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Article

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Research Article

Impact of land use change and rapid urbanization on urban heat island in Kolkata city: A remote sensing based perspective

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ABSTRACT

Kolkata is one of the cities located in the eastern parts of India and experiences rapid urban growth. Because of the rapid urbanization, land use and land cover are changing very rapidly in which impacts on the local land resources and the surface temperature of Kolkata are much higher than its surroundings. In this study, an effort has been done to find out how the vegetation cover is affected by urban growth and how the built up area grew over time. Except this, the attempt has also been made to scrutinize the trends of surface temperature in Kolkata city. This study was done between 2005 and 2019. To find out the vegetation cover and built up area of Kolkata city, Normalized Difference Vegetation Index and Normalized Difference Built up Area Index and Landsat satellite images between the year 2005 and 2019 have been used. This study reveals that vegetation area is declining towards the city core areas and percentages of built up areas are increased towards the urban area. Surface temperature is high in the city core areas which records 41 °C temperature in 2019. This study will throw new light in case of urban heat island studies.

1. Introduction

Urbanization means the process of an area to be urbanized. Urbanization is very rapid in the case of developing countries and it decreases towards developed countries. In the case of developing countries, metropolitan cities have been playing a vital role in the high growth rate of urbanization. According to various researchers, urbanization has been categorized as a process of urbanization (He et al., 2006; Wang et al., 2014; Song et al., 2012; Shahbaz et al., 2014). Many International Organizations like the United Nations, FAO have been tried to project future populations. According to the report of the United Nations (2019), global population will be increased by 8.5 billion in 2030, 9.7 billion in 2050 and 10.9 billion in 2100. According to the latest report of the United Nations (2018), 55% percentage of the population will be lived in urban areas which will be 68 percent in 2050. The population of India will be increased by 273 million between 2019 and 2050 (United Nations, 2019). Urbanization means the expansion of urban area (Seto et al., 2011). Angel et al. (2011) makes an attempt for the projection of urban area which was 3,00,000 km² in 2000 and will be increased into 1,200,000 km² in 2050. Types of urbanization in the world vary from country to country (Pannell, 2002) and they also cause threat to resources and environmental issues among the many countries like China (Fang, 2009). It also leads to the problems of soil erosion, desertification, scarcity of water resources, etc. (Wang & Fang, 2011). It also threatens to natural and semi natural habitats because of the indirect impacts of urbanization (Ruppert et al., 2012).

With the rates of urban expansion urban land use and land cover pattern hugely change with the time. The environmental impacts of

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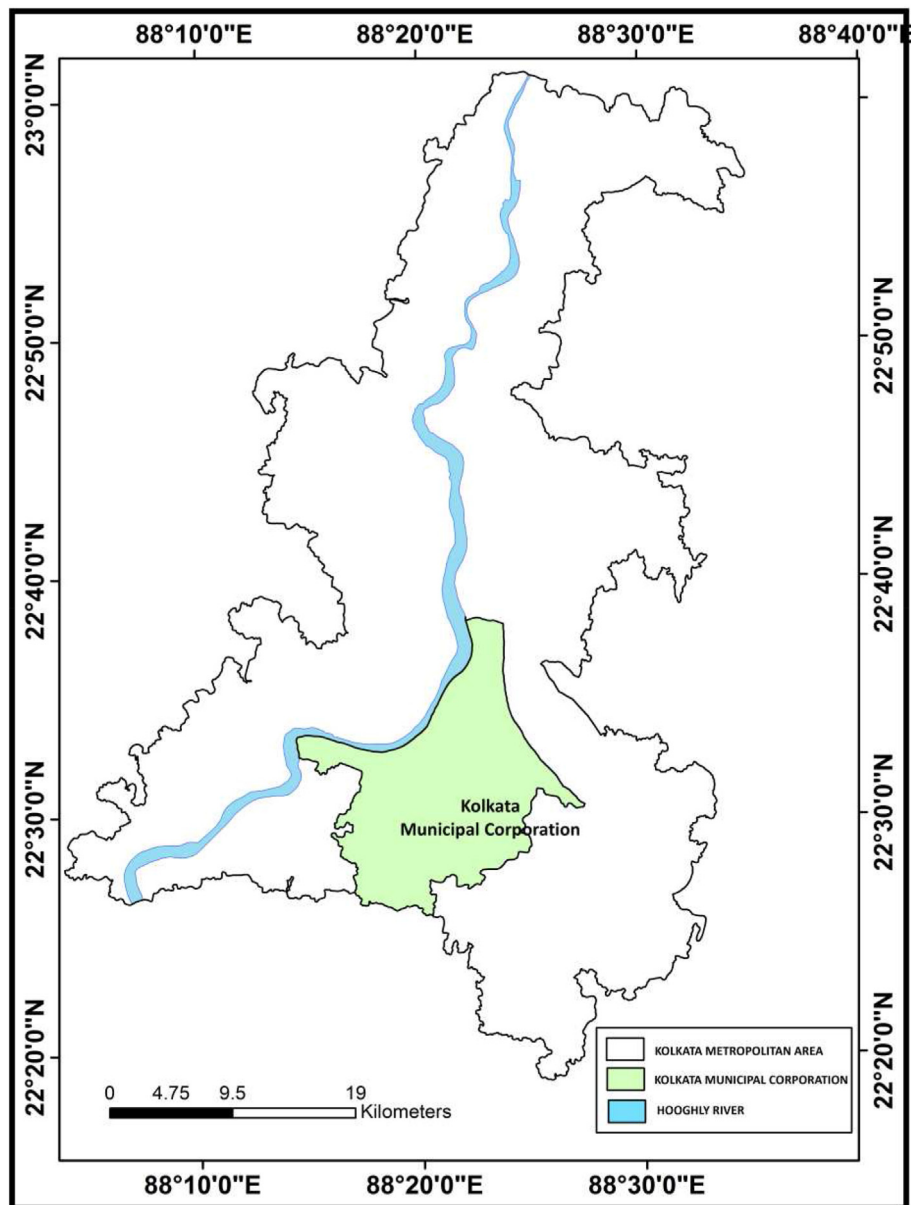


