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

Synopsis of Thesis submitted for the partial fulfilment of the requirement for the award of Ph. D. (Arts.)

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Synopsis of the Ph. D. (Arts) Thesis

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by
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1.0 Introduction

Urbanization is a vigorous process and one of the main anthropogenic factors of 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) which has not been fully explored (Hafner and Kidder, 1999; Poreh, 1995). Urban Heat Islands not only generate a temperature higher than the average temperature of the adjoining areas, but may also lead to further deterioration of the environment by causing less rainfall, consequently increasing pollution and suspended solid particulate matter in the air. During the 100 years ending in 2005, global surface temperature increased by 0.74 0.18° C (Masson-Delmotte, V., P. Zhai, H.-O). As per the most recent IPCC report(2022), the global surface temperature will likely rise by another 1.1 to 6.4 degrees Celsius during the twenty-first century.

Remote sensing, although challenged by the spatial and spectral heterogeneity of urban environments (Jensen and Cowen 1999; Herold et al., 2004) seems to be an appropriate source of urban data to support such studies (Donnay et al., 2001). Reduced sky-view factor, replacement of soil covered by concrete/asphalt surfaces, and emission of a large amount of waste heat from the transportation, commercial, residential, and industrial sectors all contribute to a rise in temperatures over urban areas when compared to surrounding rural areas (P. Pandey et al., 2012).

In Kolkata, the rapid expansion of the central part of the city and its periphery has led to in many cases, a series of complex problems related to environment. The increased heat in urban areas requires an increase in the amount of energy used for cooling buildings, leading to a deterioration of Air Quality and negative health effects. The UHI signals consider a broad suite of important land surface changes impacting human health, ecosystem function, local weather, and possibly climate (Imhoff, Zhang, Wolfe, Bounoua, et al., 2010). The mapping of urban thermal conditions and the relation with land use and land cover (LULC) and air pollution has been of increasing interest among researchers. The rapid population growth, in conjunction with urbanization, expansion, and encroachment into limited agricultural and green areas, leads to the destruction of vegetation coverage (B. Ruchi. P. Rajendra.et *al*., 2021).

It is obvious that urbanization causes environmental impacts such as intensified land surface temperature (LST), UHIs and air pollution. Several studies have shown that the air temperature in urban canyons is not dependent solely on urban and street geometry but is also governed by complex and regional factors (Bärring, Mattsson, and Lindqvist 1985). LST research shows that the balance of land surface energy can be influenced by the conversion of surface soil, water

content, and vegetation (Li and Zhou, 2011). Based on these ideas, the main objective of this research is to understand the urban heat island effects caused due to land use land cover and air pollution changes in different years (i.e., 1996 and 2016) using remote sensing satellite images and locally collected air pollution data.

2.0 Literature Review

Before one starts an investigation into a particular concept, its origin and development should be considered. It would be more useful for comparing the views and ideas expressed in the researcher's findings in the light of earlier work and if we learned from some reports or journals. Various literature on Land Use and Land Cover (LULC) change and Air Temperature, Land Surface Temperature (LST), Urban Heat Island (UHI) pattern, and changing issues has been reviewed in order to develop clear ideas and concepts about them. In this thesis, existing literature related to major issues of the study has been categorized into four types, namely:

- Land Use Land Cover (LULC) Literature Definition, Classification, and Types of LULC in Tropical Regions, including Kolkata Metropolitan Area
- Literature on Urban Heat Island (UHI), changing air temperatures, changing land surface temperatures, and various bio physical indices such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Building Index (NDBI).
- Literatures On Air Quality, Air Pollution Pattern and its monitoring Instrument Related
- Relevant works on development

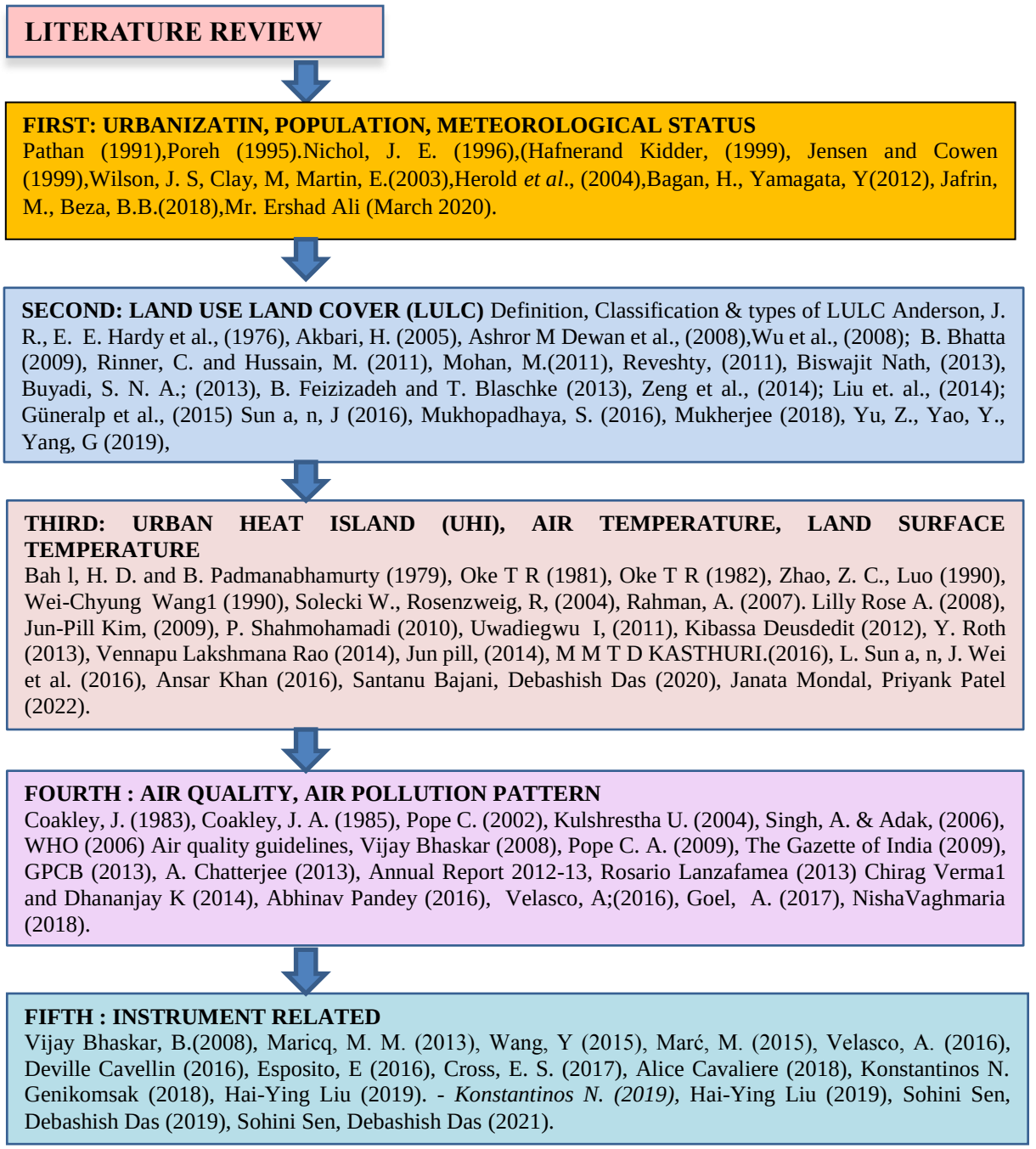


Figure 1.0: Details of category wise relevant papers in journals reviewed

2.1 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.

- **Pradnya Nesarikar – Patki and Pratima Raykar – Alange (2012),** *"Study of Influence of Land Cover on Urban Heat Islands in Pune using Remote Sensing"*: In this paper whether change in land cover in Pune contributes to the change in Land Surface Temperature or not was ascertained to understand the role and influence of various land covers to achieve better micro-climate in urban area. This investigation was carried out involving the Remote Sensing application IDRISI - Andes for prediction of temperature variations associated with different land cover types.

- **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.

- 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 field campaign during summer, May 2008 named DELHI-I (Delhi Experiments to Learn Heat Island Intensity -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.

- **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 at a resolution of 1 km and two spatial renderings of metropolitan areas—based on the official tabulations of population and settlement types—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.

- **Jayanta 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 investigated the high-rise buildings and population density has increased rapidly with concomitant decline in greenery during the study period the Normalized Difference Vegetation Index (NDVI) values are lower within the KMA but more enhanced in the surrounding rural areasusing multi-temporal MODIS satellite data.

2.2 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 develop when a large fraction of the natural land cover in an area is replaced by built surfaces that trap incoming solar radiation during the day and reradiate it at night. Also this increase in urban air temperature as compared to surroundings suburban and rural temperature is referred to as the heat island effect.

- **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 emperical evidence linking recent fluctuation in regional temperatures to enhanced ozone formation within the country's 50 largest metropoliton regions,and he also analysed of regional climate and ozone formation during the1990s indicate that annual violations of thenational ozone standard were more strongly associated with regional temperatures than with the 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 investigate local air pollution patterns in Guangzhou in the period of 1980 to 2000",* and to examine the relationship of the Air Pollution patterns with Land Use And Land Cover changes,and urban thermal landscape.The spatial patterns of air pollutants probed were positively correlated with urban built up density,and with satellite derived Land Surface Temperature values, particularly with measurements taken 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 most significant Land Surface feature in urban system. UHI means that the surface temperature over urban is higher that over rural regions.

- **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 was that 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*". In this paper using a Triangulated Irregular Network (TIN) model based on air pollution monitor observations of quantify the cause and effect between LULC and Air Quality.

- **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.

- **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 basic observation in this paper is, the three sensors provide quite similar results, with inter sensor correlations exhibiting R values higher than 0.97 and all three sensors demonstrate quite high linearity against officially measured concentrations of $PM_{2.5}$, with R^2 values ranging from 0.55 to 0.71. High RH (over 80%) negatively affected the sensor response. The results demonstrate the general feasibility of using these low cost SDS011 sensors for indicative $PM_{2.5}$ monitoring under certain environmental conditions.

3. Research Gap

There is a need for research on comparative analysis within Kolkata among Urban Heat Island effects with respect to the change of LULC and Air Quality pattern. Analysis using real-time data collection has not yet been performed across the area of our concern.

The fast expansion of city limits in almost most of the metropolitan cities all over the world coupled with the emission of sub-microcin particles both from vehicular traffics and industrial stacks in the vicinity of township has caused an exponential rise in particulate matters like 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 the need of hour to find measures to reduce Urban Heat Island Effect (UHI) and optimise Land Use and Land Cover (LULC) for better city life. To understand the UHI impacts an investigation on land use land cover types changes 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.

