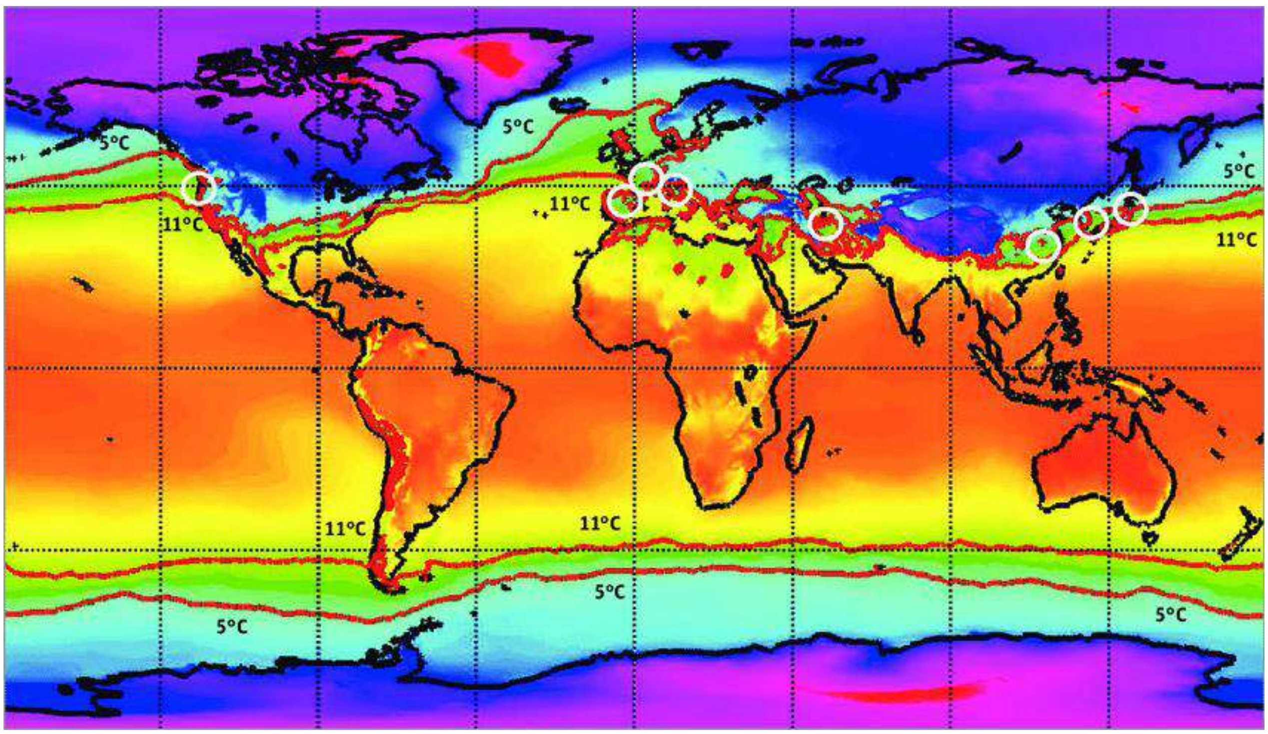
Dissertation

On

"ANALYSING WARD LEVEL LAND SURFACE TEMPERATURE DYNAMICS IN KOLKATA MUNICIPALITY CORPORATION BETWEEN 2000-2022"

M.Sc. Semester-IV Practical Examination 2023



PAPER: GEO 496 **UNIT: GEO 496.2**

Submitted by

Roll…………………No…….

Reg……………………………

Supervised by
Dr. Sk Mithun
Assistant professor
Department of Geography
Haldia Government College

HALDIA GOVERNMENT COLLEGE

DEPERTMENT OF GEOGRAPHY (UG & PG)

DEBHOG, PURBA MEDINIPUR

To Whom It May Concern

This is to certify that……………………………………………………………………

Roll…………………………………………… No…………………..has prepared the Field Report on **“ANALYSING WARD LEVEL LAND SURFACE TEMPERATURE DYNAMICS IN KOLKATA MUNICIPALITY CORPORATION BETWEEN 2000-2022”** for M.Sc. Semester-IV Examination in Geography 2023 as a partial fulfillment of paper GEO-496.2. It is also certified that the present dissertation is his/her own work and may be placed before the Examiner for evaluation.

Signature of the Supervisor

Dr. Sk Mithun
Assistant Professor
Department of Geography
Haldia Government College

ACKNOWLEDGEMENTS

I express my sincere gratitude to all people who have directly and indirectly helped me during this special paper dissertation journey. First and foremost, I express my most profound sense of gratitude to my dissertation supervisor, Dr Sk Mithun, Department of Geography, Haldia Government College for his continuous guidance, constructive suggestions, and encouragement throughout this research work. Similar profound gratitude to the other teaching and non-teaching members of our college, particularly Dr. Pijush Kanti Tripathi, Prof. Gopal Chandra Hembram, Prof. Sarbeswar Haldar, Prof. Yogia Dutta, Prof. Pranay Santra and Sukumar Adhikari for their continuous support and encouragement.

I am thankful to the Google Earth Engine from where I have downloaded all the required dataset that constitutes the necessary data for my research work, free of cost. I am also thankful to some organizations and websites, from where we download some valuable data and map for this work.

Finally, I express my heartfelt gratitude to my family members. Without their unconditional support, love and sacrifice, this journey would not have been possible. After all, I owe it all to Almighty for giving me the strength, wisdom, ability, and opportunity to undertake this research study, and enabling me to its completion.

Date Signature of the Candidate

TABLE OF CONTENTS

INTRODUCTION

Land Surface Temperature (LST) is a fundamental aspect of climate and biology, affecting organisms and ecosystems from local to global scales. Identified as one of the most important Earth System Data Records by NASA and other international organizations, LST measures the emission of thermal radiance from the land surface where the incoming solar energy interacts with and heats the ground, or the surface of the canopy in vegetated areas. This quality makes LST a good indicator of energy partitioning at the land surface-atmosphere boundary and sensitive to changing surface conditions. At spatial scales ranging from the leaf-level to the landscape, the knowledge LST provides on the redistribution of energy into latent and sensible heat fluxes makes it one of the most important parameters in the physical processes of surface energy and water balances. Its retrieval from remotely sensed thermal-infrared (TIR) data provides spatially continuous LST measurements with global coverage to examine the thermal heterogeneity of the Earth's surface, and the impact on surface temperatures resulting from natural and human-induced changes. Daytime LST is more tightly coupled with the radiative and thermodynamic characteristics of the Earth's surface than standard air temperature measurements. LST is also more sensitive to changes in vegetation density and captures additional information on the biophysical controls on surface temperature, such as surface roughness and transpiration cooling. A growing body of work has demonstrated the utility of LST datasets for ecological and biogeographically studies. Temperatures derived from TIR data have been combined with vegetation indices to separate land cover classes, monitor land cover dynamics and ecosystem disturbances. Used LST as an indicator of surface-moisture status, and thermal datasets have been used for monitoring drought and plant stress in agricultural and natural ecosystems. LST has been used to examine the consequences of land cover changes on climate, and to investigate the association between maximum thermal anomalies, heat waves, melting ice sheets, and droughts in tropical forests. Thermal data has been used to understand the effects of heat waves on avian community structure and habitat usage by koalas. LST is a basic determinant of the terrestrial thermal behavior, as it controls the effective radiating temperature of the earth's surface. However, because of the extreme heterogeneity of most natural land surface, this parameter is difficult to estimate and validate. Several factors can fundamentally influence the derivation of LST including the following: (i).Temperature variations with angles. (ii)Sub pixel in homogeneities in temperature and cover. (iii) Surface spectral emissivity at the channel wavelengths. (iv) Atmospheric temperature and humidity variations. (v) Clouds and large aerosol particles such as dust.

Important Parameters:

Land surface temperature holds significant importance in the field of remote sensing due to its role in providing valuable insights and faciliting various applications:

- Calibration and validation: LST serves as a crucial parameter for calibrating and validating remote sensing instruments, ensuring accurate temperature measurements from satellite sensors.
- Atmospheric correction: LST calculations often involve correcting for atmospheric interference in remote sensing data. Accurate LST values require accounting for the absorption and emission of radiation by the atmosphere.
- Thermal Infrared Bands : LST is measured using thermal infrared bands, which capture radiation emitted by the Earth’s surface . These bands provide valuable information about surface temperature variations.
- Climate studies: LST data contributes to climate studies by providing information on temperature variations and trends, aiding in understanding climate change impacts and assessing the urban heat island effect.
- Vegetation Analysis: LST data combined with other remote sensing data can help analyze vegetation health and stress. Higher temperature might indicate water stress or other environmental factors affecting vegetation.
- Hydrological Studies: LST data supports hydrological studies by indicating areas with different rates of evapotranspiration, helping in water resource management and assessing drought condition.

LITERETURE REVIEW

Increasing land surface temperature (LST) is one of the major anthropogenic issues and is significantly threatening the urban areas of the world. Therefore, this study was designed to examine the spatial variations and patterns of LST during the different seasons in relation to influencing factors in Kolkata Municipality Corporation (KMC), a city of India. The spatial distribution of LST was analyzed regarding the different surface types and used 25 influencing factors from 6 categories of variables to explain the variability of LST during the different seasons. All-subset regression and hierarchical partitioning analyses were used to estimate the explanatory potential and independent effects of influencing factors.

It is the gateway city of the eastern part of India and is the capital city of West Bengal. After independence, a rapid rate of urban growth was observed in Kolkata City and the surrounding areas due to the adoption of a mixed economy. Originating as a colonial city, Kolkata City had a population of 2.92 million in 1961. However, according to the census of India 2011, it is the third most populous metropolitan city (4.49 million) in India with a population density of 24,252 per sq. km, and the population is expected to reach 4.97 million by 2022. The rapid rate of urbanization has led to the transformation of natural land into artificial land , and as a result, the land surface temperature is increasing in the city and its surrounding areas . As reported by , the land surface temperature has increased by 4.72 °C between 1990 and 2020 as the built-up area increased by 33.758% and the vegetation cover decreased by 25.521% in Kolkata and its adjacent areas. World urbanization is increasing, with more than 55% of the world's population living in cities, and this figure is expected to reach up to 68% by 2050 . Due to rapid urbanization, the world's urban area has increased by 168% from 2001 to 2018, with the largest growth in Asia and Africa. Over the past three decades, India has experienced rapid urban growth due to the new economic reform during the 1990s. In 2020, more than 35% of the population was residing in urban areas , but almost 50% of India's population will live in urban areas by 2050. The rapid urbanization process will transform the natural landscape into an impervious surface, which will alter the radiative, thermal, moisture, and emission properties, thereby leading to a significant increase in land surface temperature (LST). Due to the increase in urban LST, extreme weather events, such as the frequency and intensity of heat waves and extreme summer rainfall, have increased in urban areas. Furthermore, the energy consumption rate, air pollution, health risks, and heat-related deaths have increased throughout the world's urban areas. Therefore, there has been increasing interest among researchers of urban LST for the development of suitable strategies for sustainable development and to create an eco-friendly environment in urban areas.