Fig. 1. The study area.

land use change are the results of the urbanization process (Carlson & Traci Arthur, 2000; Xiao et al., 2006). According to the various researchers, urban area occupies only four per cent of the total land surface but it impacts on the physical environment and social environment (Tang, 2011, Van Delm & Gulinck, 2011; Su et al., 2014, Lee & Choe, 2011). The urban expansion also causes habitat destruction, resource destruction, loss of biodiversity and fragmentation of landscape (Sala et al., 2000; Song, 2014; Song & Liu, 2014; Batisani & Yarnal, 2009; Rebele, 2009; Su et al., 2011; Seto et al., 2012). Extreme impact of urban expansion leads to the scarcity of the water resources (Guttikunda et al., 2003; Wang et al., 2013) and bad impact on public health (Khoo et al., 2003).

1.1. Urbanization and land use change

The population has been playing a dominant role in the process of urbanization from the beginning of civilization (Seto et al., 2011). Food, clothing and human employment are the basic requirements of human life. Urban areas are the hub of these things. People of the surrounding areas want to settle down in urban areas to fulfill their essential requirements. These are the causes of the process of urbanization. Tremendous demand for land in urban areas creates a huge problem for the city officials as the supply of the land is limited. The Lack of open space and overpopulation of cities creates an adverse impact on the environment (Wei, 2015).

Table 1
Detailed information about satellite images.

Acquisition Date	Sensor	Spatial Resolution	Projection
08-03-2019	OLI-TIRS	30m	WGS 84 UTM 45 N
21-01-2010	TM	30m	WGS 84 UTM 45 N
17-11-2005	TM	30m	WGS 84 UTM 45 N
14-11-2000	TM	30m	WGS 84 UTM 45 N

1.2. Increase in land surface temperature

Decrease in vegetation and an increase in the urban area or built up area increases the surface temperature of the area. Temperature is high in the central areas of the city which gradually decreases towards the peripheral areas. It creates serious causes to the global biosphere (Turner et al., 1994). It is also responsible for the local climate, habitat destruction and loss of biodiversity (Foly et al., 2005; Kalnay and Cai, 2003). The magnitude of UHI is particularly enhanced in China, which has experienced a rapid urbanization during the last three decades (Sun et al., 2016; Zhou et al., 2016). Yao et al. examined the impacts of urbanization on the vegetation coverage of 59 large cities in Africa, and vegetation decreased significantly in 44 of the 59 cities. At present, India and China experience high rates of urban land expansion in the last 30 years (Bai et al., 2014; Seto et al., 2011).

Land surface temperature can be estimated both in the day time and in night time. According to the Jusuf et al. (2007), surface temperature is relatively high in the commercial and airport areas than the other areas. Bokaie et al. (2019) opined that there is a significant relationship between the land surface temperature and land use-land cover change of an area. Van and Bao (2010) also showed that surface temperature will be high in the industrial and urban areas than the other urban vegetative areas. According to (Oke, 1981, 1982; Nunez & Oke, 1977) geometry of the urban areas also regulate temperature of the surface by absorbing incoming solar radiation. Chow (2006); Lan and Zhan (2017) opined that building geometry also controlled the temperature of the area i.e. dense building structure reduce the temperature by shading effect but it increases temperature during the nighttime. Lan and Zhan (2017) also suggested that high rise buildings may reduce the temperature in day time, but it increases temperature in nighttime.

Recently, Kolkata city has been experienced with rapid destruction of vegetation cover and increase in the built up area within a shorter period. So, in this study, an effort has been done to investigate the nature of vegetation cover and increase of built up area in Kolkata. From the field visit, it has also been done that the surface temperature of Kolkata city has been increasing day by day. The person inhabited in the surroundings of Kolkata enjoys better weather than the people in the city core area. So, in this study, an effort has been done to measure the land surface temperature of Kolkata. The objective of this study is as follows-

1.3. Objectives

The objective of this study is to investigate the vegetation cover and built up area of Kolkata city between 2005 and 2019. Except this effort has also been done to find out the surface temperature of Kolkata city between these periods.

2. Study sites

Kolkata is one of the oldest metropolitan cities in India which is located in the eastern part of India over a large alluvial plain. It is situated over the moribund delta of the Hooghly river. From the topographical sheet or from the geological map of Kolkata it has been found that the height of Kolkata ranges from 1.5 to 9 m from mean sea level. Kolkata is under the jurisdiction of Kolkata Municipal Corporation. The total number of wards in Kolkata is 144 which are subdivided into 16 boroughs. This study has been done after the addition of 2 g panchayats with KMC. For this study, the area of Kolkata Metropolitan Area has been considered which is delineated by Kolkata Metropolitan Development Authority or KMDA. Kolkata city recently has experienced a negative growth rate of population between 2001 and 2011. Six districts partially are under Kolkata those are likely Kolkata, Howrah, North 24 Parganas, Hooghly, South 24 Parganas and Nadia. Among them, only the entire Kolkata district is under KMDA (Fig. 1).