Many of the past research works had focussed on the above parameters. There are data sources collected by many government and non-government organizations. However no 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 aimed at fulfilling the gap in systematic and collective way with suggestion, improvement and optimization of the above parameters as an initial step towards implementation.

4.0 Objectives and the Scopes of the Study

4.1 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

4.2 Objectives of the study

- To study the Urban Heat Island (UHI) intensity with respect to different LULC changes.
- To study the Urban Heat Island (UHI) intensity with respect to Air Quality, with a special emphasis on respirable Particulate Matter.
- To investigate the interrelationship and correlation among UHI, LULC and Air Quality patterns in Kolkata.
- To make and recommend recommendations for mitigating UHI and improving Air Quality for various land use land cover types.

4.3 Research Questions

- Whether Land Use Land Cover Changes has any effect on Urban Heat Island of the city?
- Whether Land Use Land Cover Change has any effect on Air Pollutant change/concentration?
- Whether the increase of Air Pollutants has any role is the UHI change in the city?
- Whether there is any relationship between Land Use Land Cover Change, Air Pollutant level and UHI of an area or place?

4.4 Research Hypothesis

Urban Heat Island scenario changes with respect to the change in Land Use Land Cover (LULC) and Ambient Air Quality.

4.5 Scopes of the Study

- To study the Land Use Land Cover change in Kolkata for last 2 to 3 decades.
- To understand the impact of LULC on Air Pollution level within the city of Kolkata for last 2 decades.
- To observe the impact of LULC and Air Pollution change on Air Temperature and Heat Island Effect in Kolkata.
- To analyze and highlight the interrelationship among LULC, Air Pollution level and UHI.
- To recommended and suggest interventions for mitigating the Urban Heat Island Effects in Kolkata with respect to LULC change and Air Pollution.

5.0 Methodology

The research contributes to the current literature by adding more evidence on the correlation among urban thermal patterns (i.e., UHI), Air Pollution, and urban Land Use and Land Cover change. However, there is a gap in studies within Kolkata that fully utilized the state-of-the-art technologies of satellite, Remote Sensing, and GIS, which have been some of the most appropriate and effective for handling spatial data such as urban air pollution, urban heat, and land use patterns.

Data collected for this study can be classified into primary and secondary data. The primary data includes satellite images which were downloaded from Earth Explorer website (earthexplorer.usgs.gov) and developed by real time sensor. The real-time Ambient Air Quality monitoring was carried out at different land use sites in Kolkata.

Current remote sensing technology allows for obtaining a considerately, high quality of LST estimates through various stages of the correction process (Voogt and Oke, 2003). GIS technology provides a flexible environment for entering digital data from various sources and is a powerful tool for analyzing numerical relationships within and among the map layers.

It is advantageous that a comprehensive approach of remote sensing and GIS can be developed and applied when examining the relationships among spatial variables such as urban land use land cover, pollution, and thermal variation within an urban context.

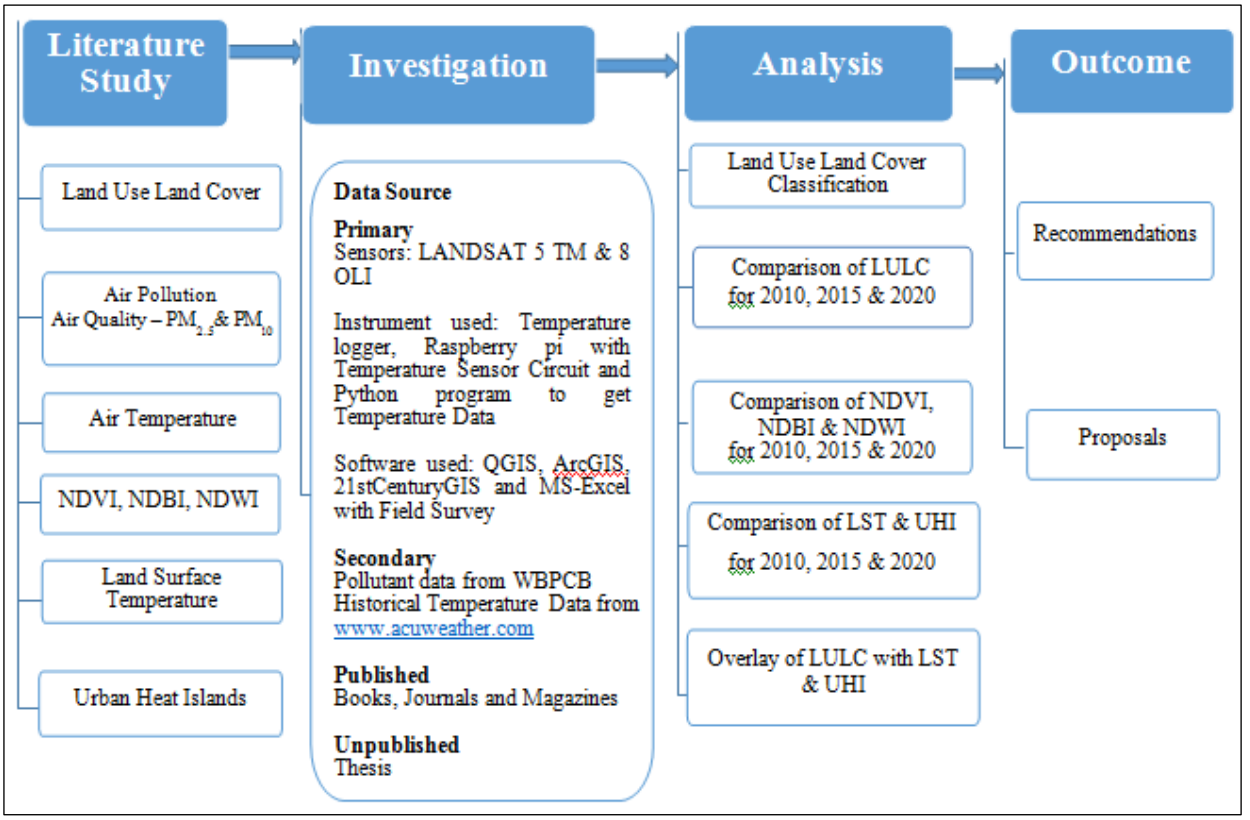


Figure. 2: Work flow Methodology

Remote Sensing data is a primary source for analyzing environmental processes on a local or global scale. These data are used to detect changes over the last few decades. Remote sensing data (such as Landsat data, Sentinel data, Spot images, etc.) is very useful for visualization, classification, and analysis of an area. These datasets can be categorized based on their resolution, electromagnetic spectrum, energy source, imaging media and number of bands. The higher the resolution of satellite data (spatial resolution, spectral resolution, radiometric resolution, temporal resolution), the higher the degree of accuracy will be achieved during classification.

In general, Landsat data are used for classification, which is divided into several bands based on wavelength (blue, green, red, infrared, thermal, and panchromatic band). A panchromatic band is used to increase the resolution of data. Landsat 5 (TM & ETM) data has a total of 7 bands, while Landsat 8 Operational Land Imager **(OLI) and Thermal Infrared Sensor (TIRS)** data have 11 bands. For analysis of the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI) and Normalized Difference Water Index (NDWI), only four bands are used (Green, Red, NIR and SWIR).

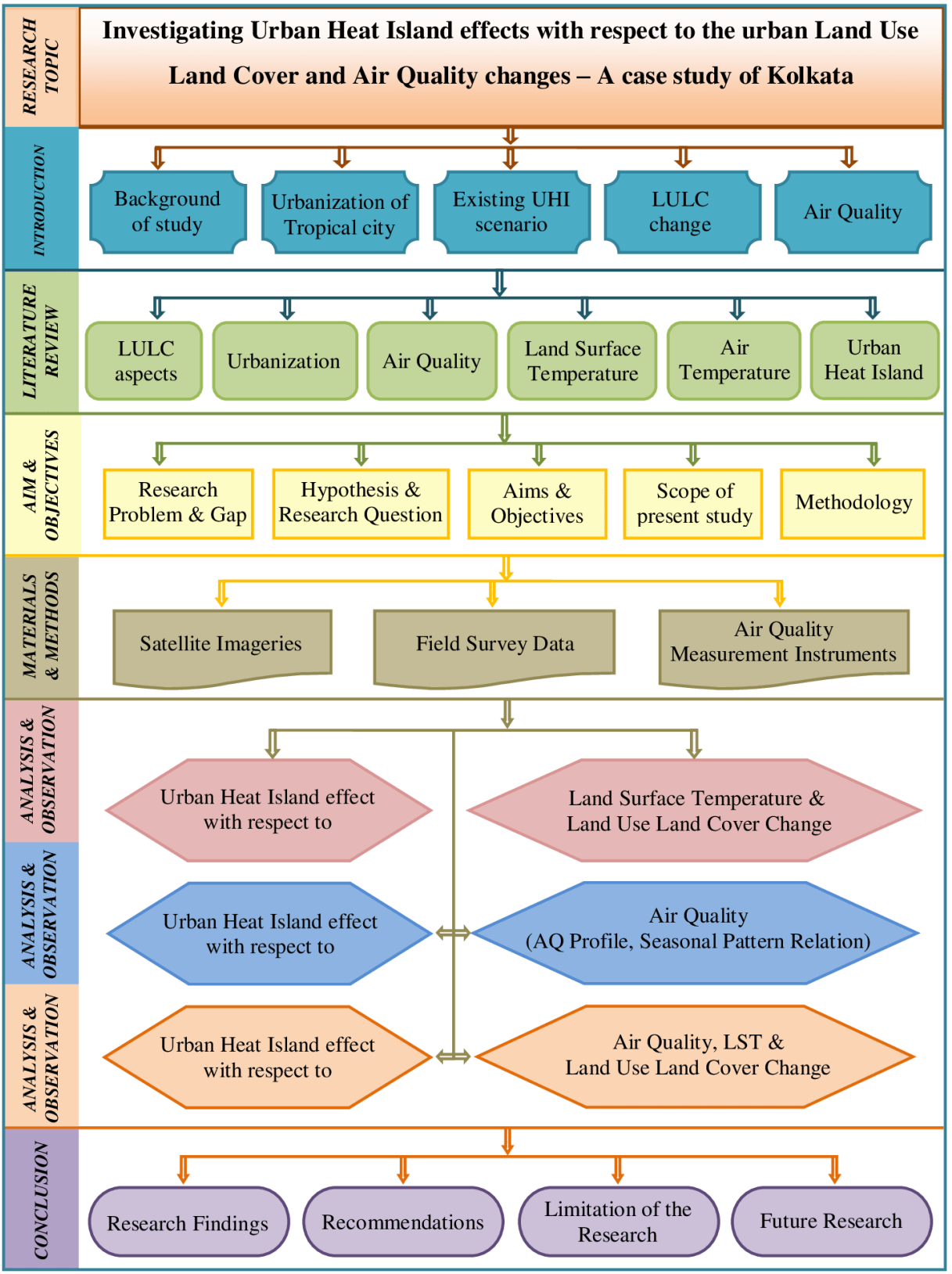


Figure: 3 Methodological Structure of the Research Work

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

Plate 1: ABP Ananda Live show of Real Time Air Quality Monitoring of Different Dense Built up and High Traffic Area in Diwali period, Kolkata, 2018 by the Author