Aim & Objectives:

The present dissertation attempts to study spatiotemporal LST dynamics in Kolkata Municipal Corporation with the following objectives:

- Study minimum, median and maximum LST in Kolkata Municipal Corporation in 2000 and 2022.
- Study the difference in ward level minimum, median and maximum LST between 2000 and 2022.
- Analyzing spatial variability of LST with respect to present built-up growth.

STUDY AREA

Kolkata Municipal Corporation (KMC) is located on the east bank of the Hooghly River (**Figure 1**) in the state of West Bengal, India. It extends 22°27′12″ N to 22°37′56″ N and 88°14′33″ E to 88°27′32″ E, and covers an area of approximately 185.52 sq. km. The KMC contains 141 wards, and these small wards were chosen as a spatial unit for the study because they are the small administrative units under the jurisdiction of KMC for urban planning and management. It is the gateway city of the eastern part of India and is the capital city of West Bengal. After independence, a rapid rate of urban growth was observed in Kolkata City and the surrounding areas due to the adoption of a mixed economy. Originating as a colonial city, Kolkata City had a population of 2.92 million in 1961. However, according to the census of India 2011, it is the third most populous metropolitan city (4.49 million) in India with a population density of 24,252 per sq. km, and the population is expected to reach 4.97 million by 2022. The rapid rate of urbanization has led to the transformation of natural land into artificial land , and as a result, the land surface temperature is increasing in the city and its surrounding areas . As reported by , the land surface temperature has increased by 4.72 °C between 1990 and 2020 as the built-up area increased by 33.758% and the vegetation cover decreased by 25.521% in Kolkata and its adjacent areas.

CLIMATE:

Kolkata has a subtropical climate with a seasonal regime of monsoons (rain-bearing winds). It is warm year-round, with average high temperatures ranging from about 80 °F (27 °C) in December and January to nearly 100 °F (38 °C) in April and May. The average annual rainfall is about 64 inches (1,625 mm). Most of this falls from June to September, the period of the monsoon. These months are very humid and sometimes sultry. During October and November the rainfall dwindles. The winter months, from about the end of November to the end of February, are pleasant and rainless; fogs and mists occasionally reduce visibility in the early morning hours at this season, as also do thick blankets of smog in the evenings. The atmospheric pollution has greatly increased since the early 1950s. Factories, motor vehicles, and thermal-generating stations, which burn coal, are primary causes of this pollution, but monsoon winds act as cleansing agents by bringing in fresh air masses and also hastening the removal of water pollution.

Basin: KMC is located in the lower part of the Ganga basin. 1.3. Drianage: The area is drained by major Hugli river along its Northwestern boundary and by several canals like Bagjola Khal in the north and Beleiaghata and Circular Khal in the central part and Adi-Ganga (a paleo channel), and Talli nala in the southern part, which flows in the NNW-SSE direction. These khals and nalas cover a large area of the city. At present all the khals and nalas have been silted. They need proper desiltation as they are the main surface water sources inside the city and they can be used for inland water transport.

Rainfall & Climate: The normal annual rainfall is 1647mm.Monthwise normal rainfall (mm) is given in fig3. Kolkata experiences the following four distinct climatological features eg. i) Mild Winter, ii) Brief Spring, iii) Summer with occasional Norwesters and iv) Prolong Monsoon. The mean temp in winter is 22.50 C, which goes down to a minimum of 100 C in the months of December-January. The mean temp in summer is 29.250 C and goes up to a maximum of 400 C in the month of April. The climate during monsoon months is warm and humid.

Geomorphology & Soil Types: Kolkata forms a part of the lower deltaic plains of the Ganga- Bhagirathi river system. It is a typical deltaic flat land with surface elevation ranging between 3.5 to 6m above mean seal level. Several low lying depressions in the form of marshes, shallow lakes or jills occur within the city and most of these represent river scars of the post river channels of Bhagirathi. The master slope of the land is towards south. Younger levee, deltaic plain, interdistributory marsh, paleo channels and younger levee adjacent to river Hugli and older levee on both sides of the old Adi Ganga are the important geomorphological units present in the area (Fig-4). The area is covered with younger alluvial soil mainly of silty & clayey loams.

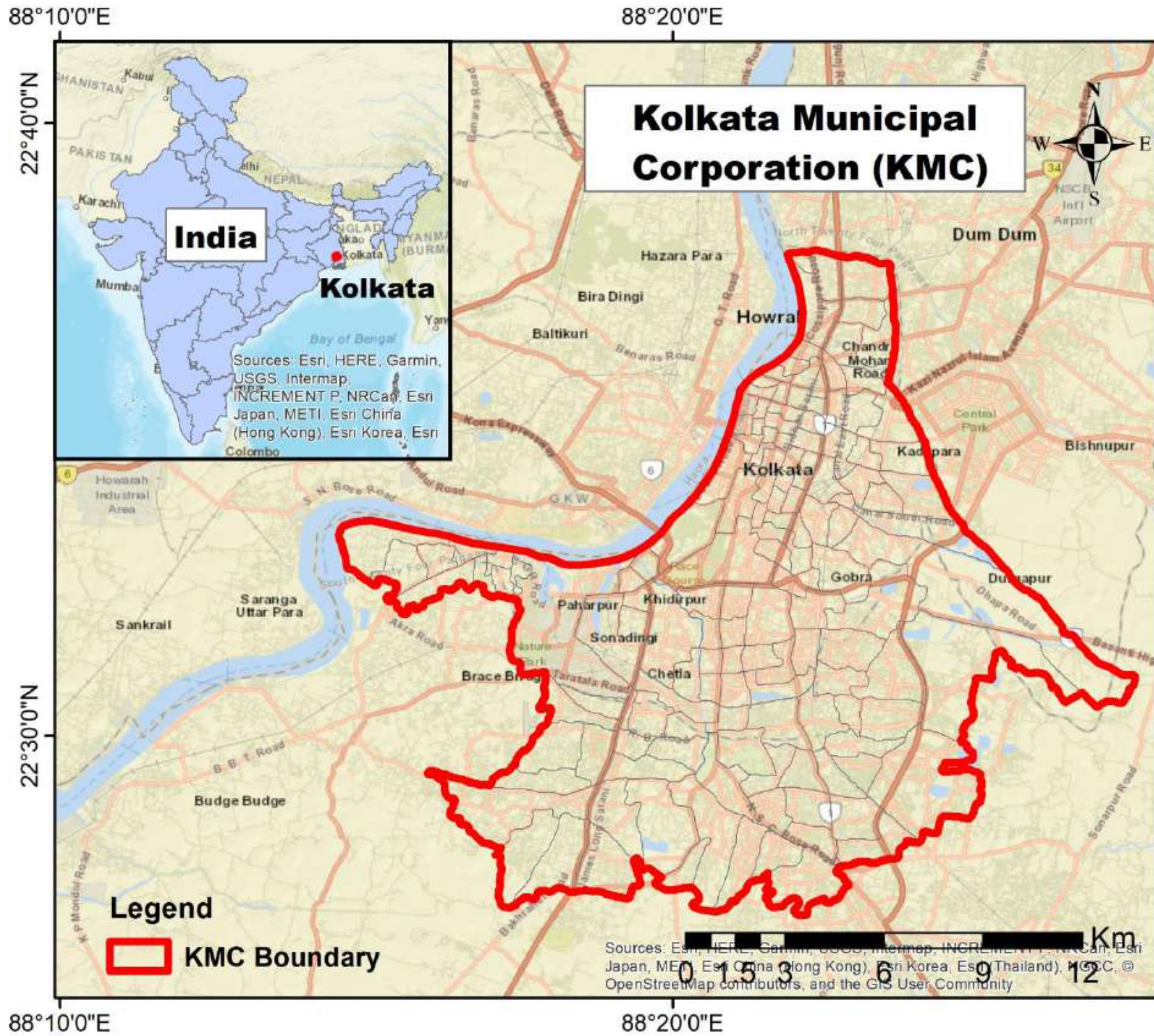


Fig. Location map of Kolkata Municipal Corporation (KMC)

DATABASE & METHODOLOGY

DATABASE:

Landsat 8 and Sentinel-2 satellite images, global digital surface model data, and geospatial information were used in this study. The AW3D30 global digital surface model (DSM) dataset was produced using an image matching method and stereo pairs of optical images at 30-m spatial resolution acquired by ALOS/PRISM from 2000 to 2022. Clouds, snow, and ice were automatically identified and masked during processing of the DSM data. . It has been used to extract 3D urban morphology in complex urban environments with reasonable accuracy. Thus, the dataset was used to extract 3D urban characteristics such as land surface temperature in Kolkata city.

METHODS

- Landsat 8 thermal infrared satellite data were used to derive ward wise LST in the Kolkata municipality in 2000 & 2022.
- Sentinel 2 thematic mapper in 2022 geospatial data were used for making LULC maps for the municipality in Kolkata.
- Lastly, flow chart were used to investigate the degree of association between ward wise LST in 2000-2022.

SOFTWARE Used

- Google Earth Engine web portal necessary data extraction.
- Arc GIS 10.8 for thematic mapping and analysis
- MS Excel for statistical analysis.

