWIR – NIR) / (SWIR + NIR)

For Landsat 5 data, NDBI = (Band 5 – Band 4) / (Band 5 + Band 4)

For Landsat 8 data, NDBI = (Band 6 – Band 5) / (Band 6 + Band 5)

3. NDWI estimation:

NDWI can be calculated by following formula:

NDWI = (GREEN – NIR) / (GREEN + NIR)

For Landsat 5 data, NDWI = (Band 3 – Band 5) / (Band 3 + Band 5)

NDWI = (NIR – SWIR) / (NIR + SWIR)

For Landsat 8 data, NDWI = (Band 5 – Band 6) / (Band 5 + Band 6)

4. Process of Land Surface Temperature using the TIR Band (Band 10) of Landsat 8 OLI for 2020

Landsat Level 1 radiometrically calibrated and atmospherically corrected data (LC08_L1TP_138044_20210103_20210308_02_T1_B10) provided by the United States Geological Survey (USGS) has been used for the process of Land Surface Temperature evaluation. Thermal band (Band 10 in Landsat-8 OLI) provided as the atmospheric brightness temperature in Kelvin (K). In the data selection stage, the following attributes were considered for generating quality and reliable outputs like - (i) daytime dry-season data, (ii) cloud-free images (iii) geo-rectified using Universal Transverse Mercator (UTM) with zone 45 North projection.

Step 1: Conversion to Top of Atmosphere (TOA) Radiance

Using the radiance rescaling factor, Thermal Infra-Red Digital Numbers can be converted to TOA spectral radiance. The following equation is used to convert a digital number in a Landsat level 1 back to radiance (L).

$L\lambda = ML * Q_{cal} + AL - O_i$

$L\lambda = (0.0003342 * Band10 + 0.10000) – 0.29$

Where:

$L\lambda$ = TOA spectral radiance (Watts/ (m^2 * sr * μm))

ML = Radiance multiplicative Band (3.3420)

AL = Radiance Add Band (0.10000)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

O_i = correction value for band 10 is 0.29

Output: TOA_{max} = 10.013 and TOA_{min} = 8.44798

Step 2: Conversion to Top of Atmosphere (TOA) Brightness Temperature (BT)

Spectral radiance data can be converted to top of atmosphere brightness temperature using the thermal constant values in Metadata file.

Kelvin (K) to Celsius (ºC) Degrees

$BT = K2 / \ln (k1 / L\lambda + 1) - 273.15$

BT= (1321.0789 / ln(774.8853/ToA+1)) – 273.15

Where:

BT = Top of atmosphere brightness temperature (°C)

$L\lambda$ = TOA spectral radiance (Watts/(m2 * sr * μm))

K1 = K1 Constant Band (774.8853)

K2 = K2 Constant Band (1321.0789)

Output: BT_{max} = 30.734 °C and BT_{min} = 19.5027 °C

Step 3: Normalized Differential Vegetation Index (NDVI)

The Normalized Differential Vegetation Index (NDVI) is a standardized vegetation index which has been calculated using Near Infra-red (Band 5) and Red (Band 4) bands.

NDVI = (NIR – RED) / (NIR + RED)

NDVI = (Band 5 – Band4) / (Band 5 + Band4)

Where:

RED= DN values from the RED band

NIR= DN values from Near-Infrared band

Output: $NDVI_{max}$ = 0.396295 and $NDVI_{min}$ = -0.0889339

Step 4: Land Surface Emissivity (LSE)

Land surface emissivity (LSE) is the average emissivity of an element of the surface of the Earth calculated from NDVI values using the formula -

$PV = [(NDVI – NDVI\ min) / (NDVI\ max + NDVI\ min)]^2$

Where:

PV = Proportion of Vegetation

NDVI = DN values from NDVI Image

NDVI min = -0.0889339 (Minimum DN values from NDVI Image)

NDVI max = 0.396295 (Maximum DN values from NDVI Image)

Output: PV_{max} = 0.282784 and PV_{min} = 0.00216649

LSE = 0.004 * PV + 0.986

Where:

0.986 corresponds to a correction value of the equation

Output: LS E_{max} = 0.987131 and LSE $_{min}$ = 0.986009

Step 5: Land Surface Temperature (LST)