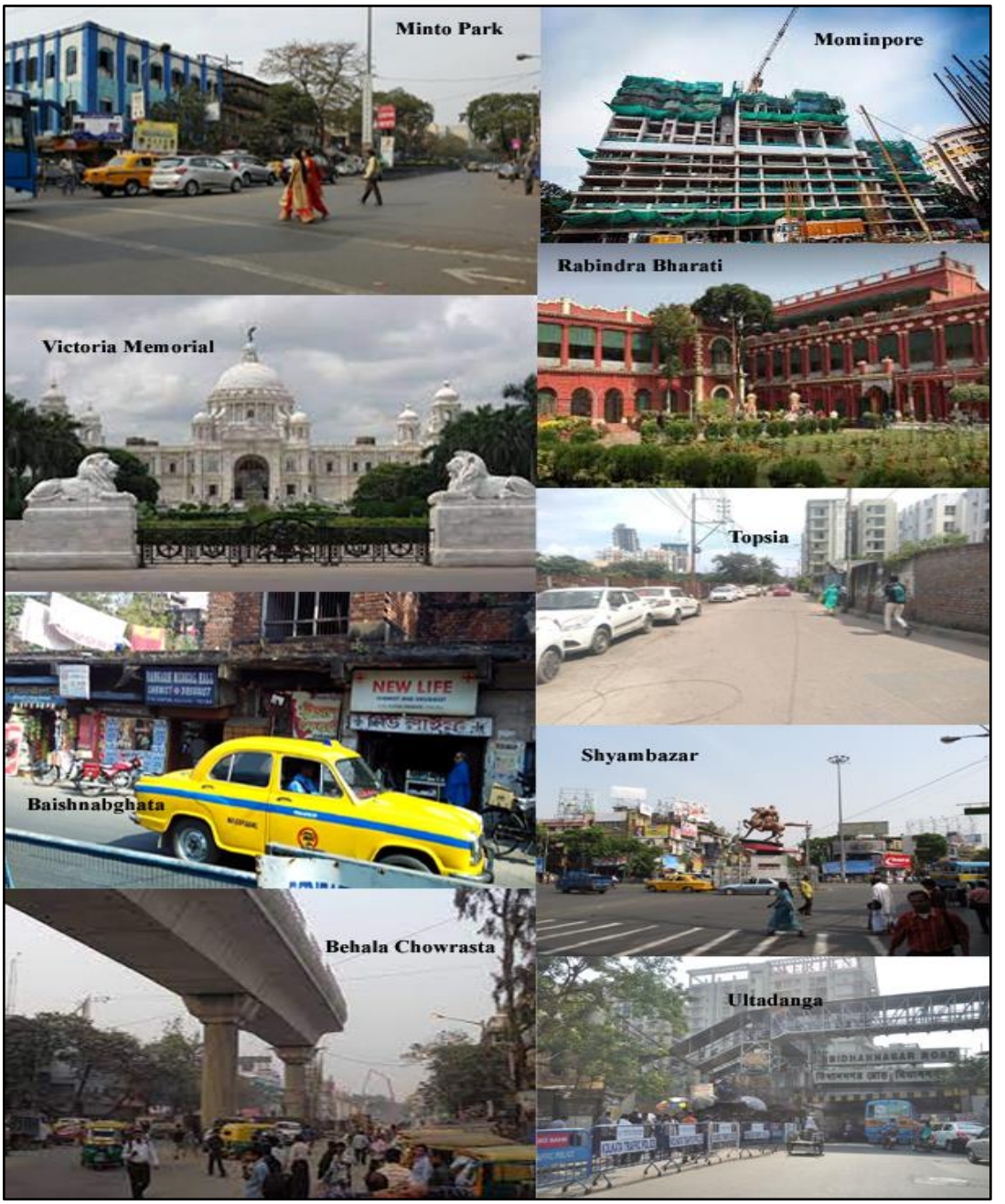


Plate: 2 Pollution Monitoring Stations

This study conducted a comparison study of ambient Air Quality monitoring with 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.

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 in the monitoring locations power for these systems is not available, and carrying that equipment in remote locations is difficult (Sen,

S., Das, D. *et al*.) which is actually in our case. The locations in which we conducted our study has problem of providing powers to the standard devices like high volume samplers (APM 460 BL). So this study suggests the usage of a Raspberry Pi 3 board that is completely programmable, affordable, and open-source free to utilise 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 utilising the Pub Nub web service method.

Plate 3.: Fine Particulate ($PM_{2.5}$) Sampler

Plate 4: Submicron Particulate Sampler

Plate 5 : Dust-Track™ Ii Aerosol Monitor

Plate 6 : Hioki LR8514 wireless Humidity and Temperature logger

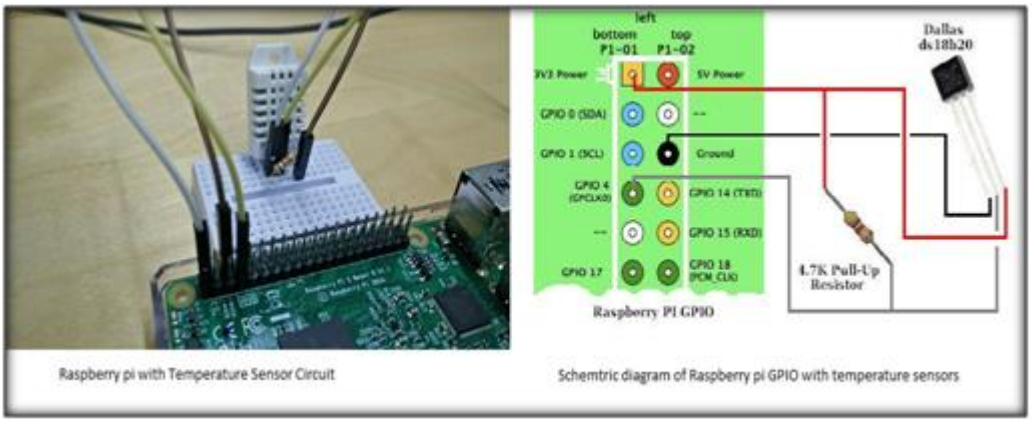
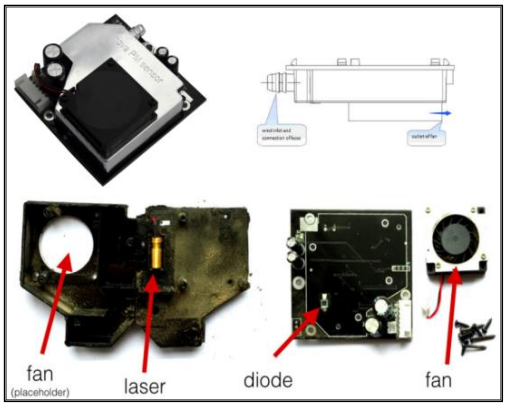


Plate 7: Raspberry Pi with Temperature Sensor Circuit



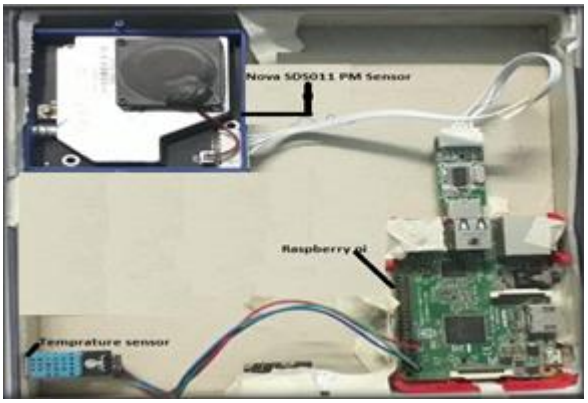


Plate 8: Complete set up of deviceCertification: Sensor has passed CE/FCC/RoHS certification

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

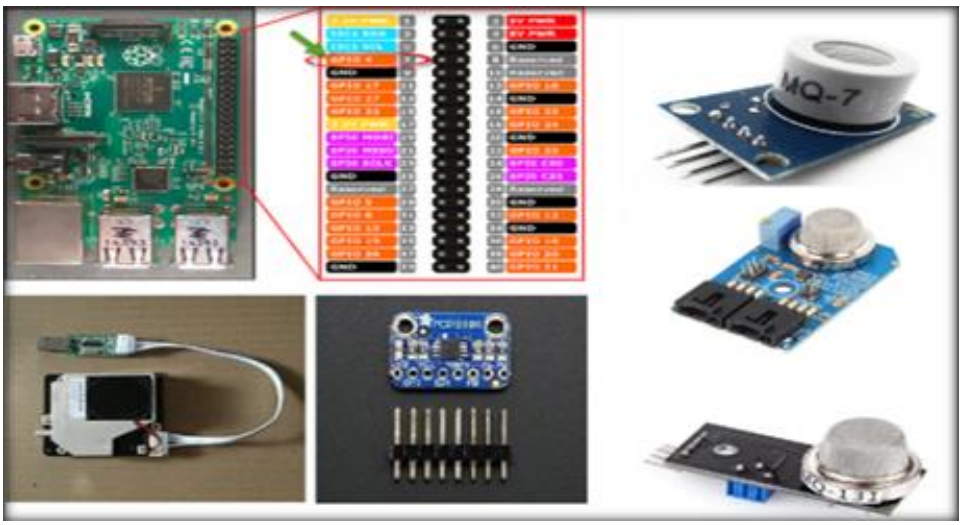


Plate 9 : Different devices of Raspberry Pi

Measurements of Ambient Air Quality and air temperature were carried out at the Environmental Engineering of University of Jadavpur (the location is presented in field visit area in the Supplementary Material). The observatory is located in an area of different Land Use Land Cover (like dense built up, water bodies, vegetation cover, open area, etc), and high and low traffic intersection zones. Emission sources of Particulate Matter are related mainly to individual heating systems in households, city road transportation, construction sites, from Chulas of road side eateries. The Observatory is equipped with PM_{10} and $PM_{2.5}$ measuring instruments SDS011 sensors, mainly because of their low price (≤20$) and small size.