Among the total areas of KMA, Kolkata district covers 10.78 per cent of the total area, whereas Hooghly, Howrah, Nadia, North 24 Parganas and South 24 Parganas district covers 19.13 per cent, 14.67 per cent, 6.90 per cent, 25.63 per cent and 22.89 per cent of the total area. Among the total population of KMA, Kolkata comprises 28.66 per cent of the total population. Hooghly, Howrah, Nadia, North 24 Parganas and South 24 Parganas district covers 12.83 per cent, 16.12 per cent, 1.79 per cent, 30.14 per cent, 10.46 per cent of the total population. According to the latest census, population growth of Kolkata city is quite high which experiences 10.30 percent. The rate of land use change is very high in Kolkata city and the rate of land use change is relatively high towards the peripheral areas of the city.

3. Data and methods

3.1. Collection of data (images and information)

This study is based on satellite images. Satellite images have been collected from the United States Global Survey on various dates. Table 1 shows detailed information about the satellite images used for this study. For the analysis cloud, free images of the same time

Table 2
Index values for NDVI.

Categories	Values
Low	−0.51–0.00
Medium	0.01–0.25
High	0.26–0.50
Very High	0.51–0.75

Table 3
Index values for NDBI.

Categories	Values
Very Low	−0.60–0.30
Low	−0.30–0.00
Medium	0.01–0.30
High	0.31–0.60

period have been chosen to minimize the errors. For the analysis, ground verification has been done for some ground truth information. Some information regarding the growth and development of Kolkata city and its surrounding information has been collected from the various offices like Kolkata Municipal Corporation, Kolkata Municipal Development Authority etc. This study has been done after the addition of several rural mouzas with Kolkata Municipal Corporation.

3.2. Image processing

For the analysis, both the remote sensing and GIS techniques have been used. For mapping purposes, various cartographic techniques have been used. For the mapping purposes, Arc GIS 10.3 and Erdas Imagine 2014 software have been used. To scrutinize the demographic growth and surface temperature prediction, statistical analysis has been done. For the calculation of NDVI and NDBI index, Erdas Imagine 2014 software has been used. For the mapping of land surface temperature, Arc GIS 10.3 software has been used.

3.3. NDVI index

NDVI Index (Normalized Difference Vegetation Index) is a graphical indicator of satellite images, mainly used for the remote sensing measurements especially vegetation mapping. Mainly two bands have been used for the calculation of NDVI Index. Those are Near Infrared (which vegetation reflects) and Red Band (which vegetation absorbs most). It always ranges from −1 to +1.

$$\text{NDVI Index} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

It is mainly used to measure healthy vegetation where a positive value indicates healthy vegetation and vice versa. NDVI can also be used for farmland mapping (Majumdar, 2019). Table 2 showing index values for NDVI in Kolkata city.

3.4. NDBI index

NDBI Index is another graphical indicator, used for measuring the urban areas specially built up areas or artificial structure areas. Mainly, two bands are used for the NDBI mapping purposes, those are likely Short wave Infrared and Infrared Band. Like NDVI and other indices, it also ranges from −1 to +1.

$$\text{NDVI Index} = \frac{\text{SWIR} - \text{NIR}}{\text{SWIR} + \text{NIR}}$$

This index is mainly used for the built up index mapping where a positive value indicates the presence of artificial structure or built up areas and the lower value indicates the availability of physical features. Table 3 showing values of NDBI index in Kolkata city.

3.5. Land surface temperature

For the analysis, Landsat satellite images (Landsat 5 TM and 8 OLI) of 2005, 2010, 2015 and 2019 have been used (same period). For the surface temperature analysis at the time of layer stacking thermal bands were stacked. For measuring the LST and Normalized Difference Built up Area Index (NDBI), various statistics have been used. For the LST mapping, first radiance values have been calculated using this formula.

$$\text{CVR1} = \frac{L_{\text{MAX}\lambda} - L_{\text{MAX}\lambda}}{(Q_{\text{CALMAX}} - Q_{\text{CALMIN}}) * (Q_{\text{CAL}} - Q_{\text{CALMIN}})} \text{ (For Landsat 5 TM)}$$