The Land Surface Temperature (LST) is the radiative temperature which calculated using Top of atmosphere brightness temperature, Wavelength of emitted radiance and Land Surface Emissivity using the following formula -

LST = (BT / 1) + W * (BT / p) * ln(LSE)

Where:

BT = Top of atmosphere brightness temperature (°C)

W = Wavelength of emitted radiance (11.5µm)

p = h * c / s ($1.438 * 10^{-2}$mk) = 14388mk

h = Planck’s constant ($6.626 * 10^{-34}$ JS)

s = Boltzmann Constant ($1.38 * 10^{-23}$ JK)

c = Velocity of light ($2.998 * 10^{8\ m/s}$)

LSE = Land Surface Emissivity

Output: LST_{max} = 29.852ºC &LST_{min} = 19.0264ºC

APPENDIX: B

Appendix Table B1: Field Survey Data used in the study

Location	Latitude	Longitude	Temperature (ºC) during January(Day time)			Land Use
			2010	2015	2020	
Mominpur	22° 31' 37.44"	88° 19' 19.01"	30	32	29	Built up
Ultadanga	22° 35' 43.76"	88° 22' 57.48"	28	29	27	Dense Built up
Baishnabghata	22° 28' 14.79"	88° 23' 30.02"	24	25	25	Mid rise Built up
Topsia	22° 32' 22.94"	88° 23' 14.94"	23	24	25	Built up
Behala Chowrasta	22° 29' 11.61"	88° 18' 49.13"	26	27	28	Dense Built up
Minto Park	22° 32' 25.41"	88° 21' 17.86"	25	25	25	Built up
Shyambazar	22° 36' 4.58"	88° 22' 26.22"	28	29	25	Dense Built up
Moulali	22° 33' 38.20"	88° 21' 51.90"	28	29	26	Dense Built up
Rabindrabharati	22° 37' 37.16"	88° 22' 43.99"	28	28	23	Vegetation with Built up
Hide Road	22° 31' 31.60"	88° 18' 20.79"	27	28	25	Built up
Picnic Garden	22° 31' 44.44"	88° 22' 54.31"	25	26	23	Built up
Victoria Memorial	22° 32' 29.22"	88° 20' 29.50"	23	25	21	Vegetation & Open Space
Paribesh Bhawan	22° 33' 45"	88° 24' 30.87"	22	23	22	Vegetation with Built-up

Appendix Table B2: Area of LULC type from the year 2000, 2010, 2015, 2020 and 2030 (estimated)

Kolkata Municipal Corporation (186.35 Sq. Km). Areas are in percentage (%)					
LULC	**2000**	**2010**	**2015**	**2020**	**2030 (Estimated)**
Waterbody	5.45	5.72	4.75	9.12	8.79
Vegetation	30.70	37.78	28.73	31.21	29.1
Open Space	0.72	2.73	1.68	1.21	0.98
Built up	63.13	53.77	64.84	58.46	61.13

Appendix Table B3: LST and three spectral indices for the year 2000, 2010, 2015, 2020 and 2030 (estimated)

	2000	2010	2015	2020	2030 (estimated)
LST_{Max} (ºC)	33.06	28.65	29.85	24.10	25.2
LST_{Min} (ºC)	22.75	17.25	19.02	17.40	18.19
$NDVI_{Max}$	0.542130	0.422680	0.196974	0.396300	0.369507
$NDVI_{Min}$	-0.032540	-0.254902	-0.034913	-0.088930	-0.082917
$NDWI_{Max}$	0.529332	0.555556	0.272500	0.321822	0.310177
$NDWI_{Min}$	-0.449247	-0.471503	-0.167946	-0.251219	-0.242428
$NDBI_{Max}$	0.618599	0.526882	0.251219	0.167946	0.175616
$NDBI_{Min}$	-0.547902	-0.466667	-0.321822	-0.272540	-0.284987

Appendix Table B4: Percentage of area and average temperature change from 2010 to 2015

Percentage of area change from 2010 to 2015	
Builtup	11.07
Vegetation	-9.05
Waterbody	-0.97
Open Space	-1.05
Average Temperature	1.48