METHODOLOGY

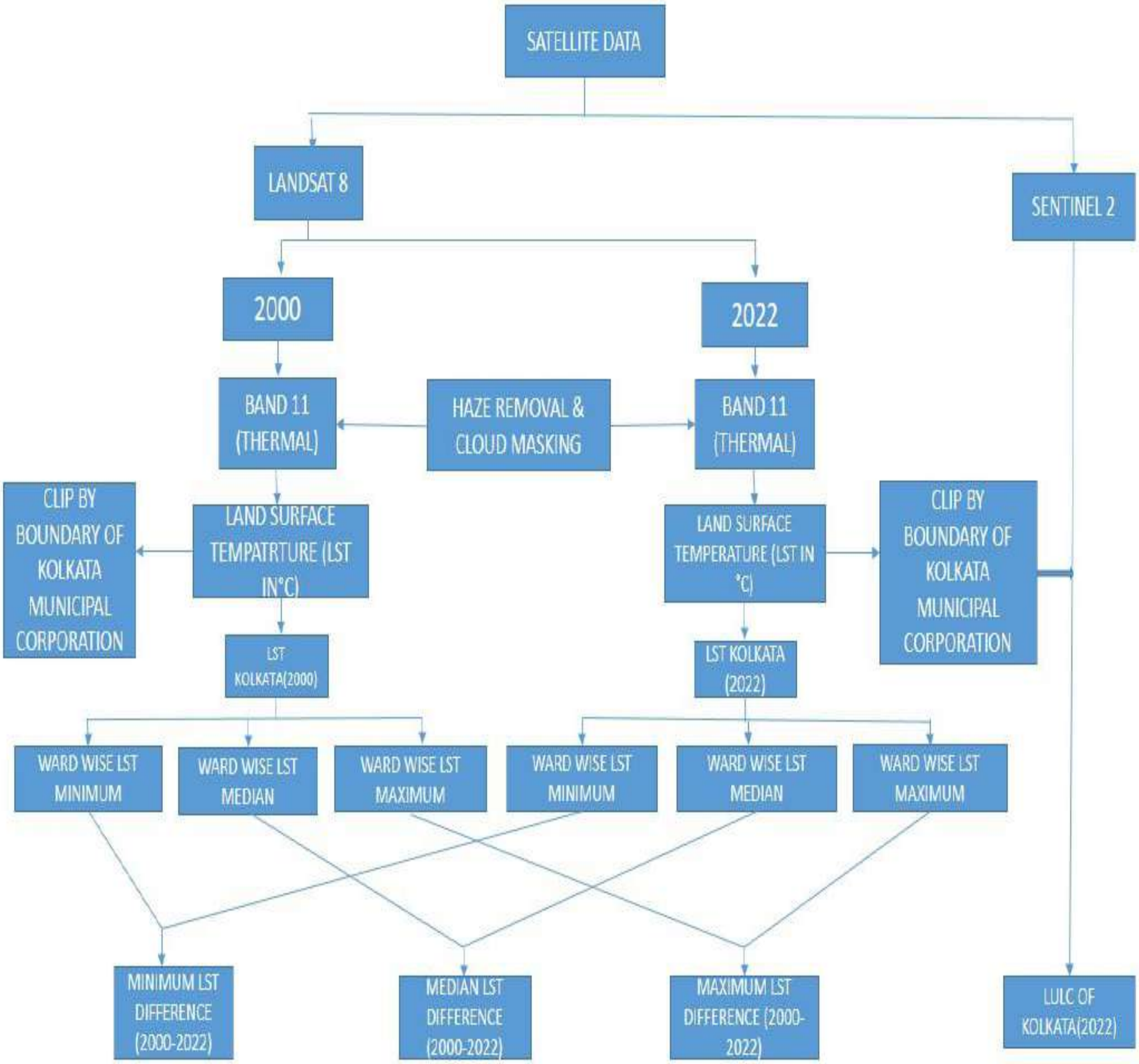


Fig. Methodological flowchart

Land Use Land Cover (LULC) of KMC:

Based on the SFCC images of 2022 the corresponding LULC map of the municipality was derived. The LULC map below of 2022 depicts seven classes in each map, i.e. , tree cover, grassland, cropland built-up sparse vegetation, permanent water bodies. The corresponding area statistics area also presented in the table below

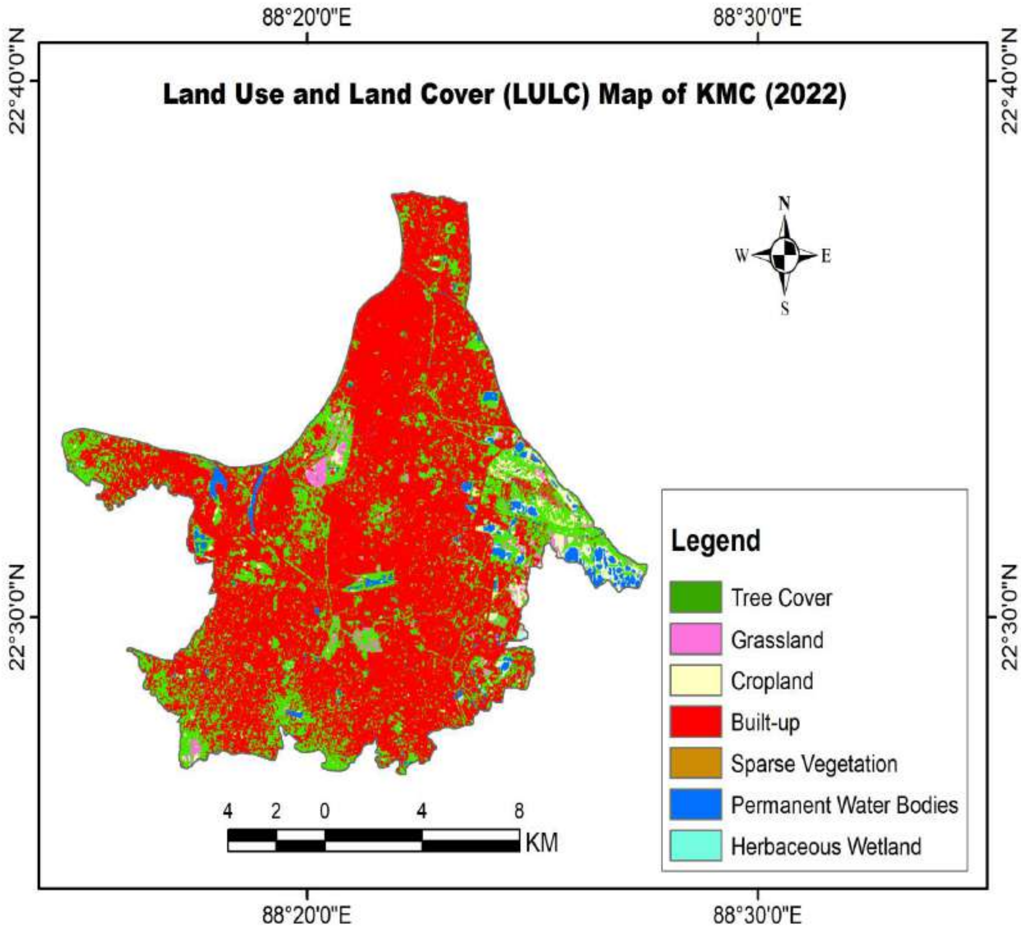


Fig. Land use and land cover (LULC) map of KMC

MINIMUM LST OF 2000 & 2022

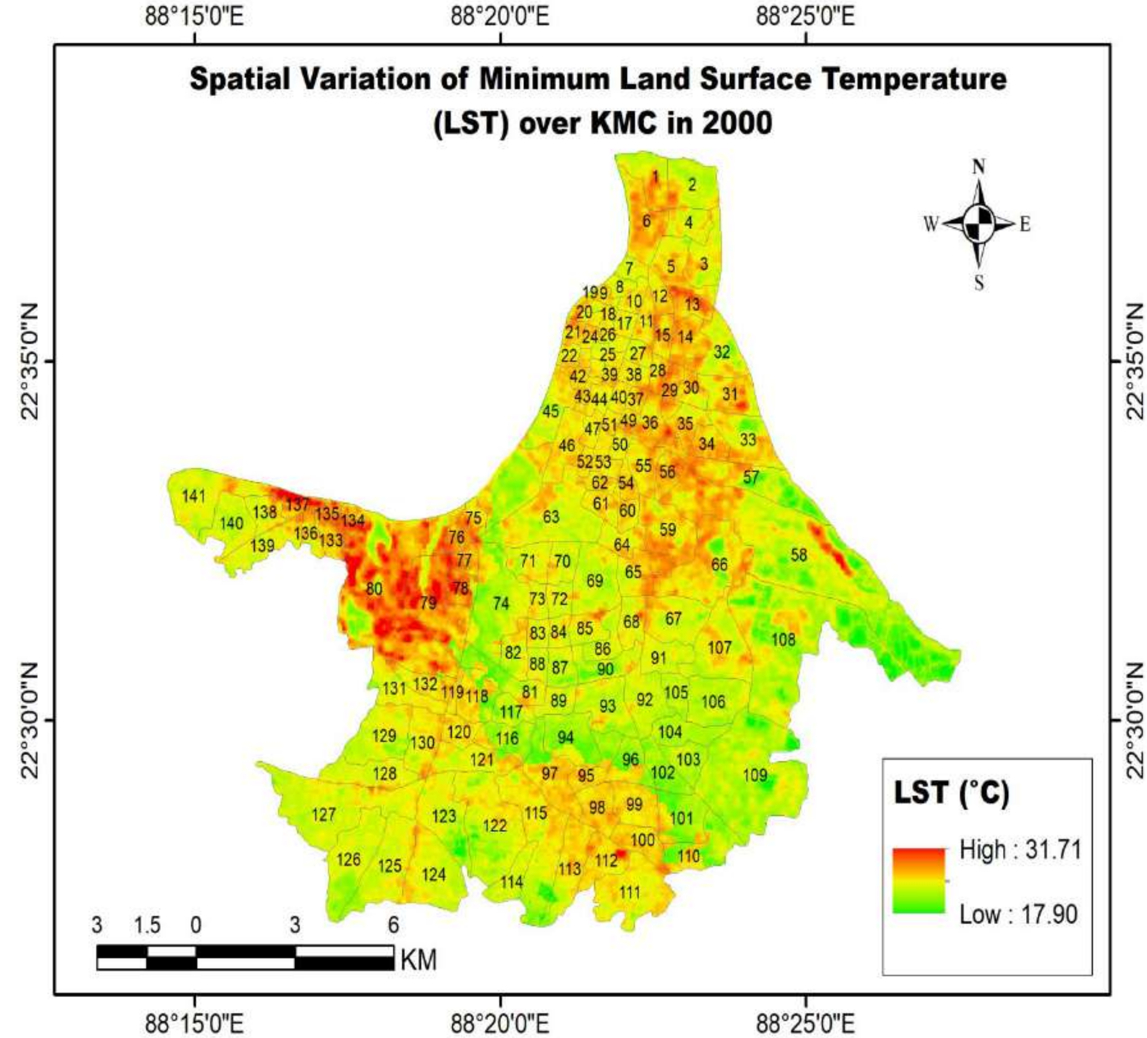


Fig. 1.1: Spatial variation of minimum Land Surface Temperature (LST) over KMC in 2000

Based on the following map represents spatial variation of minimum LST in the Kolkata Municipality in the year of 2000. Land Surface Temperature of the municipality ranges from 17.90ºc to 31.71ºc. The north-western part of the area was high LST (ºc) comparison to the western part of the area. Owing to the high vegetation cover and densely populated.