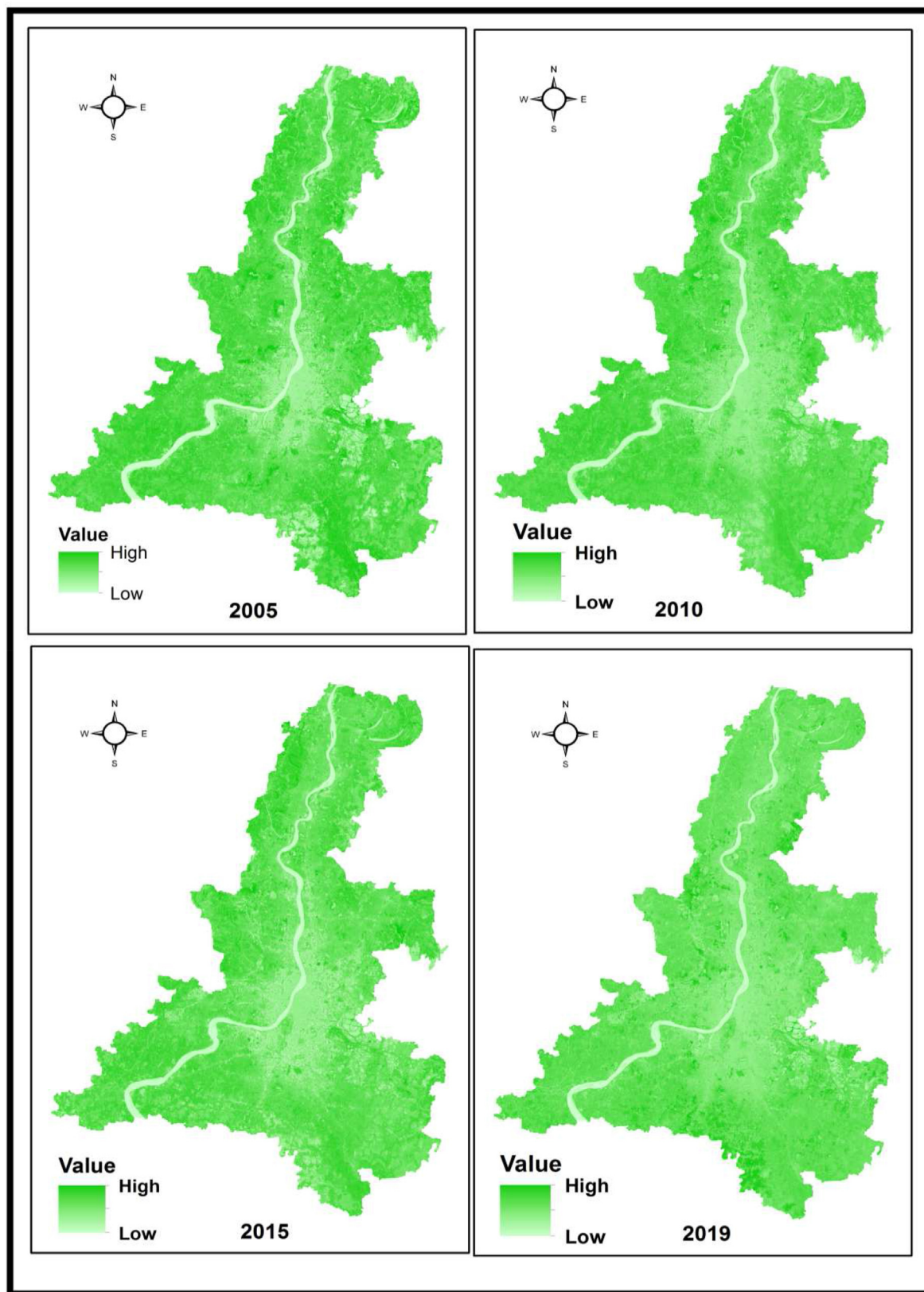


Fig. 2. Normalized difference vegetation index of Kolkata city.

Table 4
NDVI values for Kolkata.

Index Values	2005		2010		2015		2019	
	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent
Very Low	537	29.17	616	33.46	658	35.74	687	37.32
Low	456	24.77	527	28.63	578	31.40	613	33.30
Medium	103	5.59	69	3.75	54	2.93	49	2.66
High	273	14.83	226	12.28	198	10.76	184	9.99
Very High	472	25.64	403	21.89	353	19.17	308	16.73

Where, CVR1 indicates cell value as radiance, QCAL is the Digital Number, LMIN indicates Spectral radiance scales to QCALMIN, LMAX indicates Spectral radiance scales to QCALMAX, QCALMIN = the minimum quantized calibrated pixel value of the images and QCALMAX is the maximum quantized calibrated pixel value of the images. From the radiance value of the temperature of the image of the Kolkata, the city has been measured.

$$L\lambda = MLQcal + AL - 0i \quad (\text{For Landsat OLI 8})$$

Where, $L\lambda$ = TOA spectral radiance (Watts/(m² × srad × μm)), ML = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number), AL = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number), QCal = Quantized and calibrated standard product pixel values (DN) and is the correction for band 10. From the radiance value, LST has been collected applying these statistics (Mallick and Bharath, 2008; Barsi et al., 2014). LST has been calculated in degree Celsius.

3.6. Mapping techniques and Software's

For the analysis, both the remote sensing and GIS techniques have been used. For the mapping purposes, various cartographic techniques have been used. For the mapping purposes, Arc GIS 10.3 and Erdas Imagine 2014 software have been used. To scrutinize the demographic growth and surface temperature prediction statistical analysis has been done. For the calculation of NDBI and NDVI indices, Erdas Imagine 2014 has been used. For the mapping of land surface temperature, Arc GIS 10.3 software has been used. For the future prediction of the surface temperature, Microsoft Excel 2019 has been used.

4. Results and analysis

4.1. Changes in vegetation and built up area

Among the natural Land Use and Land Cover (LULC), vegetation and water body are the major features in KMA. Among these two LULC types, vegetation is more dynamic in nature. Vegetation is mainly high in the peripheral areas of the city which gradually decreases towards the central part of Kolkata city.

To investigate the nature and patterns of vegetation cover in Kolkata city, NDVI indices have been done (Fig. 2). NDVI indices have been done over the years 2005, 2010, 2015 and 2019. Table 4 showing NDVI values for Kolkata. Table 4 shows the distribution of the NDVI index in Kolkata between 2005 and 2019. In 2005, 29.17 percent of the total KMA experiences very low NDVI values and 25.64 percent experiences very high NDVI values. In 2010, because of the destruction of vegetation cover areas of high vegetation cover completely disappears. Both in the years 2015 and 2019, vegetation cover hugely decreased. In 2019, only 16.73 per cent of the area is under good vegetation cover and nearly 70 percent of the area experiences low density of vegetation which creates an adverse impact on vegetation (Fig. 3).