Appendix Table B5: Percentage of area and average temperature change from 2015 to 2020

Percentage of area change from 2015 to 2020	
Builtup	-6.38
Vegetation	2.48
Waterbody	4.37
Open Space	-0.47
Average Temperature	-3.685

Appendix Table B6: Converted area of LULC type from the year 2015to 2020

Changed Feature (2015 - 2020)	Changed Area (in Sq. Km.)
Builtup–Builtup	89.15
Builtup - Vegetation	14.84
Builtup - Waterbody	17.06
Open Space –Builtup	1.33
Open Space - Vegetation	3.32
Open Space - Waterbody	0.95
Vegetation –Builtup	14.57
Vegetation - Vegetation	18.31
Vegetation - Waterbody	17.65
Waterbody –Builtup	0.38
Waterbody - Vegetation	0.43
Waterbody - Water body	6.22

APPENDIX: C

PUBLICATIONS

THE FOLLOWING PAPERS ARE FULLY EMBODIED IN THE PRESENT THESIS

Journal

1. Sohini Sen, Debashish Das, Raja Ghosh (June 2019), "Investigating PM_{10} level with respect to the Urban Land use and its effect in Urban Heat Island", Indian Journal of Regional Science, Vol-L1, No-1,pp.27-39,ISSN: 0046- 9017(Print), ISSN : 2456 – 6519 (Online), Indian Journal of Regional Science, June 2019.

2. Sohini Sen, Debashish Das, Anupam Deb Sarkar, Raja Ghosh, "Investigating Real-Time Ambient Air Quality Status and Land Surface Temperature during Kalipuja/Diwali Festival in different Land use types – Case study Kolkata", International Journal of Advances in Mechanical and Civil Engineering (IJAMCE), Volume-7, Issue-1, pp.21-27, ISSN (P) : 2394-2817, International Journal of Advances in Mechanical and Civil Engineering (IJAMCE), December,2019.

3. Sohini Sen, Ashwini Kumar Singh, Debashish Das, Anupam Deb Sarkar, Raja Ghosh, "A Study of the Spatio-temporal Variations in PM_{10} and $PM_{2.5}$ with Air Temperature, Traffic Volume and different Land Use types during the Diwali festival period: A case study of Kolkata, India", ISSN: 0046- 9017 (Print), ISSN : 2456 – 6519, The Indian Journal of Spatial Science, 2021

Book Chapter Accepted:

Sohini Sen, Debashish Das, Pankaj Chakraborty, Raja Ghosh, 'Assessment of LULC changes and it's impact on Surface Temperature and Urban Heat Island conditions in Kolkata during SARS COVID 19 period"Climate Crisis: Adaptive Approaches and Sustainability **Springer Nature Switzerland AG.**

Papers under Review:

Sohini Sen[1], Dr. Debashish Das[2], Dr.Anupam Deb Sarkar[3], Dr. Sucharita Mitra[4] , Mr. Suman Patra[5], Mr. Pankaj Chakrobort[6], Mr. Raja Ghosh[7], Dr.Soumik Sarker[8] "Comparison of the Performance of Low Cost SDS Particulate Sensor and Standard Measuring Devices at Ambient Air Quality and Temperature condition".

Conference presentation

1. Presented a paper on**,** "Mother Earth: in the International Conference on "Environmental Crisis & Sustainable Strategies", held on January, 16thto18th, 2018, organized by Department of Environmental Science, Burdwan University, West Bengal, India.

2. Presented a paper on "Investigating Real-Time Ambient Air Quality Status and Land Surface Temperature during Kalipuja/Diwali Festival in different Land use types – Case study Kolkata", at the International Conference on "International Conference on Civil and Architectural Engineering (ICCAE)", 14th November 2019, Shanghai, China.

Investigating Urban Heat Island effects with respect to the urban Land Use Land Cover change and Air Quality: A Case Study of Kolkata

ORIGINALITY REPORT

5%
SIMILARITY INDEX

PRIMARY SOURCES

1	www.researchgate.net Internet	851 words — 2%
2	Manju Mohan, Shweta Bhati, Ankur Prabhat Sati. "Urban heat island effect in India", Elsevier BV, 2022 Crossref	297 words — 1%
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