It can be seen that the year of 2022, the overall spatial distribution of LST was generally high in the south-eastern part of the area, while the LST was low in the eastern part of the area of Kolkata municipal corporation. The high value areas have 31.38ºc due to flat terrain, obvious urban expansion, large human distribution and prominent social and economic development area. The low value areas have 3.33ºc due to wide water coverage, dense cropland, and week human activities with less urban areas of the municipality.

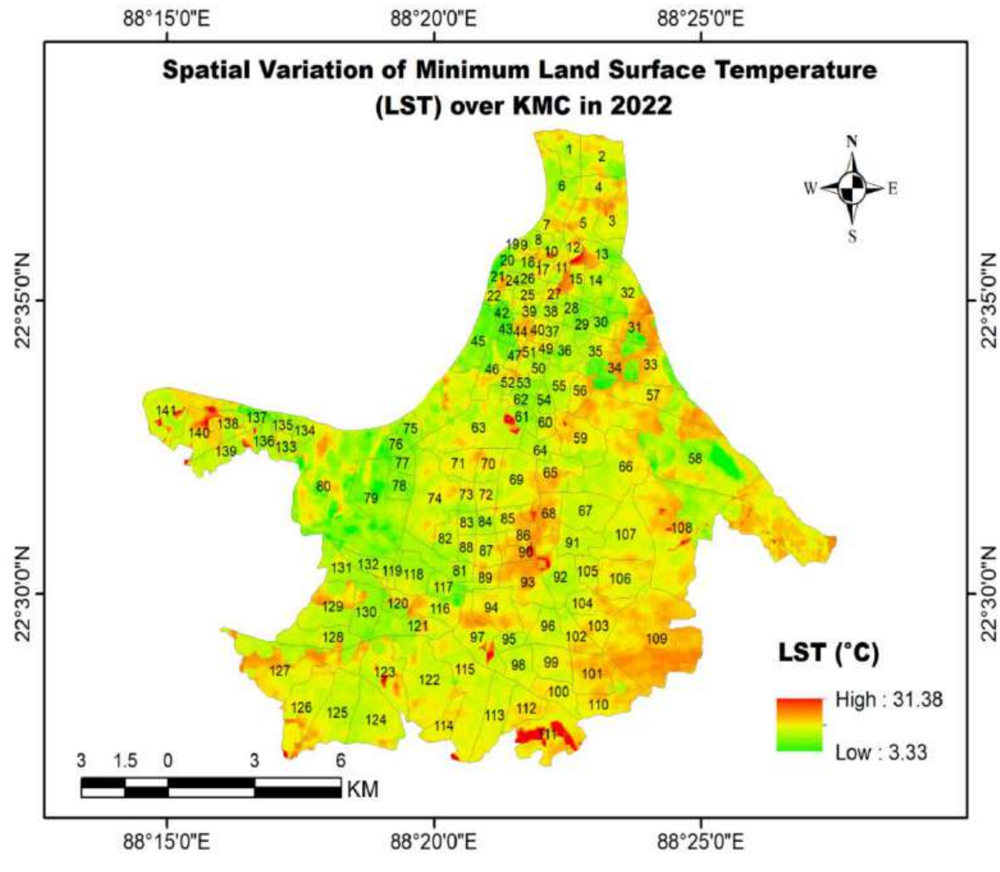
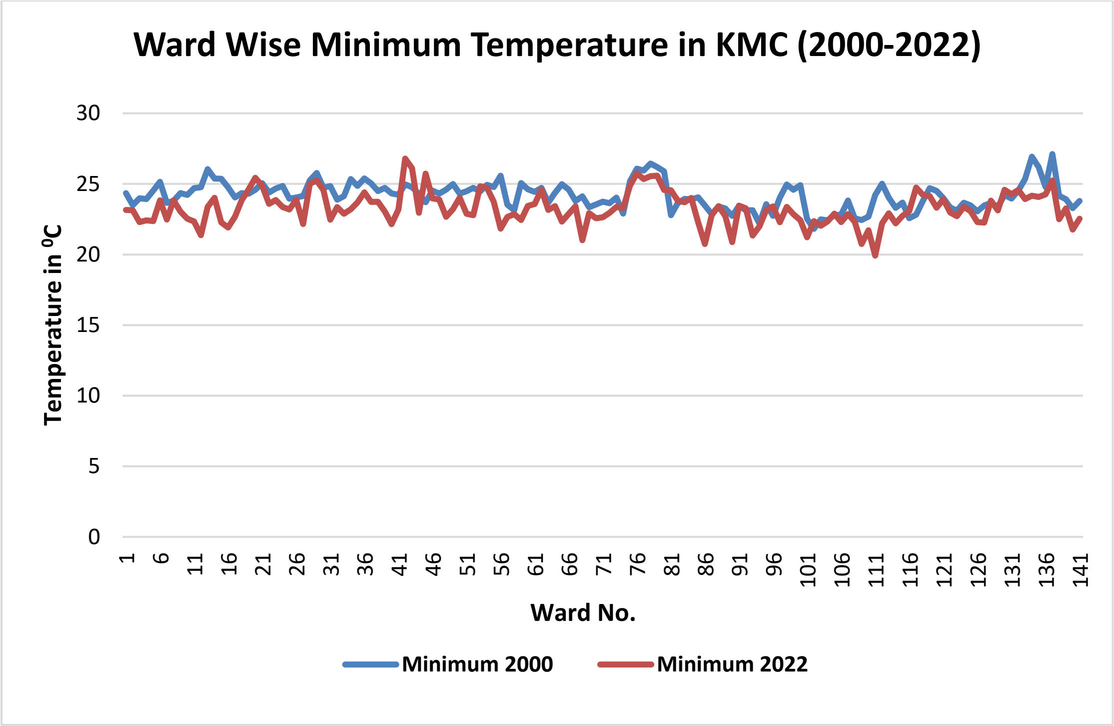


Fig.1.2: Spatial variation of Minimum LST over KMC in 2022



The trend of minimum LST association between 2000-2022 has been presenting using line graph taking LST (^{o}c) as the response variable. The figure of line graph represents minimum LST of 2000 was high comparison to the minimum LST OF 2022.

MEDIAN LST OF 2000-2022

It can be seen that from 2000, the overall spatial distribution of LST median was generally high 48.42ºc in the north and western part (ward no. 1, 2, 6, 14, 137, 77, 76, 134) of the KMC due to high human activities, industries Land Surface Temperature was high and the distribution of lowest LST median was 21.61ºc in the eastern part(ward no. 58, 109, 107, 63, 105, 91) of KMC due to some vegetation cover, wetland and agricultural land.