From the NDVI images of Kolkata city of 2005, it has been found that values for NDVI ranges from +0.71 to −0.89. In 2005, the amount of vegetation is very low in the Central Business part of the area which is slightly high in the northern parts of KMA i.e. towards Kalyani city, but it experiences very high in the western parts (rural blocks of Hooghly district) and northern parts (rural blocks of Nadia district). Percentage of vegetation cover in this area is comparatively higher than the other areas. In 2010, the percentage of vegetation cover is very less in the CBD areas. These areas are totally vegetation less areas. The percentage of vegetation cover is also slightly high in the northern and eastern peripheral areas of the city. In 2010, the values of NDVI in Kolkata city ranges from +0.61 to −0.59. In 2015, values of NDVI in Kolkata city ranges from +0.54 to −0.57. In this time period, the percentage of vegetation cover was also very less in the CBD areas, Central Kolkata areas and Dharmatala areas. Between this time period, the percentage of vegetation cover in the northern parts slightly decreased, but the percentage of vegetation cover was also high in the western parts of KMA. In 2019, the values of vegetation indices ranges from +0.43 to −0.51. Vegetation cover is very less in the CBD, Central Kolkata area and Esplanade area and it was high in the western parts of Kolkata. Table 5 showing NDVI values in the different parts of KMA.

Among the cultural features of LULC types, built up area is one of the important features which can be used as a parameter to measure the pace of the urbanization and the process of urbanization of an area. In this study, NDBI indices have been used to find out the growth of urban areas or built up areas. For this study, any type of concrete structures, artificial surfaces, buildings, houses have been considered as a built up area.

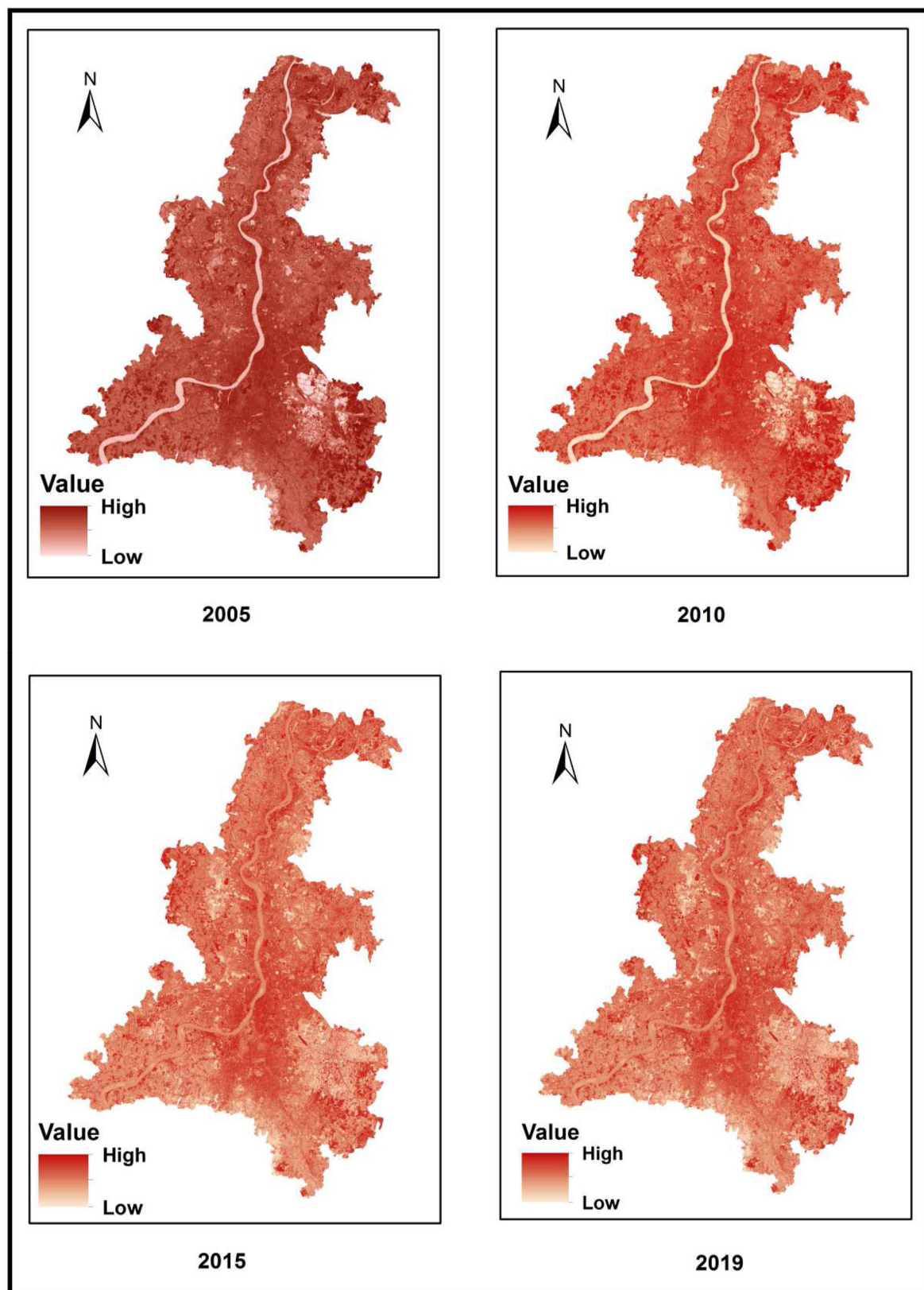


Fig. 3. Normalized difference built up area index of Kolkata city.

Table 5
NDVI values in KMA.