The SDS011 sensor from Nova Fitness also demonstrated its usefulness for particulates measurements, but in a portable version.

6.0 Research Findings and Observations

Observations 1 (*Investigation of relationship among UHI/LST, Air Quality and LULC in KMC Area*):

- With the rapid increase in built-up area there is a decrease in vegetation cover from 30.7% to 29.73% of total LULC between the years 2000 and 2016. Similarly, we observed an increase in built-up area from 63.13 % to 65.13% of total Land Use Land Cover during the same time span. The LST ranged from (22.23–30.12) ˚C for 2000 and (23.21–32.11) ˚C for 2016 respectively.

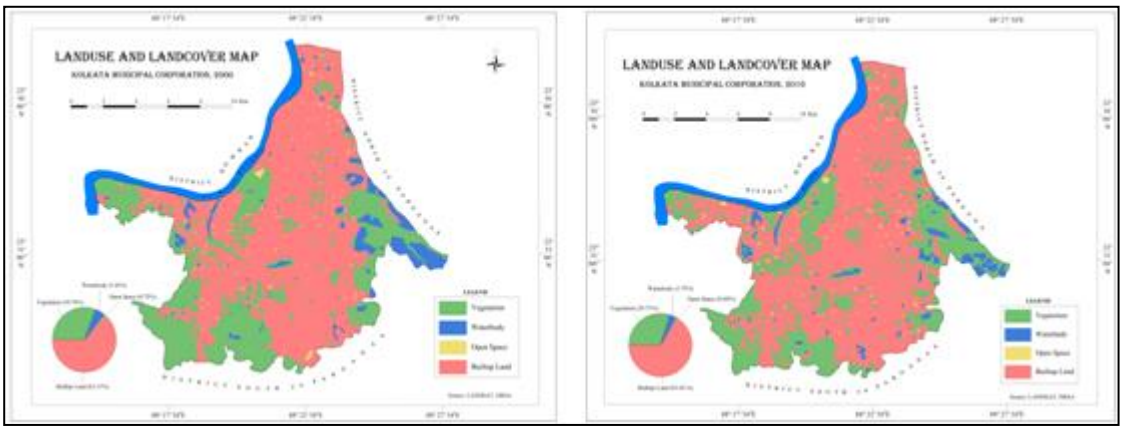


Figure: 4 Land Use & Land Cover change in KMC (2000-2016)

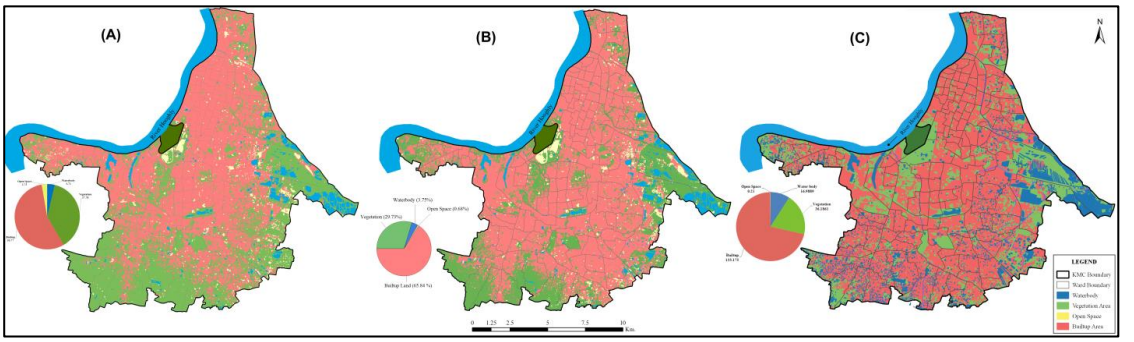


Figure: 5 Comparison of Land Use Land Cover change of Kolkata Municipal Corporation (2000, 2010 & 2020)

- These changes result in the reduction of natural cooling effects of shading and evapotranspiration on plants. This in turn encourages the expansion of UHI in Kolkata and its surroundings. But interestingly, in the year 2020, during the COVID-19 lockdown period, we observed a decrease in built-up area of 58.63% from previous years. Land Surface Temperature(LST) has decreased to a minimum of 17.40˚C and the maximum is 24.10˚C, to the tune of 1.62˚C as minimum and 5.75˚C as maximum, indicating an improvement in the context of Kolkata's land surface temperature.

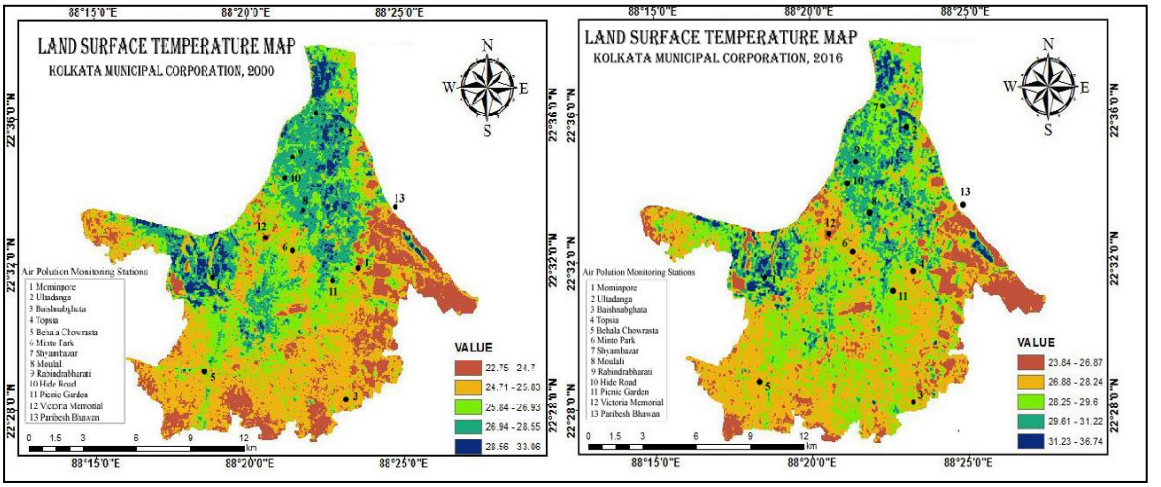


Figure: 6 The spatial distribution of Land Surface Temperature over different Land Use and Land Cover type in KMC area (2000-2016)

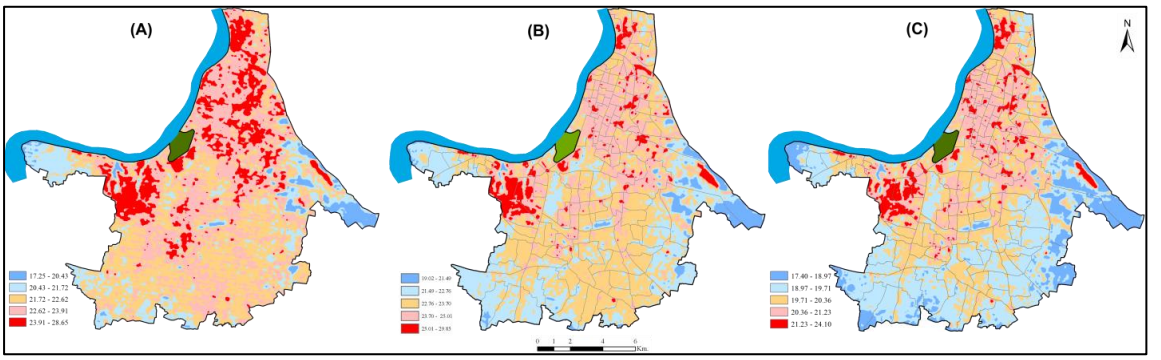


Figure: 7 Comparison between Land Surface Temperature in KMC area (2000, 2010 & 2020)

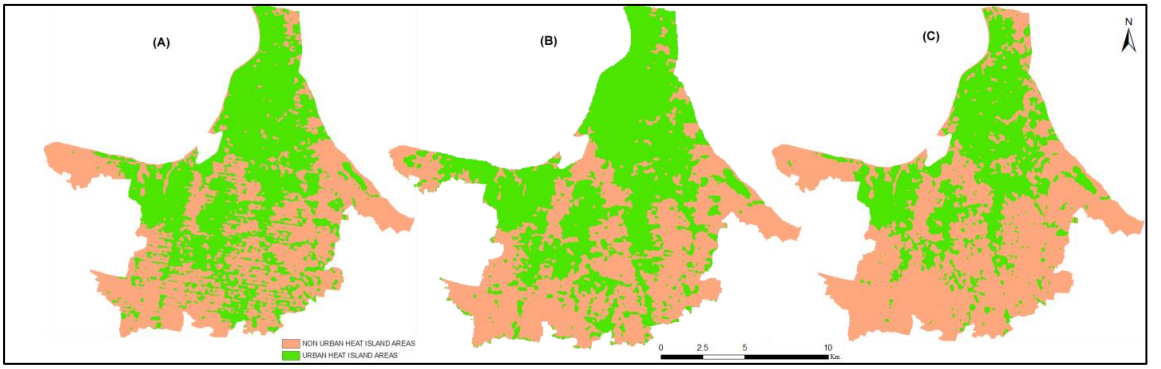


Figure: 8 Comparison of Urban Heat Island zones in KMC area (2000, 2010 & 2020)

- UHI effect is mainly concentrated in the north-central part of the study area, which is considered as the main overpopulated (built up area) of KMC. The correlation maps of LST and UHI on the LULC of Kolkata for the years 2010, 2015, and 2020 shows that mainly the built-up areas of north Kolkata and Garden Reach areas are very much correlated, as the LST of those areas is high and they fall under Urban Heat Island zones within the study area. On the other hand, south and east Kolkata wetland areas have low surface temperatures and fall under non-Urban Heat Islands within the study area.