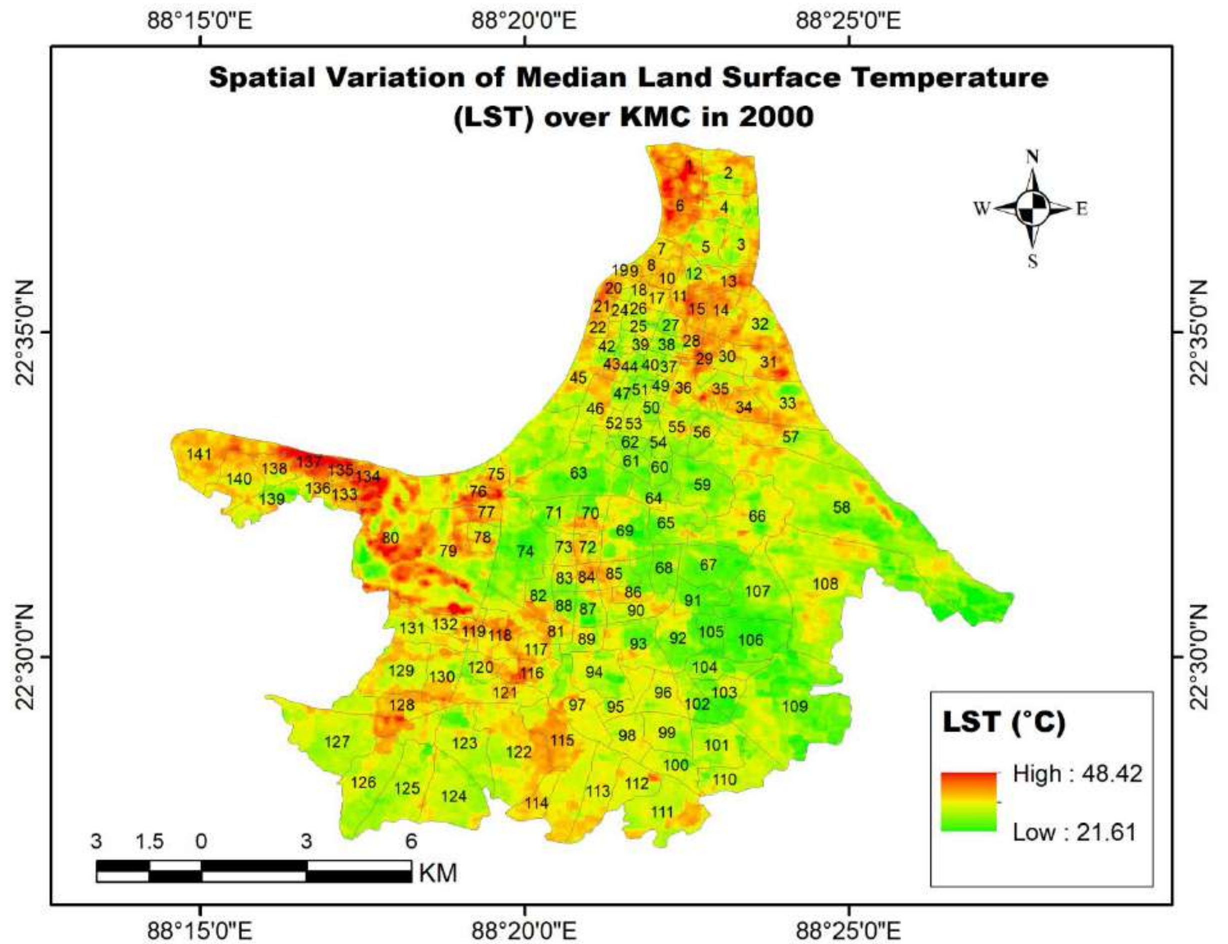
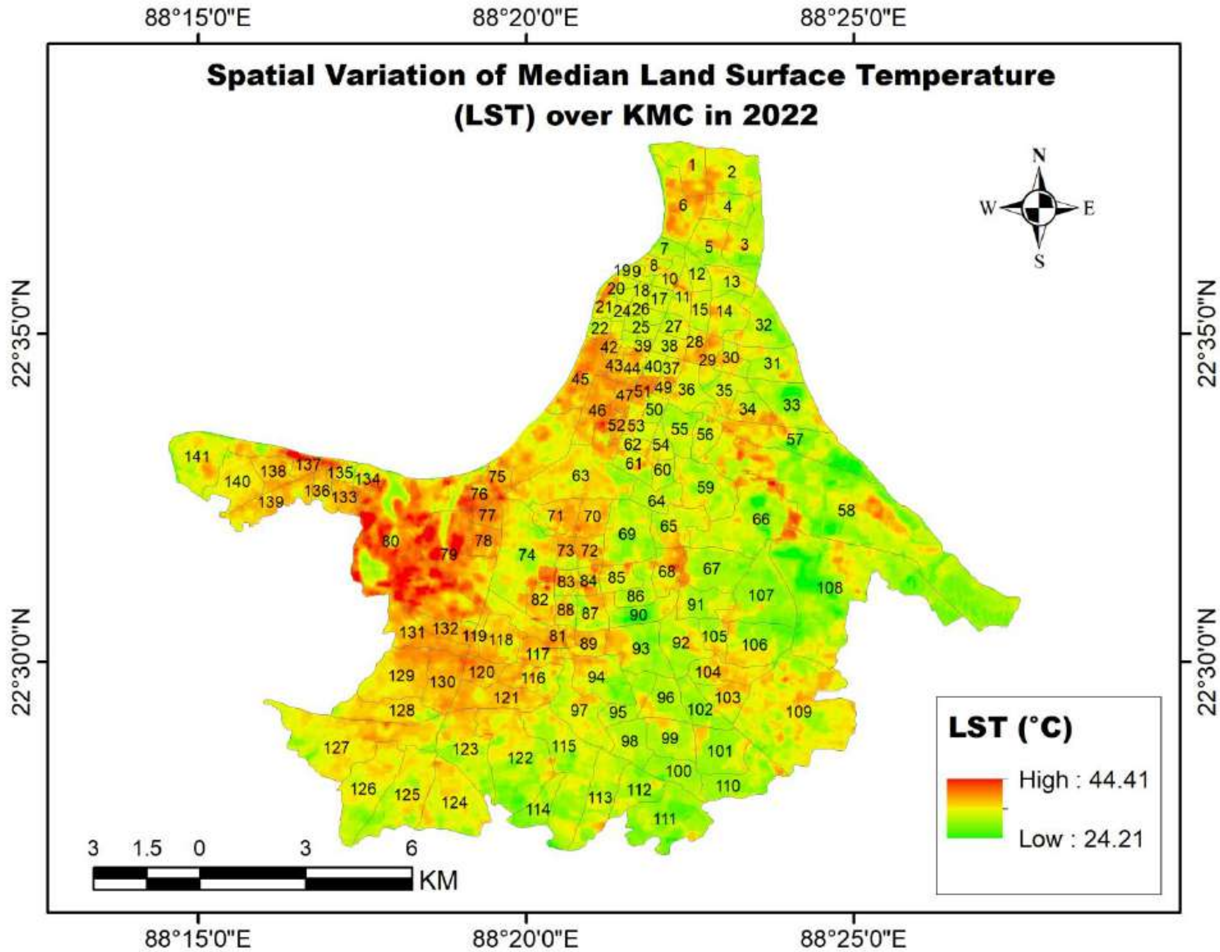
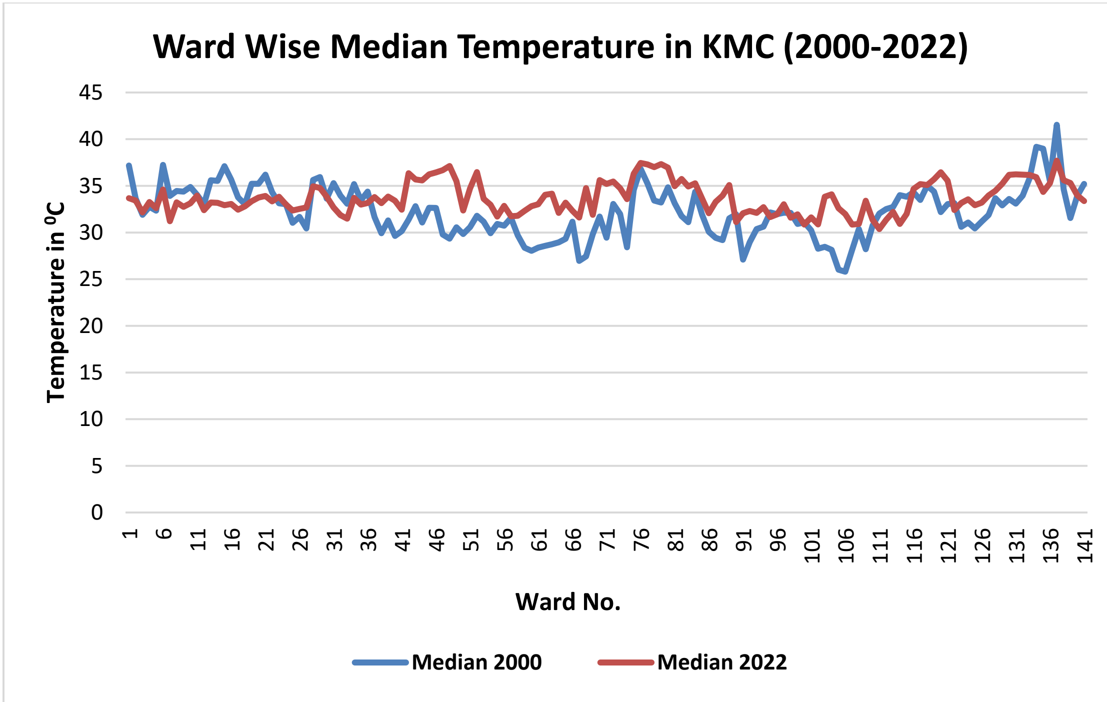


Fig.2.1: Spatial variation of median LST over KMC in 2000

Median land surface temperature refers to ward wise median temperature was derived for all the 141 municipal wards in the Kolkata municipality and the same has been represented in the following map fig.2.2. The map reflects in two categories. Ward no. 80, 79, 77, 76, 75 shows high temperate zone with 44.41ºc whereas ward no. 111, 107, 108, 101 have lower temperature zone with 24.21ºc.





The trend of Median LST association between 2000-2022 has been presenting using line graph taking LST (ºc) as the response variable. The figure of line graph represents median LST of 2000 was low comparison to the minimum LST of 2022.

MAXIMUM LST OF 2000-2022

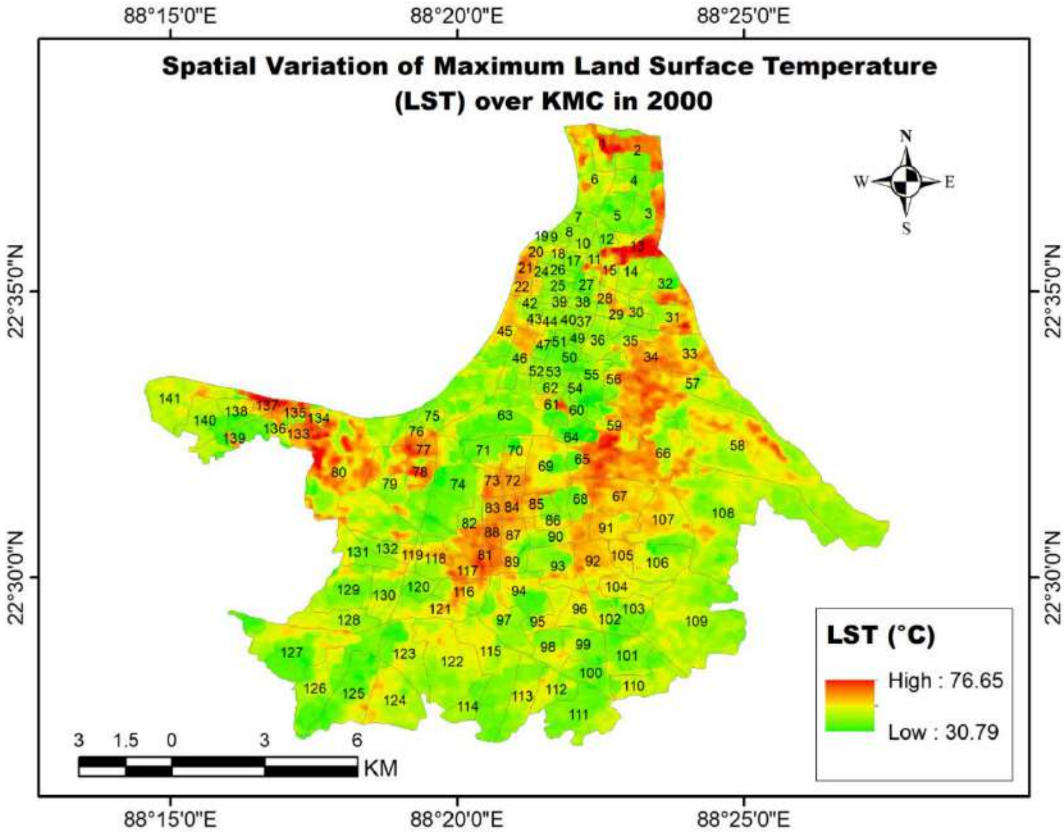


Fig .3.1: Spatial variation of maximum LST over KMC in 2000

The following maps shows that the highest maximum LST was 76.65ºc (ward no .67, 91, 107, 2, 34, 81, 83,84) in KMC due to high industrial zone, rapid growth of population and no vegetation cover. Whereas the lowest maximum LST was 30.79ºc (ward no.113, 114, 127, 129,63, 108) due to some agricultural land, water bodies in KMC.