Index Values	2005 Location	2010 Location	2015 Location	2019 Location
Low	CBD areas, South Kolkata i.e. Garia, Tollygunge	CBD Areas, Central Kolkata area, South Kolkata i.e. Garia, Tollygunge, North Kolkata i.e. Hatibagan, Baghbazar	CBD Areas, Central Kolkata area, Dharmatala area, South Kolkata i.e. Garia, Tollygunge, North Kolkata i.e. Hatibagan, Baghbazar, Eastern Kolkata	CBD Areas, Central Kolkata area, Dharmatala area, Esplanade adjacent area, South Kolkata i.e. Garia, Tollygunge, North Kolkata i.e. Hatibagan, Baghbazar, Eastern Kolkata
Medium	Howrah Municipal Corporation Area	Howrah Municipal Corporation Area and Western Kolkata and South Kolkata	Howrah Municipal Corporation Area and Western Kolkata and South Kolkata	Howrah Municipal Corporation Area and Western Kolkata and South Kolkata, North Eastern part of Kolkata
High	Northern part of KMA towards Kalyani area	Northern part of KMA towards Kalyani area	Northern part of KMA towards Kalyani area and Western parts of KMA i.e. western bank of Hooghly river	Northern part of KMA towards Kalyani area and Western parts of KMA i.e. western bank of Hooghly river
Very High	Rural Blocks of Hooghly District and Nadia District	Rural Blocks of Hooghly District and Nadia District	Rural Blocks of Hooghly District	Rural Blocks of Hooghly District

Table 6
NDBI values for Kolkata.

Index Values	2005		2010		2015		2019	
	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent
Very Low	732	39.76	657	35.69	616	33.46	563	30.58
Low	630	34.22	587	31.88	533	28.95	491	26.67
Medium	156	8.47	199	10.81	235	12.76	267	14.50
High	323	17.54	398	21.62	457	24.82	520	28.25

Table 7
NDBI values in KMA.

Index Values	2005 Location	2010 Location	2015 Location	2019 Location
Very Low	Rural Blocks of Hooghly District and Nadia District	Rural Blocks of Hooghly District and Nadia District	Rural Blocks of Hooghly District	Rural Blocks of Hooghly District
Low	Howrah Municipal Corporation Area and Western Kolkata and South Kolkata	Howrah Municipal Corporation Area and Western Kolkata and South Kolkata, North Eastern part of Kolkata	South Eastern part (Sonarpur area) South Kolkata i.e. Santoshpur, Garia, Tollygunge	South Eastern part (Sonarpur area), South Kolkata i.e. Garia, Tollygunge, North Kolkata i.e. Hatibagan, Baghbazar
Medium	South Eastern Part of Kolkata	South Eastern Part of Kolkata	South Eastern and North Eastern Part of Kolkata	South Eastern, South western, North Eastern, Part of Kolkata
High	CBD areas, Central Kolkata, North Kolkata	CBD Areas, Central Kolkata area, North Kolkata	CBD Areas, Central Kolkata area, Dharmatala area	CBD Areas, Central Kolkata area, Dharmatala area, Esplanade adjacent area

Table 6 shows the values of NDBI in Kolkata from 2005 to 2019. From the NDBI indices, it has been found that the percentage of urban areas hugely increased between this time period. The percentage of the built up area or urban core area increases from 17.54 percent into 28.25 per cent of the area, where other areas hugely decreased between this time period.

In 2005, the values of the NDBI index ranges from 0.42 to −0.76. The lowest values of the NDBI index can be found in the rural blocks of Hooghly and Nadia districts as most of the lands in this area are agricultural lands and vegetation areas. So, NDBI value experiences low in this area. In 2005, NDBI values are high in the CBD areas, Northern Kolkata and Central Kolkata areas. In 2010, NDBI values are low in the villages of Hooghly and Nadia district and high towards the Kolkata city areas. Values of NDBI in this time period ranges between +0.48 and −0.61. In 2015, NDBI value slightly increases in the south and south eastern part and north eastern part of Kolkata. Between this time period, it ranges between +0.53 and −0.52. In 2019, the values of NDBI index ranges between +0.59 and −0.43. From the overview of the NDBI indices between 2005 and 2019, it has been found that NDBI value increases towards the city area which gradually decreases towards the peripheral areas like CBD area, Dharmatala area, Rajabazar area, Garia, Santoshpur, Baghbazar etc. The values of this index is very high throughout the time period (Table 7).

Table 8 and Table 9 showing changes in NDVI and NDBI values of Kolkata city. From the NDVI values of Kolkata from 2005 to 2019 it has been found that the areas of very low indices have been increased very fast and very high indices decrease very rapidly between 2005 and 2010 which indicates the vegetation cover of Kolkata decreasing very rapidly between this time period. Between 2010 to 2015 and 2015 to 2019, very high indices have been decreasing very faster than the very low indices. This tendency indicates the vegetation

Table 8
Changes in NDVI values.

Index Values	2005–2010		2010–2015		2015–2019	
	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent
Very Low	79	4.29	42	2.28	29	1.58
Low	71	3.86	51	2.77	35	1.90
Medium	–34	–1.85	–15	–0.81	–5	–0.27
High	–47	–2.55	–28	–1.52	–14	–0.76
Very High	–69	–3.75	–50	–2.72	–45	–2.44

Table 9
Changes in NDBI values.

Index Values	2005–2010		2010–2015		2015–2019	
	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent
Very Low	–75	–4.07	–41	–2.23	–53	–2.88
Low	–43	–2.34	–54	–2.93	–42	–2.28
Medium	43	2.34	36	1.96	32	1.74
High	75	4.07	59	3.20	63	3.42

cover of Kolkata has been transforming into other land cover types very rapidly which possesses a serious threat to natural ecosystems. By over-viewing the NDBI values of KMA, it has been found that high and very low indices experience very high between 2005 and 2010, as both experience high percentage of changes between this time period. But after this time period, the areas with high NDBI values rapidly increased than the other categories. This tendency indicates that the demand for open space or vacant land in Kolkata city has been increasing very fast which accelerates the growth of built up area.