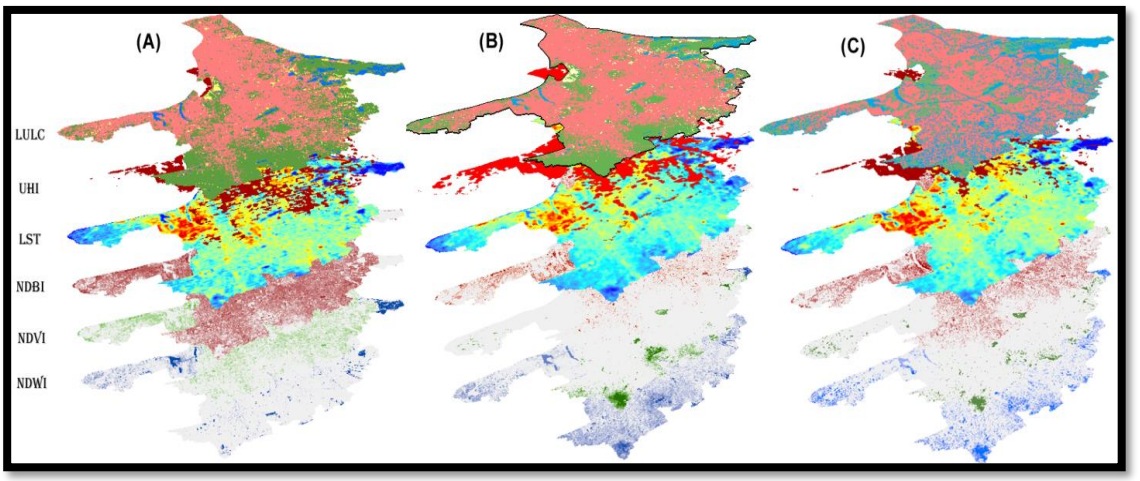


Figure: 9 NDWI, NDVI, NDBI, LST, UHI and LULC for the year 2010 (A), 2015 (B) and 2020 (C) have been overlaid as themes to show the spatial distribution of each within Kolkata Municipal Corporation.

Source: Prepared by the authors from LANDSAT 8 OLI, USGS

Observations 2: (*Investigation of relationship among LST, Air Quality and LULC in KMC Area in different season)*:

Respirable Particulate Matter (PM_{10}) range was high in winter season. There were three high levels of PM_{10} centres, one was located at Shyambazar, second at Minto Park, and the other two were located at Mominpur and Behala Chowrasta. In the month of January 2000, the maximum PM_{10} range was 271µgm/m³ to 277µgm/m³ and respectively temperature values were 26˚C, 28˚c and 30˚C for the above three areas. In 2016, this range was from 304µgm/m³ to 369µgm/m³, respectively temperature values were 27˚C, 29˚C and 32˚C. So the study shows that with increase in the particulate matter, there is an increase in the air temperature.

Table : 1 Scenario of LST, PM_{10} in different LULC types in KMC areas in 2000 and 2016

Station Name	Latitude	Longitude	LST 2000	LST 2016	PM_{10} µg/m³ (2000) January - September	PM_{10} µg/m³ (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

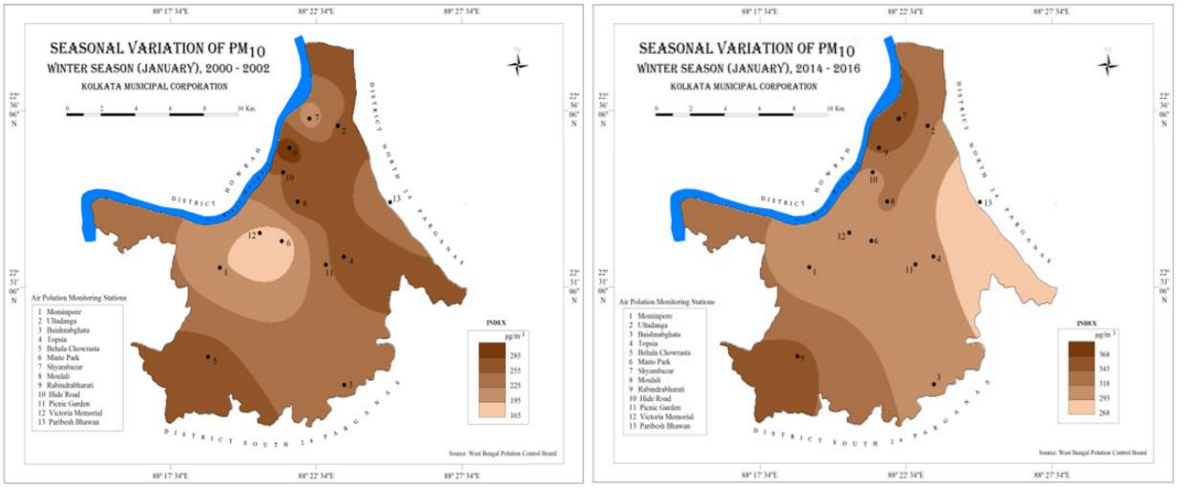


Fig. 10 : Seasonal variation of PM_{10} within KMC for the year 2000 and 2016 (January)

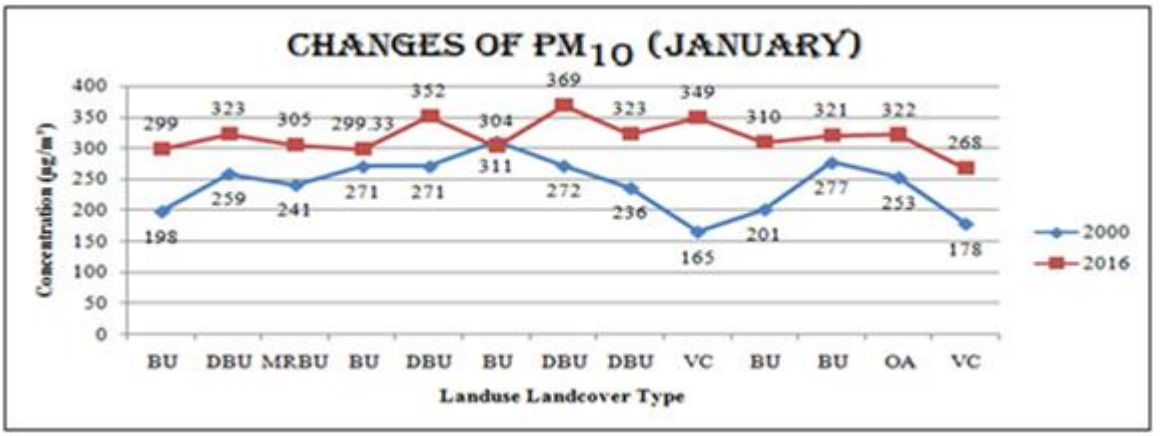


Figure. 11 : Changes of PM_{10} for the year 2000 and 2016 (January)

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

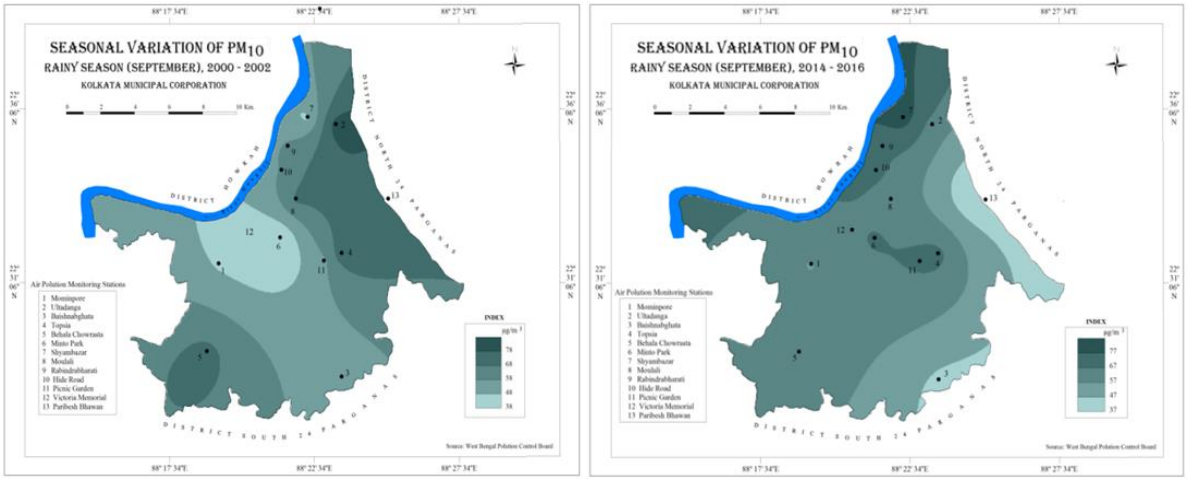


Figure. 12: Seasonal variation of PM_{10} within KMC for the year 2000 and 2016 (September)

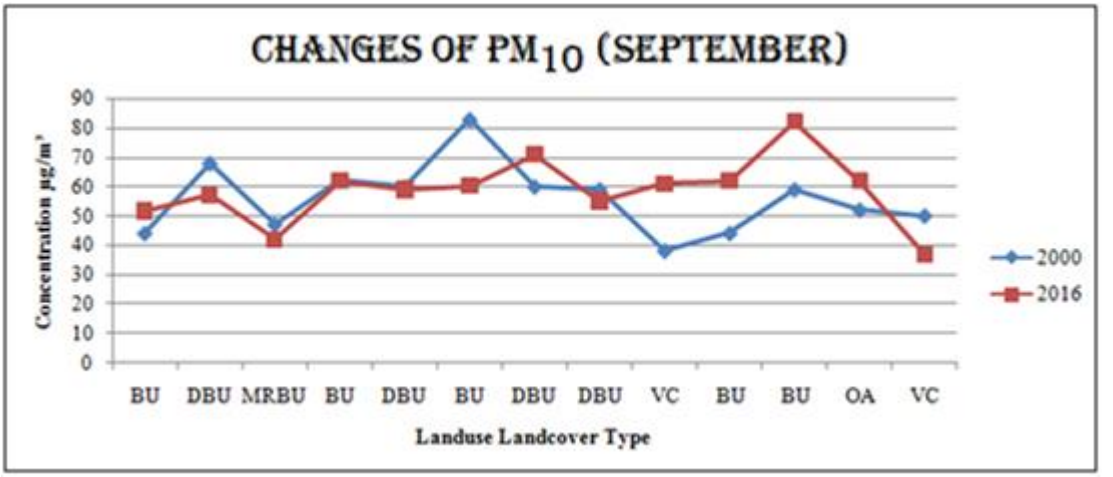


Fig. 13: Changes of PM_{10} for the year 2000 and 2016 (September)

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 averages

of PM_{10} levels were greater throughout the winter (November through March).