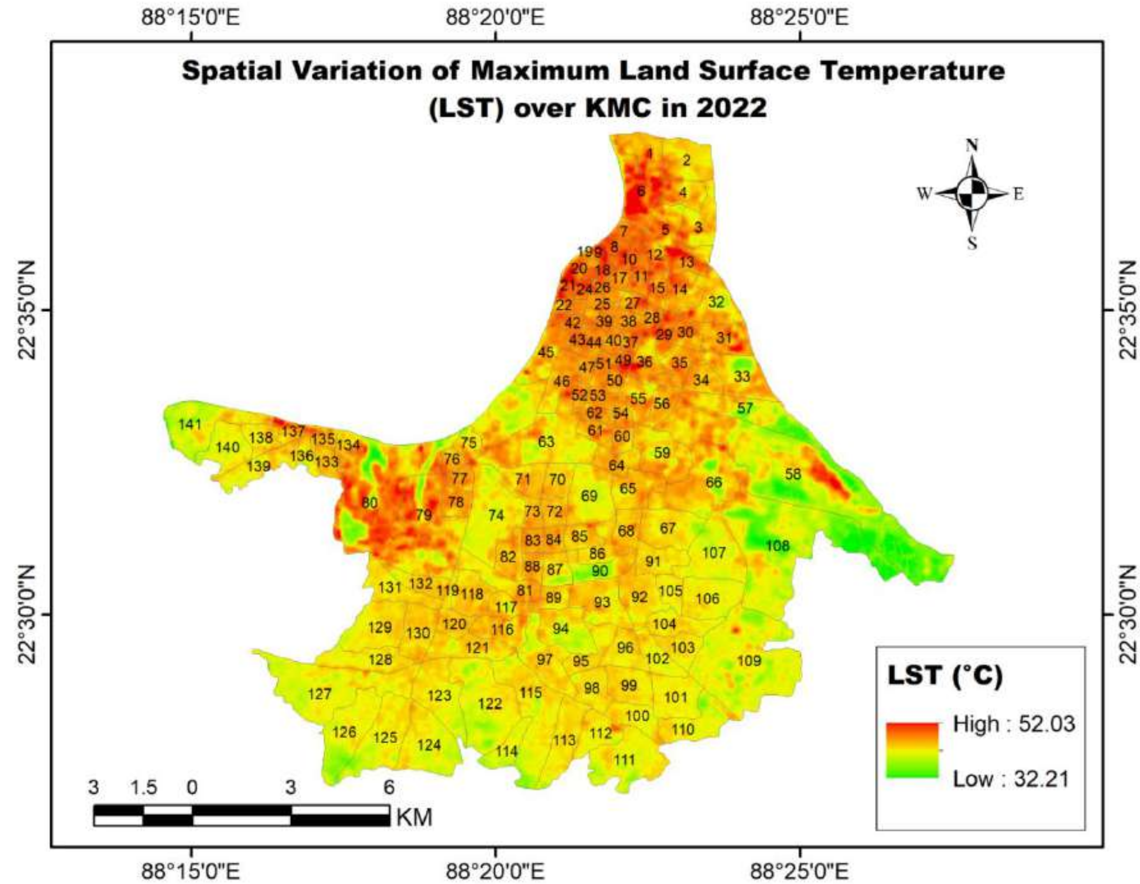
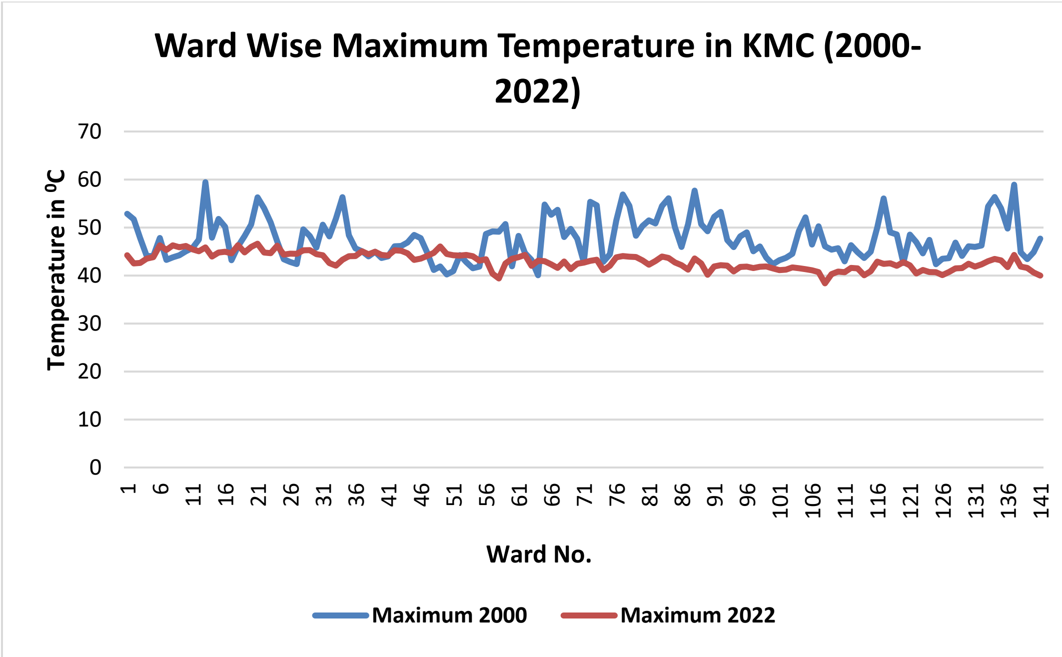


Fig.3.2: Spatial variation of maximum LST over KMC in 2022

In this map it can be seen that rapid increase of industries, roads less vegetation cover north-western part (ward no. 1, 2, 6, 4, 13, 100 maximum LST was high 52.03ºc over KMC in the year of 2022. Comparison to the north-western part presence of agricultural land, wet land the eastern part has maximum LST 32.21ºC.



The trend of maximum LST association between 2000- 2022 has been presenting using line graph taking LST (ºc) as the response variable. The figure of line graph represents maximum LST of 2000 was very high comparison to the minimum LST of 2022.

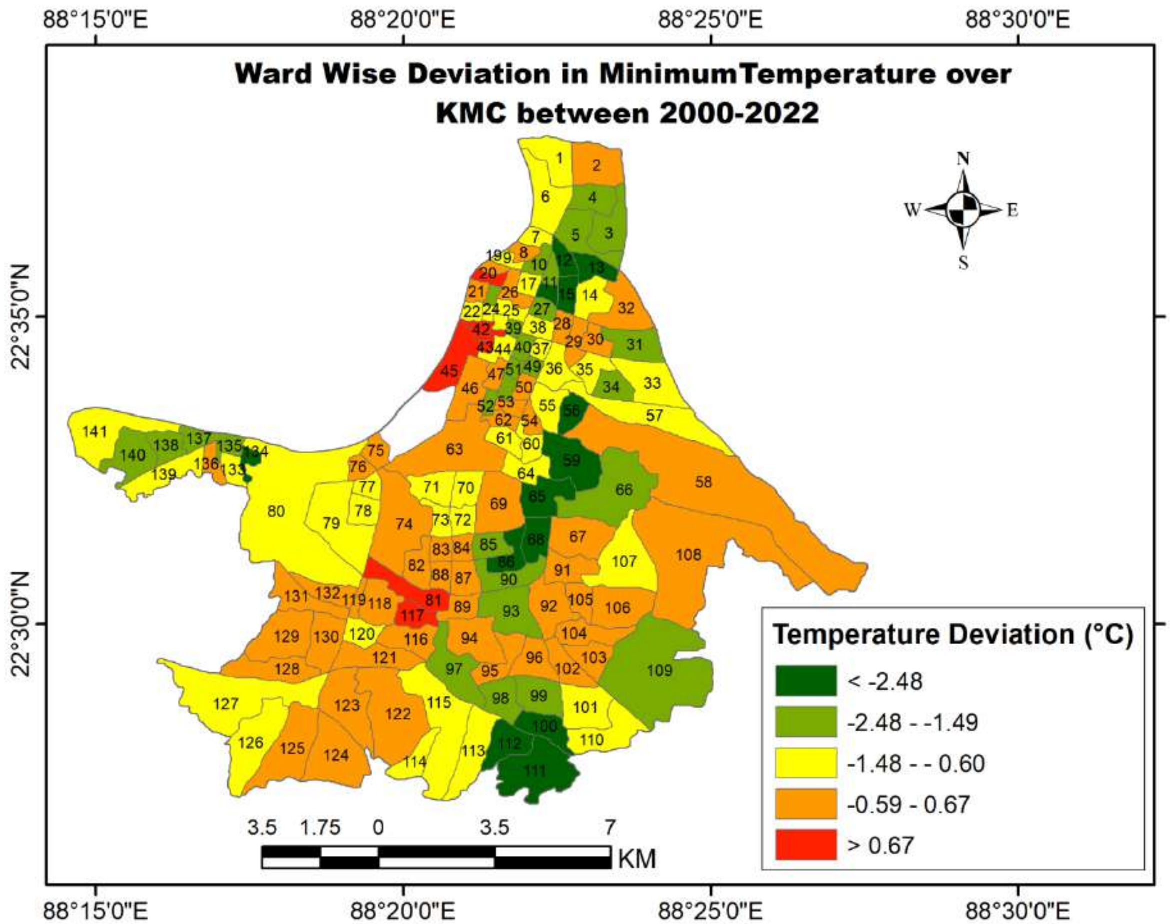
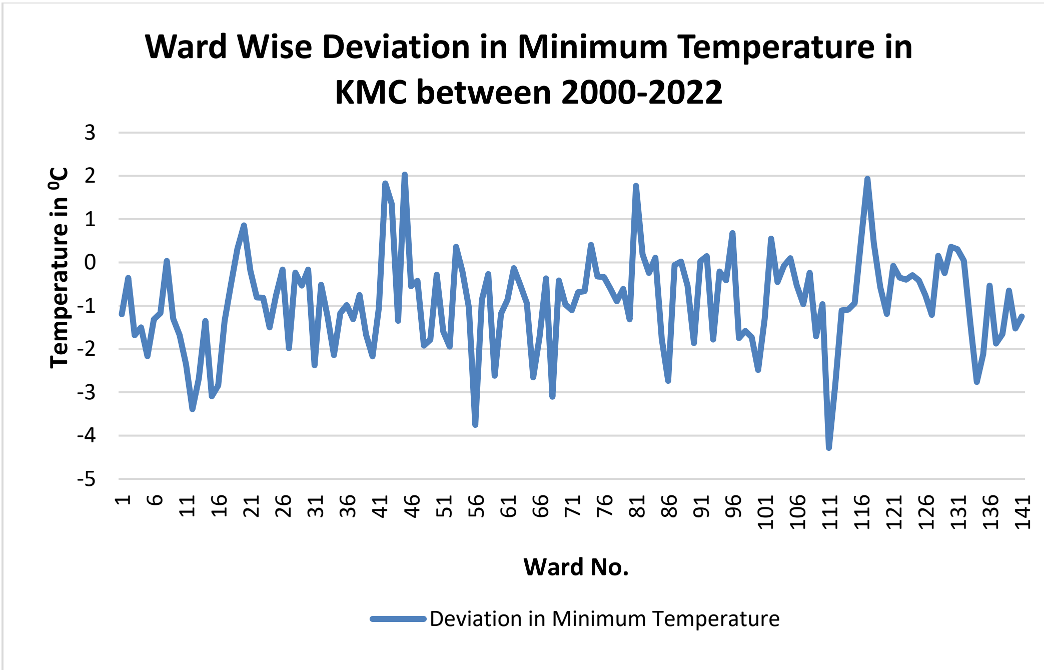


Fig.4.1: Ward wise deviation in minimum Temperature over KMC between 2000-2022

Fig.3.1 Shows the spatial deviation in minimum temperate over KMC. The very high and high LST pixels appear in urban built-up areas, especially in the areas with a high density of impervious surface across the city. Green colour wards were mainly covered by rivers, lakes, and vegetation with < - 2.48 ºc. Ward no. 81, 117, 20, 42, 43, 45 of the area was generally high with > 0.67ºc .