4.2. Increase in land surface temperature

From the field verification, it has been found that the surface temperature in the core areas of Kolkata city is quite higher than the other peripheral areas. In this study, Landsat satellite images have been used to scrutinize the land surface temperature of the area.

Fig. 4 shows the surface temperature of Kolkata city between 2005 and 2019. From the surface temperature image of 2005, it has been found that maximum and minimum temperature during that time period are 26 °C and 14 °C. By analyzing this image, it has been found that temperature is higher in the city core areas than in the peripheral areas. In 2019, maximum and minimum temperatures experience 41 °C and 23 °C. By analyzing the surface temperature between these four time period, it has been found that the average temperature of this city has been increased nearly 20 °C and 32 °C between 2005 and 2019. For this reason, Kolkata city has been suffered from heat island like situation.

Table 10 shows the distribution of surface temperature in Kolkata city between 2005 and 2019. From the temperature distribution in Kolkata city, it has been found that in 2005, nearly 1780 sq. Km. of the area is under the 11 °C and 25 °C which experiences nearly 96 per cent of the area. Only 3 per cent of the area has been experienced with high surface temperature i.e. 26 °C and 40 °C. From 2005, the area of low surface temperature has been decreased very rapidly and high temperature increases very fast which converts Kolkata into heat island like situation. In 2019, the temperature in the core areas of Kolkata (CBD area, Central Kolkata area etc.) has been reached into 41 °C which may be causes of concern among the environment researchers and urban planners. Table 11 shows the distribution of surface temperature in Kolkata city.

Table 12 showing changes in LST values in Kolkata. From the table, it has been found that the area with low temperature has been decreased and the area between 26 °C and 40 °C has been increasing very rapidly which creates lots of problem to the urban planners and decision makers.

4.3. The relationship among NDVI, NDBI and LST values

From the overview of the NDVI, NDBI and LST maps, it has been found that Kolkata city high NDVI values are declining very fast and NDBI values are increasing very fast which accelerates the increase in surface temperature. The highest temperature estimated in Kolkata city has found that it records 41 °C in 2019. Fig. 5 shows the projection of surface temperature in Kolkata city up to 2030. From this analysis, it has been found that the temperature of Kolkata city will be increased up to 53 °C in 2030. Because of the high temperature increase in Kolkata city, the inhabitants of Kolkata city will face lots of problems. To solve this problem, policy makers and decision makers will formulate new policies to minimize the surface temperature of Kolkata city.

5. Discussion

Kolkata is one of the metro cities in the eastern parts of India. Kolkata city has been developing very fast because of the influx of refugees from the former East Pakistan and migration from the rural areas because of the employment facilities, good healthcare