Observations 3: (*Investigation of relationship among UHI/LST, Air Quality and LULC through different Land use Land Cover and traffic intersection zones in the KMC Area*):

Statistical techniques were used 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 Eco- 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. There is a high correlation between urban land use and cover type and particulate matter at Ruby Crossing and Hazra Crossing (Chittaranjan Cancer Hospital) areas due to the rapid urban sprawl, concentration of commercial, public and semi-public land uses and heavy traffic, especially in the Diwali period.

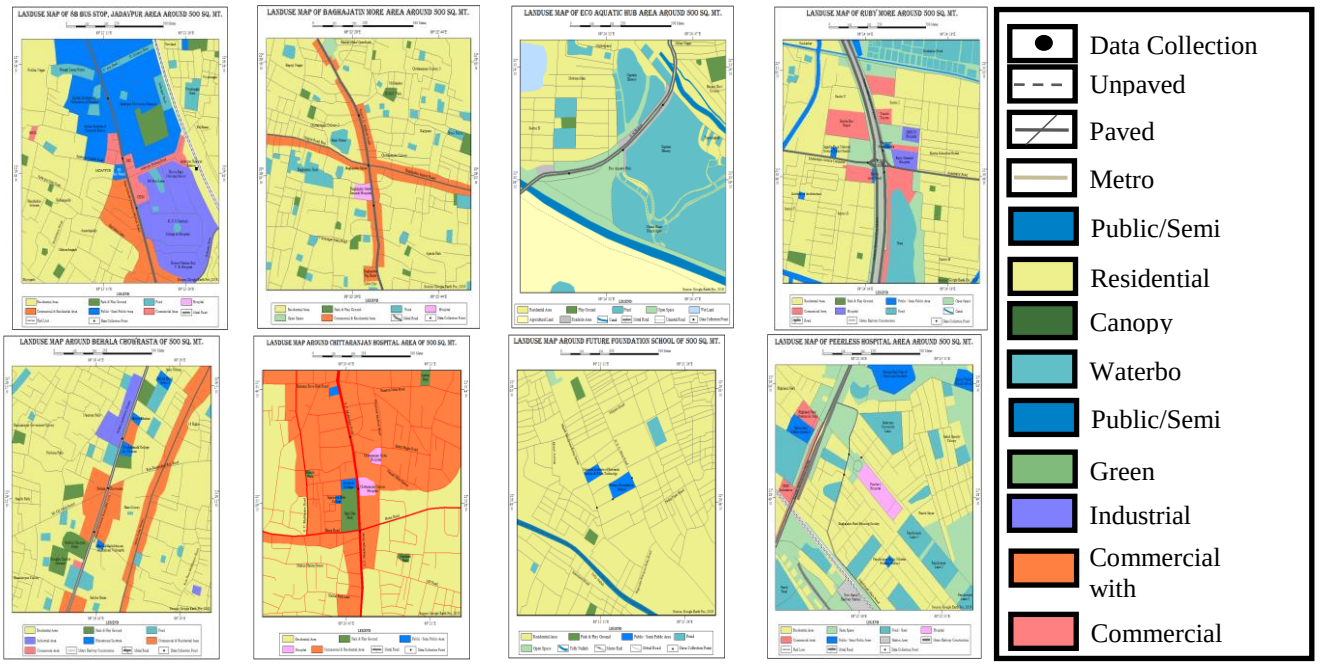


Figure 14 : Eight stations were selected having mixed land use of different type of land use categories. Monitoring was conducted near traffic intersections at all these stations namely

(1) Jadavpur 8B Bus stop (mixed land use and high traffic zone), (2) Baghajatin More (commercial/ residential and traffic zone), (3) Eco Aquatic Hub (water bodies, residential, commercial and traffic zone), (4) Ruby More (mixed land use and high traffic zone), (5) Behala Chowrasta (mixed land use and high traffic zone), (6) Chittaranjan Cancer Hospital-Hazra More (mixed land use and high traffic zone), (7) Future Foundation (residential and traffic zone), (8) Peerless Hospital (open area, water bodies, residential and traffic zone).

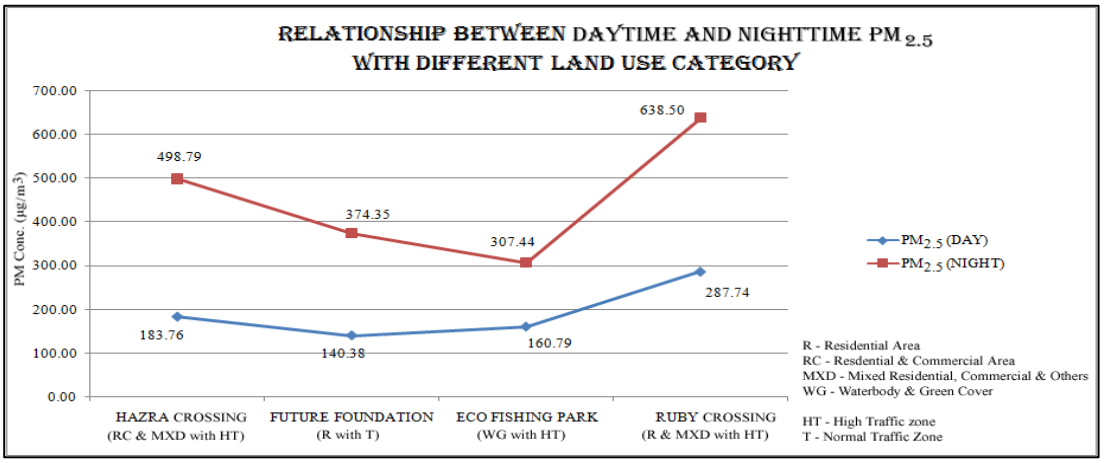


Figure. 15 : Relationship between the Daytime and Night time $PM_{2.5}$ in different land use categories

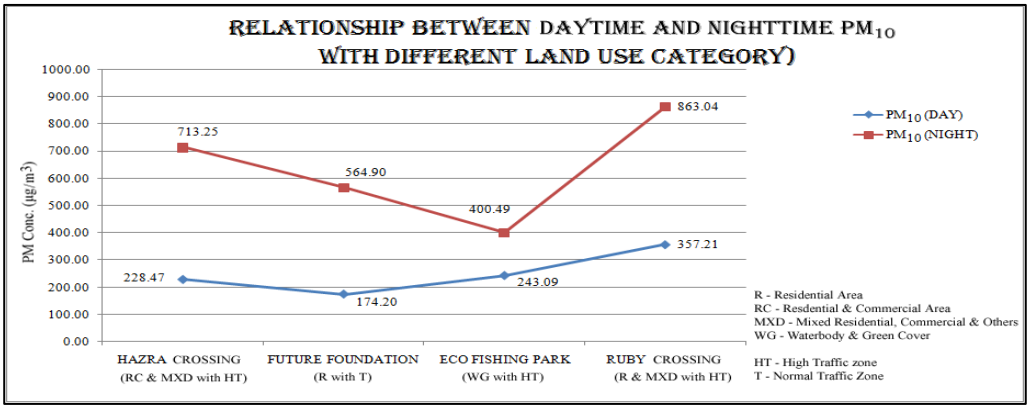


Figure 16: Relationship between the daytime and night time PM_{10} in different land use categories

- Concentration of particulate matter and the air temperature values vary with respect to various Land Use Land Cover types (like built up, Water bodies, Open areas and vegetation cover) in different season.

- Air Quality was monitored in different Land use areas during Diwali week also (mainly pre-Diwali, Diwali and post Diwali period). The study also investigated the influence of Diwali fireworks episodes on urban Air Quality and temperature of Kolkata for 2018 to understand if the land use land cover types has any role in air pollutant concentrations. As during Diwali, it is maximum, so a study was done to establish the relationship further with strong justifications.

- Correlation and Linear Regression studies were performed between PM_{10} / $PM_{2.5}$ and temperature, during Diwali day and night. High correlation coefficient was obtained between PM_{10} / $PM_{2.5}$ and temperature.

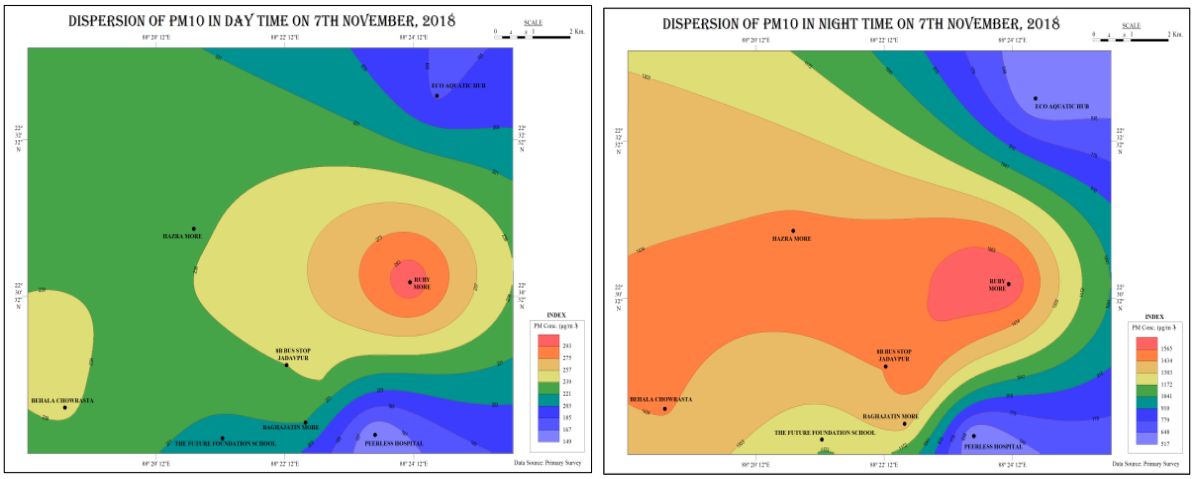


Figure 17: Dispersion of PM_{10} in Day and Night time on 7th November, 2018

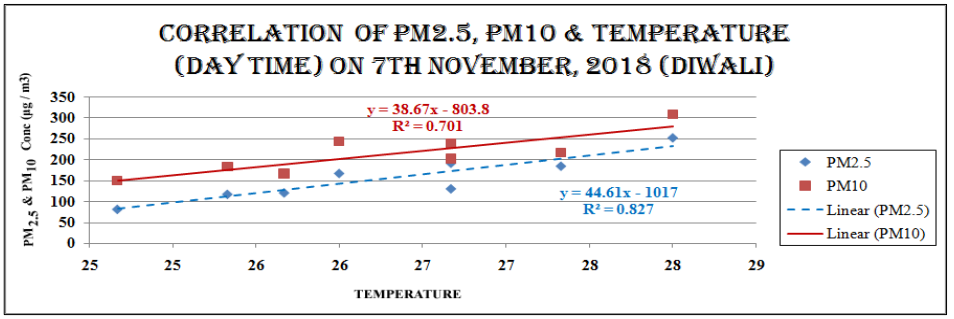


Figure 18: Correlation between PM_{10}, $PM_{2.5}$ and Temperature at Day time on 7th November, 2018.