Ward Wise Deviation in Minimum Temperature in KMC between 2000-2022
Temperature in ⁰C
3
2
1
0
-1
-2
-3
-4
-5
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
Ward No.
Deviation in Minimum Temperature

MEDIAN LST OF LST OF KMC BETWEEN 2000-20

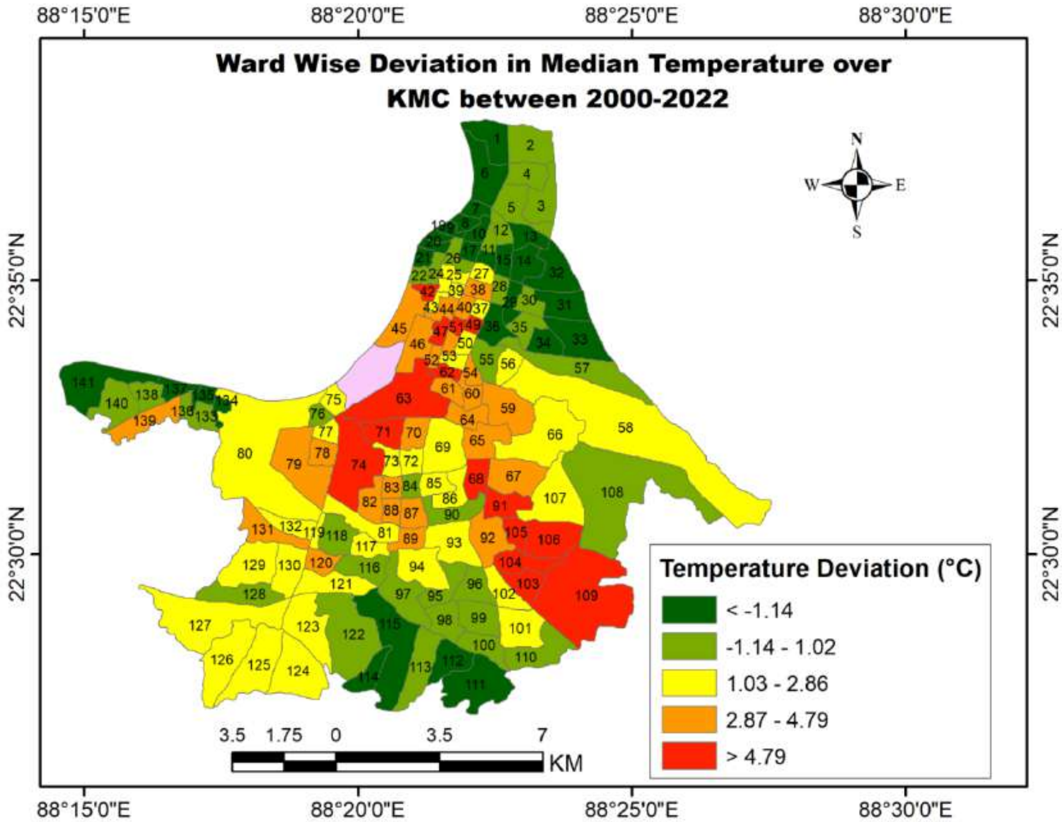
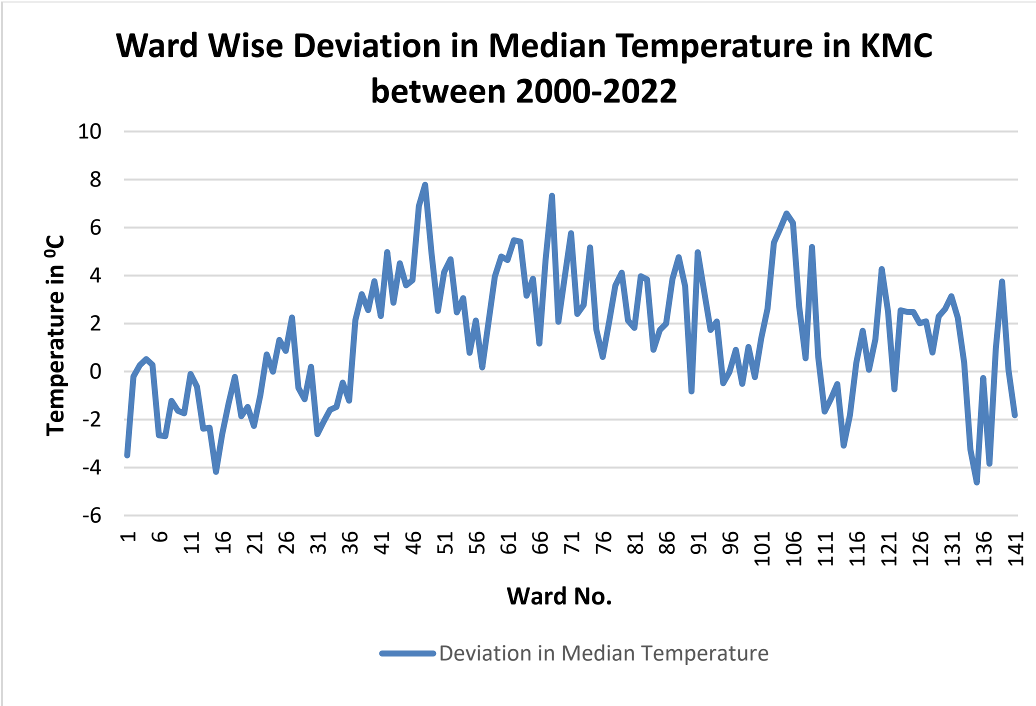


Fig.4 Fig.4: Ward wise deviation in Median Temperature over KMC between 2000-2022

Fig.4. Shows the spatial deviation in median temperate over KMC. The very high and high LST pixels appear in urban built-up areas, especially in the areas with a high density of impervious surface across the city. Green colour wards were mainly covered by rivers, lakes, and vegetation with < - 1.14 ºc. Ward no 42, 105, 103, 109, 91,68of the area was generally high with > 4.79ºc .



Ward Wise Deviation in Median Temperature in KMC between 2000-2022
10
8
6
4
2
0
-2
-4
-6
Temperature in ^{0}C
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
Ward No.
Deviation in Median Temperature

MAXIMUM DEVIATION OF LST OF KMC BETWEEN 2000-2022

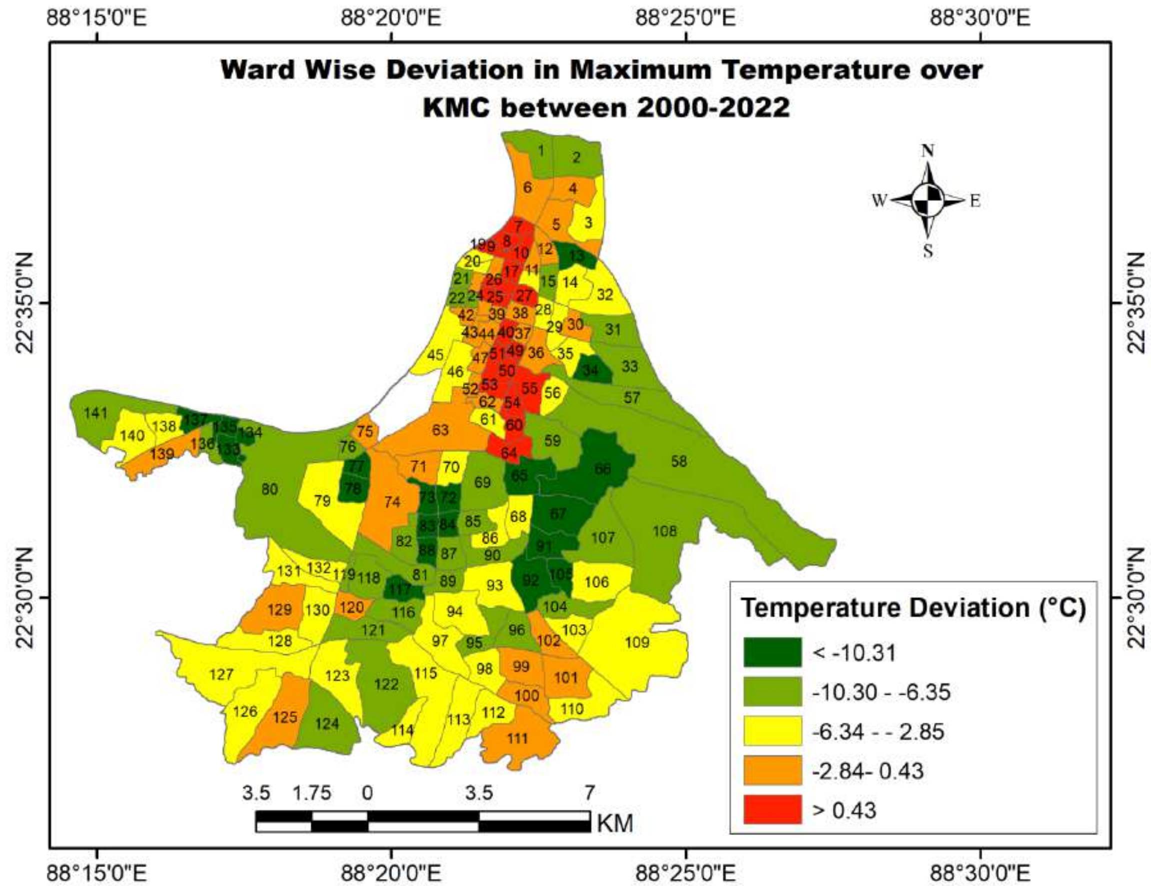
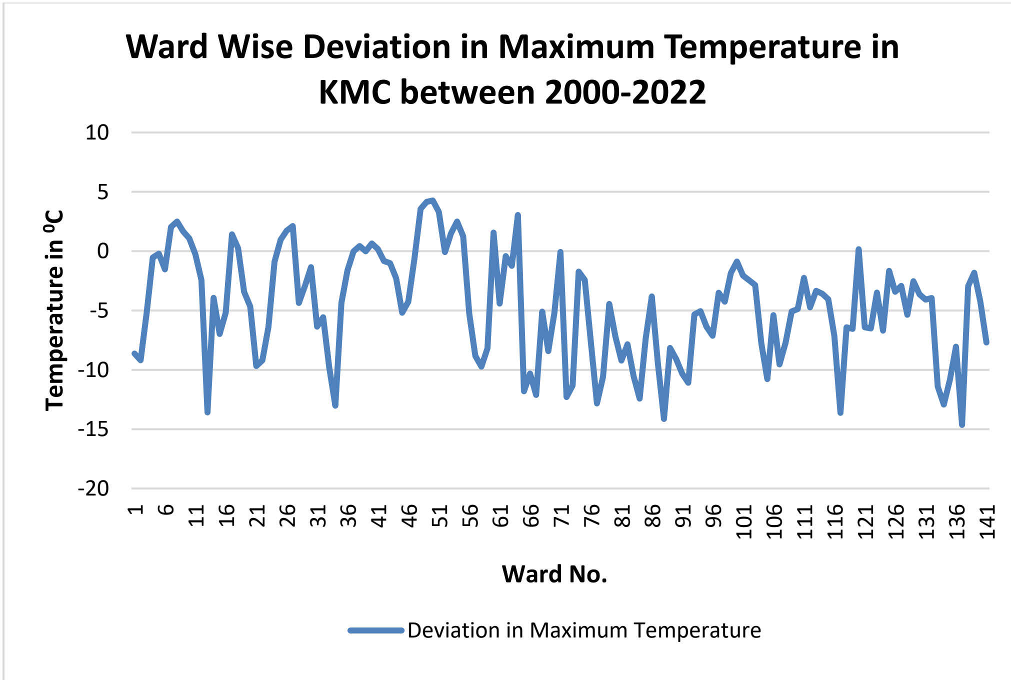