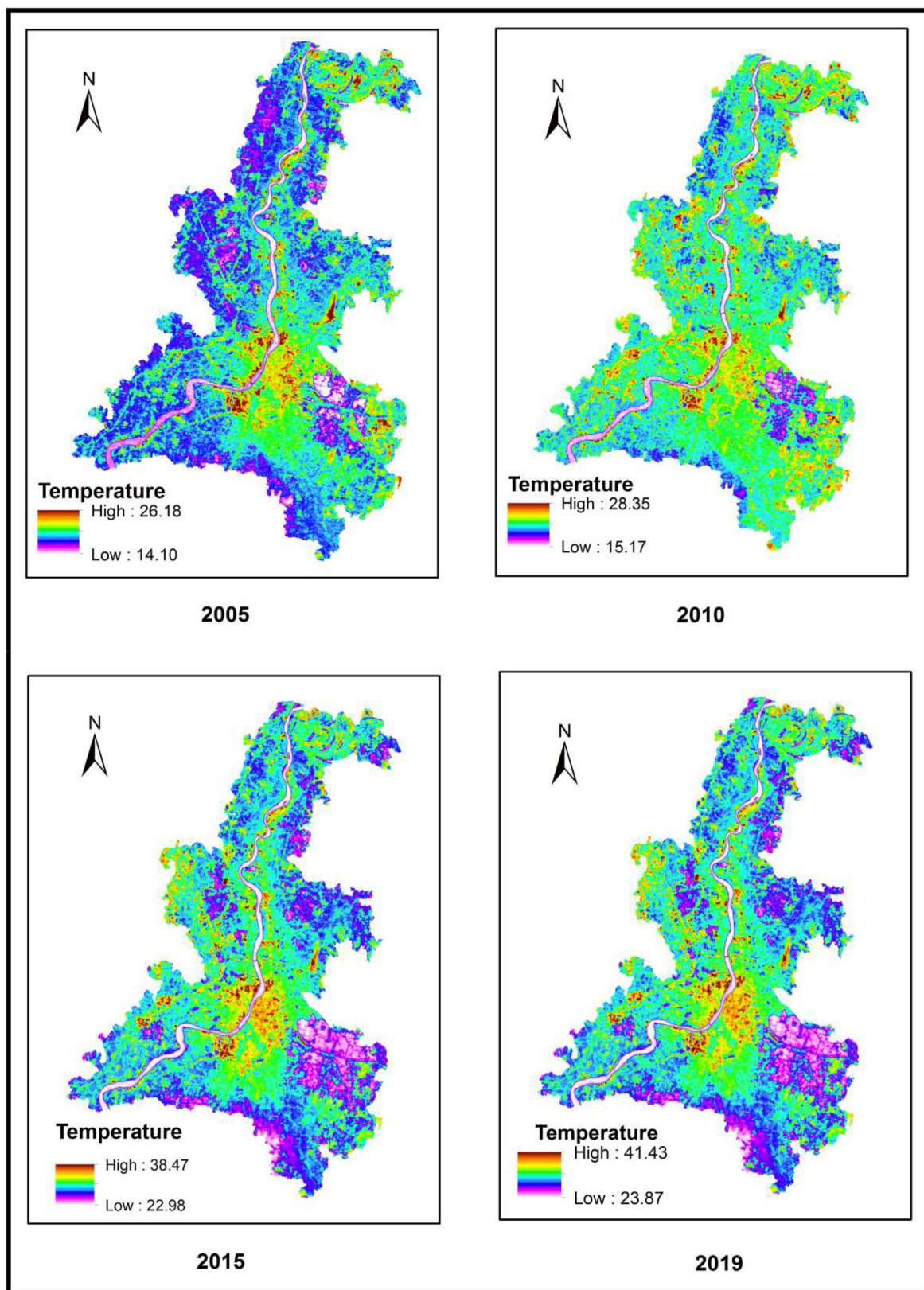


Fig. 4. Land surface temperature of Kolkata city from 2005 to 2019.

Table 10

Land surface temperature of Kolkata city.

Temperature in Celsius	2005		2010		2015		2019	
	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent
11 to 25	1780	96.69	1535	83.38	1384	75.18	1237	67.19
26 to 40	61	3.31	306	16.62	457	24.82	568	30.85
41 to 55	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	36	1.96

Table 11

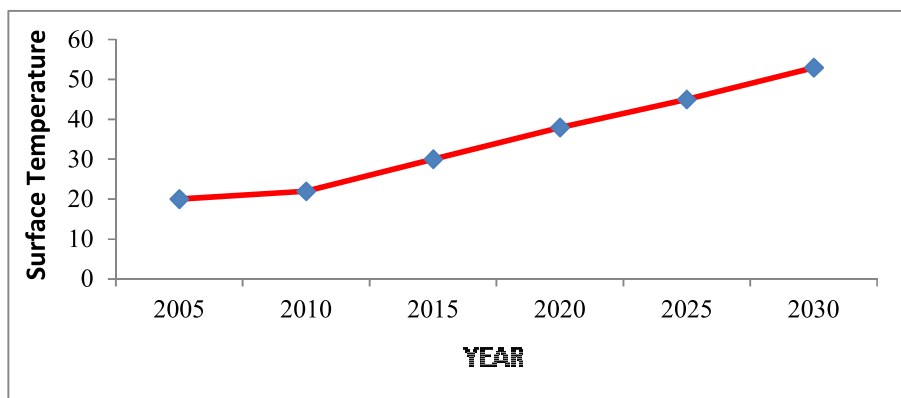
Land surface temperature in KMA.

Temperature in Celsius	2005	2010	2015	2019
	Location	Location	Location	Location
11 to 25	The whole part of KMA	Whole part of KMA	Whole part of KMA	Whole part of KMA
26 to 40	CBD areas	CBD areas, Central Kolkata, North Kolkata	CBD areas, Central Kolkata, North Kolkata, Howrah	CBD areas, Central Kolkata, North Kolkata, South Kolkata and Howrah
41 to 55	N.A.	N.A.	N.A.	CBD areas, Central Kolkata, North Kolkata, South Kolkata, Eastern Kolkata and Howrah

Table 12

Changes in LST values.

Temperature in Celsius	2005–2010		2010–2015		2015–2019	
	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent	Area (SQ.KM).	Percent
11 to 25	–245	–13.31	–151	–8.20	–147	–7.98
26 to 40	245	13.31	151	8.20	111	6.03
41 to 55	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

**Fig. 5.** Surface temperature prediction of Kolkata city.

facilities etc. Presently, Kolkata city has been growing in a south-easterly and south-westerly direction from the city core area as it has been found during the analysis of the satellite images (Majumdar, 2019). The demand for the land of Kolkata city is very high in recent decades. To meet the needs vegetation area has been declining very fast and built up area has been increased a lot which is also the main reason for increasing land surface temperature (Majumdar, 2019).

From the overview of the analysis, it has been found that the temperature of Kolkata city has been increasing very fast. Temperature is high in the central city or city core areas. From the field verification, it has been found that most of the agricultural lands, vegetation areas, water body areas have been converted into the urban area or built up area. The transformation of land i.e. non urban area or semi urban area to an urban area is high in the peripheral areas than the city areas as the availability of land is very high in those areas. Low prices of land are also another factor behind the rapid transformation of land in Kolkata city.

6. Recommendations

The temperature of Kolkata city has been increasing very fast. To minimize these problems urban planners should formulate policies for the reduction of temperature. The policy makers should formulate new laws or regulations to stop the illegal or unplanned conversion of land. Awareness among the people should be increased to combat with this problem. There is no master plan for Kolkata city. To minimize this problem, new master plan should be developed. Another noticeable fact is that there is no coordination among the developmental agencies (Like KMDA, KMC, KIT etc.). Coordination among the agencies should be increased to eradicate this problem.

7. Conclusion

Kolkata is one of the cities with 15.89 million people with the coordination of various constituent units like Municipal Corporations, Municipalities, Census Towns, Outgrowths and Rural areas. The total number of the constituent units is 594. From the study, it has been found that vegetation in Kolkata city has been decreased very fast with the rapid increase in the urban area. NDVI maps show that vegetation area is high in the peripheral areas than the city areas or urban areas. Encroachments of the urban area over the vegetation area are high in the outer peripheral areas. On the other hand, NDBI index is higher towards the city areas than the outwards of Kolkata city. The temperature in the central part is very high than in the other areas. To minimize these problems city authorities should take immediate measures. This research work will not only help the city authorities but also the decision makers and policy planners for the construction of new policies. This study which has been done over Kolkata, can be performed in any other cities in India. This study will throw new light over the urban heat island studies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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