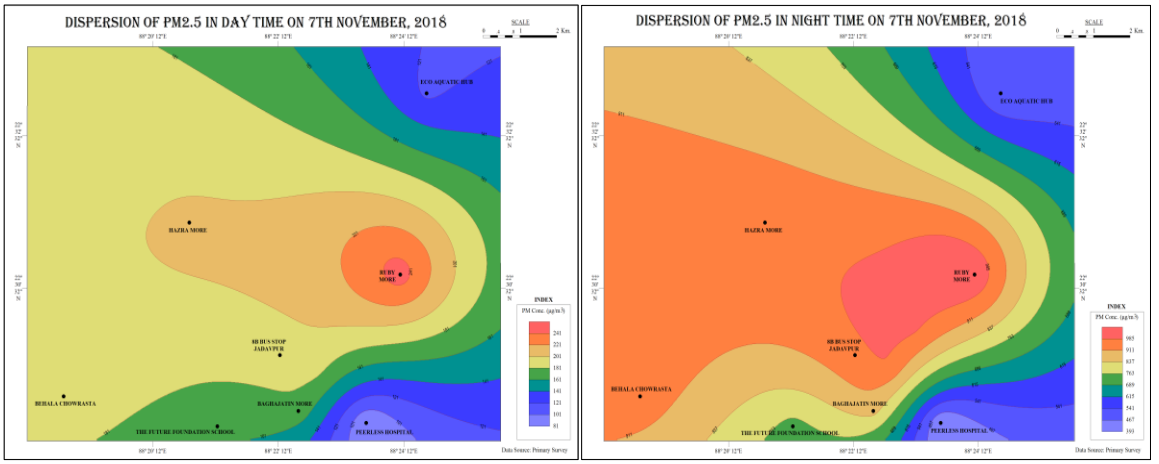


Figure 19: Dispersion of $PM_{2.5}$ in Day and Night time on 7th November, 2018

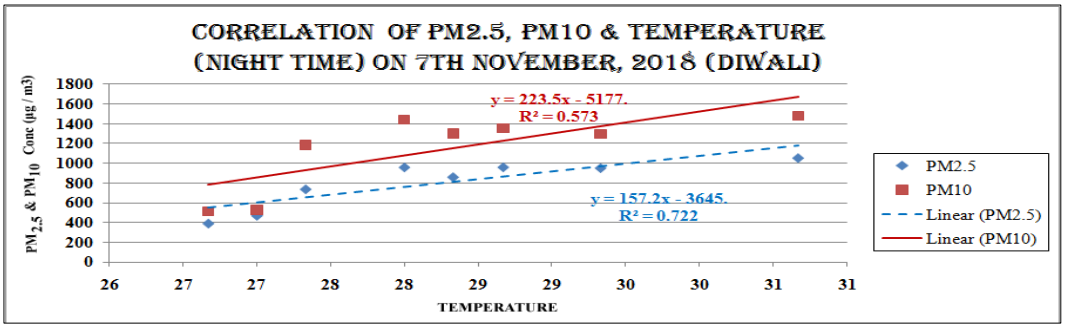


Figure 20: Correlation between PM_{10} , $PM_{2.5}$ and Temperature at Night time on 7th November, 2018.

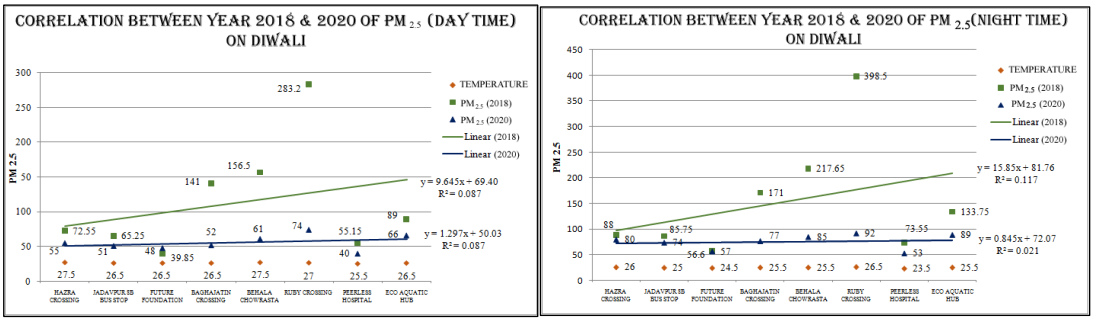


Figure 21: Correlation between $PM_{2.5}$ in Day time and Night time for 2018 and 2020

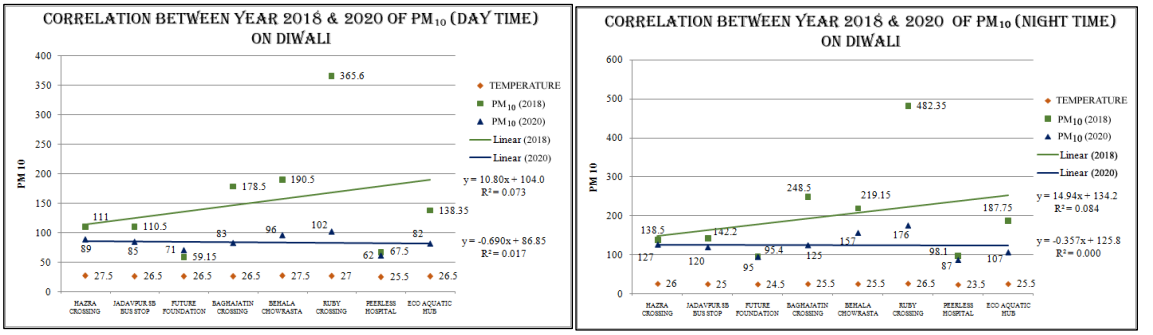


Figure 22: Correlation between PM_{10} in Day time and Night time for 2018 and 2020

The above statistical analyses, bivariate linear regressions by least square method were performed for the year 2018 and 2020 with respect to PM_{10} , $PM_{2.5}$, and air 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 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=0.021 respectively. This statistical analysis (Figure 21 and 22) also confirms the assumptions explained above during the discussion on result of dispersion seen on the day.

7.0 Conclusions from the Study

The most significant sources of air pollution in all studied areas in this research are the use of fireworks and sparklers during festival seasons, along with vehicle emissions. It is also noted that air pollution is a determinant in air temperature changes in various Land Use And Land Cover categories in different seasons, particularly during the winter and rainy season. The late-night entry of large interstate vehicles powered by diesel into the city also added to the enhanced level of air pollution.

The land use types and traffic zones with the lowest air temperatures values are along water bodies and open areas with significant vegetative cover (such as the Peerless Hospital and Eco Aquatic Hub areas), which had air temperatures ranging between 26.67°C to 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, two high temperature zones (approximately 27.33°C to 28.67°C and 29.33°C to 30.67°C) were identified within the high traffic zones of mixed commercial and residential areas (such as Behala- Chowrasta and Ruby Crossing). This established the second objective that PM concentration has an impact on air temperature in the study area.

Objectives 1

To study the Urban Heat Island (UHI) intensity with respect to different LULC change

	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

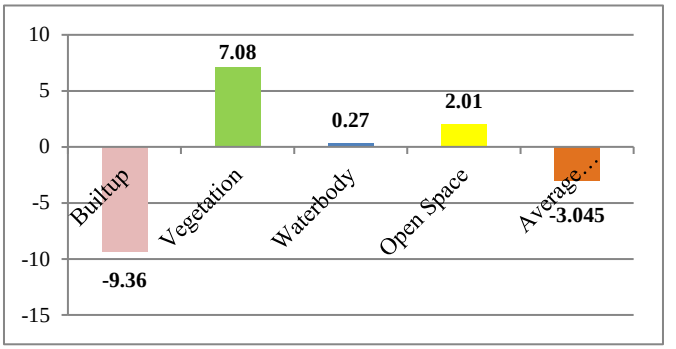


Figure 23: Bar diagram showing percentage of LULC and Average Temperature changes in KMC area from (2000 – 2016)

1. The study reveals the lowest LST values of 22.23^{0}C in 2000 and 23.21˚C in 2016 and the highest LST of 30.12˚C in 2000 and 32.11˚C in 2016. Variations in temperature are mainly due to the various land use land cover types with decreased water bodies, open space, depletion of vegetation cover and the different kinds of activities like high traffic zones, increase dense built-up area.

2. In 2020, the LST in Kolkata decreased to a minimum of 17.40ºC and a maximum 24.10ºC to the tune of 1.62ºC as a minimum and 5.75ºC as a maximum, which is a sign of improvement. The 'super cyclones' and 'Bulbul' during the months of April and November 2019 along with the lockdown (complete and partial) period due to the COVID-19 pandemic situation, were the major causes of the decrease in LST in the year 2020.

Type	2010	2015	Change (2010 - 2015)
Builtup (%)	53.77	64.84	11.07
Vegetation (%)	37.78	28.73	-9.05
Waterbody (%)	5.72	4.75	-0.97
Open Space (%)	2.73	1.68	-1.05
Average Temperature (ºC)	22.955	24.435	1.48

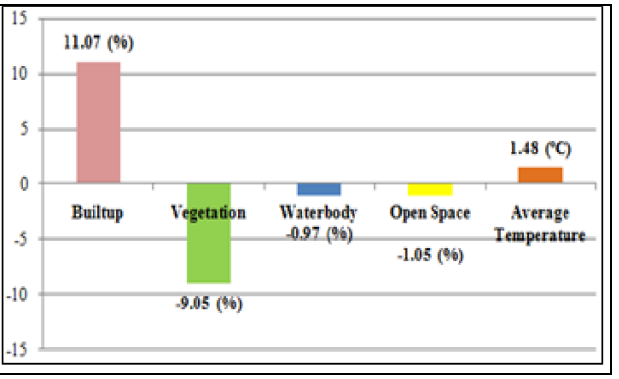


Figure 24: Bar diagram showing percentage of LULC and Average LST changes in KMC area between 2010 to 2015

3. The correlation map of LULC and LST for the year 2015 shows that the built up of the north and port areas within Kolkata Municipal Corporation exhibits the maximum LST compared to the other regions. The vegetation and water body covered area experienced the lowest LST in the East Kolkata Wetland and southern part of KMC. As a special case on the

COVID-19 pandemic time in 2020, the NDWI and NDVI analysis maps of KMC indicated that the index value of this region is high and the LST value is comparatively low compared to previous times.