Fig.5: Ward wise deviation in maximum temperate over KMC between 2000-2022

In Kolkata municipality corporation , pixels with very high maximum LST are mainly distributed in the middle north of the area with <-10.31ºc and the central part of the area was low maximum LST with>0.43ºc.


Ward Wise Deviation in Maximum Temperature in KMC between 2000-2022
10
5
0
-5
-10
-15
-20
Temperature in ^{0}C
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
Ward No.
Deviation in Maximum Temperature

MAJOR FINDINGS

In the present study some difference of LST parameters in 2000- 2022 have been studied in KMC. The major findings of the present study are listed below,

- Land Surface Temperature of the municipality ranges from 17.90ºc to 31.71ºc. The north-western wards (56, 103, 109, 92, 104,) of the municipality has higher Land Surface Temperature in comparison to the south-eastern part of the municipality over KMC in 2000.
- It can be seen that the year of 2022, the overall spatial distribution of LST was generally high (31.380in the south-eastern part of the area, while the LST was low(3.33) in the eastern part of the area of Kolkata municipal corporation.
- It can be seen that from 2000, the overall spatial distribution of LST median was generally high 48.42ºc in the north and western part of the KMC LST was high and the distribution of lowest LST median was 21.61ºc in the eastern part.
- Median land surface temperature refers to ward wise median temperature was derived for all the 141 municipal wards in the Kolkata municipality and high temperate zone with 44.41ºc whereas lower temperature zone with 24.21ºc.
- The highest maximum LST was 76.65ºc in KMC. Whereas the lowest maximum LST was 30.79ºc in KMC.

REFERENCES

Ali, S. A. (2016). Status of solid waste generation and management practice in Kolkata municipal corporation, West Bengal. *International Journal of Environmental Sciences*, *6*(6), 1173-1186.

Ali, S. A., & Ahmad, A. (2018). Using analytic hierarchy process with GIS for Dengue risk mapping in Kolkata Municipal Corporation, West Bengal, India. *Spatial Information Research*, *26*(4), 449-469.Bajani, S., & Das, D. (2020). Sustainable Planning Interventions in Tropical Climate for Urban Heat Island Mitigation–Case Study of Kolkata. *Perception, Design and Ecology of the Built Environment: A Focus on the Global South*, 167-182.

Basu, A., Basu, L . B., Barbosa, V., & Dadashpoor, H. (2022). 'Green Placemaking'in Kolkata: Role of Urban Greens and Urban Forestry. In *Conservation, Management and Monitoring of Forest Resources in India* (pp. 131-162). Cham: Springer International Publishing.

Bera, B., Bhattacharjee, S., Shit, P. K., Sengupta, N., & Saha, S. (2021). Significant impacts of COVID-19 lockdown on urban air pollution in Kolkata (India) and amelioration of environmental health. *Environment, development and sustainability*, *23*(5), 6913-6940.

Bhatta, B. (2009). Analysis of urban growth pattern using remote sensing and GIS: a case study of Kolkata, India. *International Journal of Remote Sensing*, *30*(18), 4733-4746.

Bhunia, G. S., Ghosh, A., & Shit, P. K. (2022). Comprehensive spatio-temporal analysis of ambient air quality of Kolkata Municipal Corporation, Kolkata (West Bengal, India) during 2017–2020.*Arabian Journal of Geosciences*, *15*(24), 1782.

Biswas K. Chatterjee, A., & Chakraborty, J. (2020). Comparison of air pollutants between Kolkata and Siliguri, India, and its relationship to temperature change. *Journal of Geovisualization and Spatial Analysis*, *4*(2), 25.

Chatterjee, U., & Majumdar, S. (2022). Impact of land use change and rapid urbanization on urban heat island in Kolkata city: A remote sensing based perspective. *Journal of Urban Management*, *11*(1), 59-71.

Chattopadhyay, S., Dutta, A., & Ray, S. (2009). Municipal solid waste managementin Kolkata, India–A review. *Waste Management*, *29*(4), 1449-1458.

Das, A., Ghosh, S.,Das, K., Basu, T., Dutta, I., & Das, M. (2021). Living environment matters: Unravelling the spatial clustering of COVID-19 hotspots in Kolkata megacity, India. *Sustainable Cities and Society*, *65*, 102577.

Das, K., Das Chatterjee,N., & Bhattacharya, R. K. (2023). Estimating the Variability of Ground-Level Annual PM2. 5 and PM10 Using Land-Use Regression Model in Kolkata Municipal Corporation (KMC). In *Environmental Management and Sustainability in India: Case Studies from West Bengal* (pp. 369-378). Cham: Springer International Publishing.

Das, N. (2006). *Courtyards houses of Kolkata: Bioclimatic, typological and socio-cultural study* (Doctoral dissertation, Kansas State University).

Das, S., & Jain, G. V. (2022). Assessment and prediction of urban expansion using CA-based SLEUTH urban growth model: A case study of Kolkata Metropolitan area (KMA), West Bengal, India. *Journal of the Indian Society of Remote Sensing*, *50*(12), 2277-2302.

Dasgupta, S., Gosain, A. K., Rao, S., Roy, S., & Sarraf, M. (2013). A megacity in a changing climate: the case of Kolkata. *Climatic Change*, *116*, 747-766.

Dinda, S, & Ghosh, S. (2021). Perceived benefits, aesthetic preferences and willingness to pay for visiting urban parks: A case study in Kolkata, India. *International Journal of Geoheritage and Parks*, *9*(1), 36-50.

Gazi, M. A.A., & Mondal, I.(2018). Urban heat island and its effect on dweller of Kolkata metropolitan area using geospatial techniques. *International Journal of Computer Sciences and Engineering*, *6*(10), 741-753.

Ghosh, S., Chatterjee, N.D., & Dinda, S. (2019). Relation between urban biophysical composition and dynamics of land surface temperature in the Kolkata metropolitan area: a GIS and statistical based analysis for sustainable planning. *Modeling Earth Systems and Environment*, *5*, 307-329.

Halder, B., & Bandyopadhyay, J. (2022). Potential sites' selection of groundwater zones using AHP and GIS-based multi-criteria approach of Kolkata Municipal Corporation. *International Journal of Energy and Water Resources*, 1-18.

Halder, B., Banik, P., Almohamad, H.,Al Dughairi, A. A., Al-Mutiry, M., Al Shahrani, H. F., & Abdo, H. G. (2022). Land suitability investigation for solar power plant using GIS, AHP and multi-criteria decision approach: a case of megacity Kolkata, West Bengal, India. *Sustainability*, *14*(18), 11276.

Kundu, A., & Mukhopadhyay, S. (2023). Spatio-Temporal Review of Urban Green Space Degradation at Administrative Level Using Geospatial Techniques and Multi-criteria Decision Analysis: A Case Study of Kolkata Urban Agglomeration. *Journal of the Indian Society of Remote Sensing*, *51*(5), 1057-1075.

Kundu, N., Pal, M., & Saha, S. (2008, July). East Kolkata Wetlands: a resource recovery system through productive activities. In *Proceedings of Taal2007: the 12th world lake conference* (Vol. 868, p. 881).

Maity, S., Das, S., Pattanayak, J. M., Bera, B., & Shit, P. K. (2022). Assessment of ecological environment quality in Kolkata urban agglomeration, India. *Urban Ecosystems*, *25*(4), 1137-1154.

Majumdar, A., Hazra,T. & Dutta, A. (2017). Landfill site selection by AHP based multi-criteria decision making tool: a case study in Kolkata, India. *Journal of The Institution of Engineers (India): Series A*, *98*, 277-283.

Malik, S., Pal, S. C., Sattar, A., Singh, S. K., Das, B., Chakrabortty, R., & Mohammad, P. (2020). Trend of extreme rainfall events using suitable Global Circulation Model to combat the water logging condition in Kolkata Metropolitan Area. *Urban Climate*,*32*,100599.

Mithun, S., Sahana, M., Chattopadhyay, S., Chatterjee, S., Islam, J., & Costache, R.(2022). Comparative framework for spatially explicit urban growth modeling for monitoring urban land-use efficiency and sustainable urban development (SDG 11.3. 1): a study on Kolkata metropolitan area, India. *Geocarto International*, *37*(27), 17933-17970.

Nimish, G., Bharath, H. A., & Lalitha, A (2020). Exploring temperature indices by deriving relationship between land surface temperature and urban landscape. *Remote Sensing Applications: Society and Environment*, *18*, 100299.

PAUL, S., & BARDHAN,S. (2017). Biodiversity accounting of cities: a case study of Kolkata, India. *WIT Transactions on Ecology and the Environment*, *226*, 815-826.

Sadala, S., Chakradhar, B., & Lakshmi, T. V. (2023). A review on treatment storage and disposal facilities (TSDFS)for effective management of hazardous wastes in India. *Journal of Applied Geochemistry*, *25*(2), 72-84.

Sharma, R.,Chakraborty, A., & Joshi, P. K. (2015). Geospatial quantification and analysis of environmental changes in urbanizing city of Kolkata (India). *Environmental monitoring and assessment*, *187*, 1-12.

Singh, R. B.,Haque, M. S, & Grover, A. (2015). Drinking water, sanitation and health in Kolkata metropolitan city: contribution towards urban sustainability. *Geography, Environment, Sustainability*, *8*(4), 64-81.