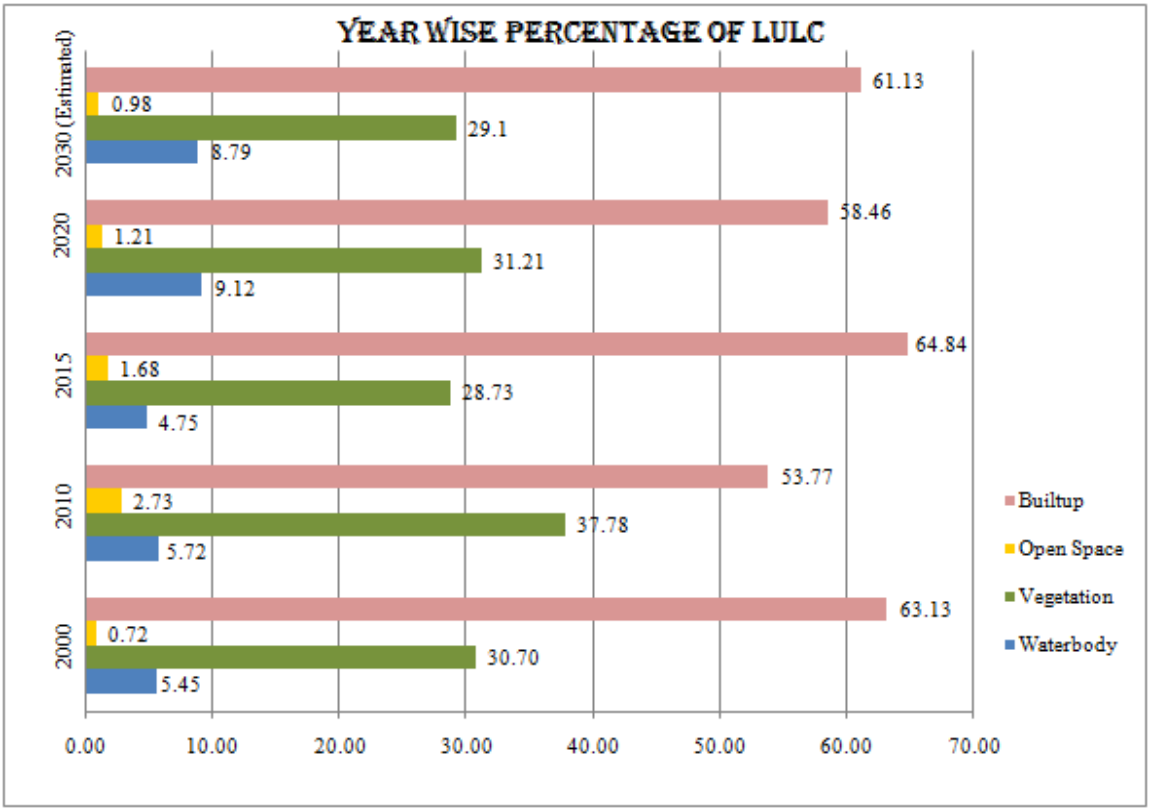


Figure 25: Year wise (2000, 2010, 2015 and 2020) calculated and estimated (2030) percentage of LULC

4. To explore the relationship between biophysical indices (NDVI, NDWI, NDBI) and LST, we have investigated the fluctuation of values derived from three years of data throughout the study periods, which shows the evident that the expansion of urban built-up land in KMC has been significantly contributing to the increase of LST.

Objectives 2

To study the Urban Heat Island (UHI) intensity with respect to Air Quality, with special emphasis on Respirable Particulate Matter,

Between the year 2000 to 2016, during the winter time PM_{10} range was found to be 247.11µg/m^3 to 292 µg/m^3 in the built – up area. The built up increased in this 16-year period while the vegetation cover decreased.

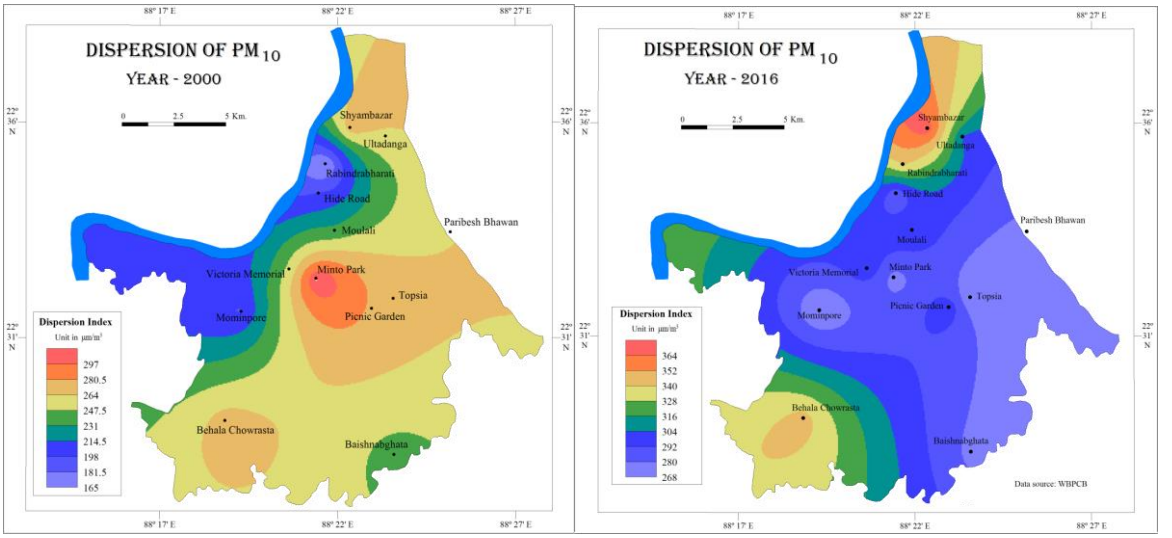


Figure 26: Dispersion Map of PM $_{10}$ for 2000 and 2016

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

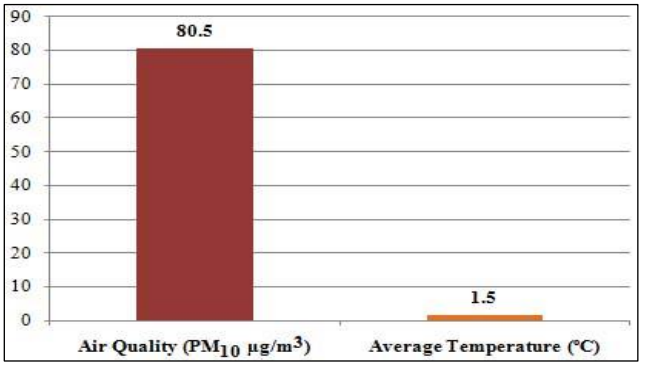


Figure 27: Change of %age in Air Quality (PM_{10}) and Average Temperature

Type	Values
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 in ^0C	27.5

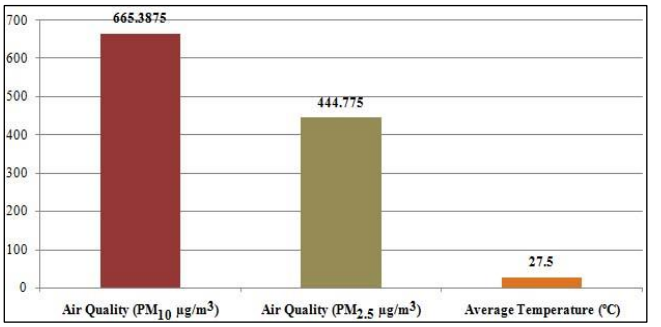


Figure 28: Air Quality (PM_{10} and $PM_{2.5}$) and Average Temperature on Diwali day (07/11/2018)

From our study data, we found that there is a variation in $PM_{2.5}$ and PM_{10} in the daytime or night-time, and in addition, it also varied during different seasons, which indicates the changing pattern of Air Temperature.

We have also demonstrated that the increase in air temperature and air quality patterns is due to the fire crackers on special occasions like Diwali.

High traffic zones on the occasion of Diwali have experienced an increase in temperature and also an increase in particulate matter.

Objectives 3

To investigate the inter-relationship and co-relationship among the UHI, LULC, and Air Quality patterns in Kolkata.

High traffic zones on the occasion of Diwali have experienced an increase in temperature and also an increase in Particulate Matter.

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

Figure 29: Variation of $PM_{2.5}$, PM_{10} and Air Temperature (Day and Night time) with respect to LULC

Objectives 4

To make and recommend recommendations for mitigating UHI and improving Air Quality for various land use classifications.

Identification of the best strategy and technology such as cool roofs, cool pavements, and urban vegetation could be effective and economically viable options for managing UHI effects, as well as effectively reducing the ambient air temperature in tropical urban areas, which is extremely important for city dwellers' thermal comfort.

8.0 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.

9.0 Limitations of the study

- The study has been conducted only in some chosen pockets of Kolkata. That is why the collected data as well as observations may not fully reflect Kolkata as a whole.
- For data collection, we have to fully depend 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 important historical Air Pollution data were not available on the Pollution Control Board Website, making it impossible to change the measure over time.

10.0 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 proposed solutions which can be used in Kolkata or any urban area to lessen the Urban Heat Island effect. The first is 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 air 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.

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) The rooftops and walls of the buildings should use light -colored roofing material or reflective coatings to increase the albedo and to reduce the incoming solar radiation.

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

f) Public transport system needs to be further strengthened to discourage the use of individual vehicles as a mode of transport. A reduction in the number o vehicles on Kolkata roads would lead to emission of less waste heat and Air Pollutants including the aerosols.

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

h) Development of Decision Support System.

11.0 Future Scope of the Study

This research provided a wealth of future research opportunities:

A number of indicators could not be measured within the limited scope of the current study. Each indicator which could not be measured represents a gap in available data and opportunity. Future research may address aspects like,

- Quantification of the environmental impact of reduced heat gain, Urban Heat Island Mitigation, Air Quality Management, urban biodiversity, and so on.
- Findings from qualitative research on the socio - economic impact on urban growth and human health Mitigating analysis of control strategies of Fire crackers on Diwali and other festivals
- Controlling assessment of vehicular emissions and promoting eco-friendly vehicles.
- Future research is required to promote urban, rooftop, and vertical farming.

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