Geospatial Analysis of the Dynamics of Climate in Kolkata Metropolitan Area

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Abstract. The Kolkata Metropolitan Area region comprises urban towns that have witnessed major changes and have been exposed to urban agglomerations, population outbursts, and have faced difficulties in regional management. The growing cities comprising these areas thus faced various kinds of natural changes. One of the major significant changes included the change in climatic conditions. Climate is the weather experienced by any region for a long period, particularly extending to 30-35 years. Therefore, the climate is a long-term study of any region where any slight change shows a significant impact on the lives and balance of the region's habitats. This paper tries to deal with the analysis of climate change in the KMA region.

Metropolitan cities in India are currently considered prime concerns due to various climatic distortion and global warming effects. Thus, the paper tries to show the factors and effects of climate change. The study period has been taken for 35 years in the paper. The analysis is carried out using various GIS techniques using the ArcMap 10.1.1 software and statistical techniques to generate graphs. From 1989 to 2006 ranged high as the population showed a rising trend in Kolkata, Howrah, and Kalyani. However, this trend changed for some time during 2014 and 2015 as various plantation activities, programs, and projects were taken up by the government to safeguard climate change's harmful effect. It shows a rise in the temperature and fall in the rainfall quantities from 2015 to 2019. It also shows the disturbed rainfall pattern as a characteristic feature in the KMA cities as sudden droughts or urban flooding rise as a common phenomenon. The area is highly exposed to constant modifications. The paper concludes in a nutshell how the changes have affected the region and are still having a significant impact on influencing lives and living.

Keywords: Air Quality parameter, Climate change, Isohyet Map, LST, Meteorological parameters, NDBI, NDVI

1. Introduction
Change in the climate is a global phenomenon that impacts the urban environment and its components. With time, under the influence of internal dynamics and various external forces, the climate system has evolved[1]. It is one of the most significant subjects relating to the world and its environs in the present-day context[2]. The cause of the existing differences involves both natural and anthropogenic[3] drivers and forces affecting the environment collectively [4]. Urbanization and the change in the vegetation cover impact climate change to a large extent[5]. Research led by S. Midha states that since 1950, human activities significantly lead to warming the climate system (Midha et al., 2015)[6]. Studies relating to the KMA region (study area), in particular, suggest the change in settlement extent to be 88.71 km², 144.64 km², and 197.5 km² from 1989 to 2010[7].

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The Kolkata Metropolitan Area (KMA) is an urban area that primarily has been subjected to climate change issues [8]. There has been a vigorous prolonged increase in temperature by about 1.2°C in the past 170 years in Kolkata and its neighboring cities (Dhara, 2019, para.7)[2,3]. Dynamics of climate are a fact of life in the study area[9], including the major suburbs of Howrah, Uluberia, Chandannagar, Chunchura, Shrirampur, Kolkata, Kalyani, Barrackpur, Barasat, Baruipur, and, as it appears is synchronous with global climate change. In cities, temperatures generally tend to be even higher, often by as much as by one °C, due to concretization, radiation off such surfaces[10], trapping of heat, and what are known as "Urban Heat Islands" (UHI) (Memon et al., 2008)[13], (Sethi, 2018, p. 22)[11]. Studies show that the northern parts of the city have been warmer than the southern areas, and heat island peaks are identified (Patel, 2009)[12].

Geospatial technologies and various indices such as the Land Surface Temperature (LST) mapping, Isohyet mapping, Normalised Difference Vegetation Index (NDVI) information, and Normalised Difference Built-up Index (NDBI) information graphing forms the major tools[14] to identify the effects of climate change and its analysis [15]. The differences in the atmospheric chemistry, temperature, and rainfall conditions are individually studied to provide analysis that supports the climatic variability[16]. The changes are studied vividly and represented in the form of graphs prepared using mathematical and statistical calculations.

2. Study Area

The study area as selected in this thesis comprises the Kolkata Metropolitan Area of West Bengal, India. KMA, or in other words, the Calcutta Metropolitan Area, also sometimes referred to as Greater Kolkata, is the urban agglomeration of Kolkata, West Bengal. The geographical location extends from 22° 21' 36" N to 23° 4' 48" N latitude to 88° 23' 24" E to 88° 25' 12" E longitude. (Figure 1). The metropolitan region sums up to an area cover of 1886.67 km² and is administered by the Kolkata Metropolitan Development Authority (KMDA) (West Bengal Gazette, 2011). The major selected cities for the thesis are Kolkata, Howrah, Uluberia, Chandannagar, Chunchura, Shrirampur, Kalyani, Barasat, Barrackpur, and Baruipur.

Located approximately lined north-south along the eastern flank of the Hugli River, KMA extends in the lower Ganges Delta of India's eastern fragment. The annual mean temperature here is more or less 27°C. The mean monthly temperature ranges between 19°C to 30°C. Monsoon ascends in early June and stays till early October. During monsoons, rainfall received is 350mm at most in July to be more likely. Out of the annual amount of 1640-2500mm, the seasonal monsoon figures to 1248 mm. The period of October and November is the transitional period between the rains and the winter. The Bay of Bengal is marked to be notorious for its constant cyclonic activities influencing and affecting the region in various ways[16]. However, winter decides to be a much pleasant and peaceful time in Kolkata Metropolitan cities (IMD, Kolkata) [17][18].

3. Materials and Methods

The paper includes an analysis of the responsible factors that affect climatic variations in the KMA region. These factors include natural as well as human-made influences. The workflow of the paper is presented as in the flow chart (Figure 2). The flow chart shows in detail the approach, to begin with, the various components that form the framework of the concerned analysis.
3.1. Data Acquisition and Processing

LST, NDVI, and NDBI Maps are prepared using Landsat 5, 7, and 8 images for March to early May. These images are geometrically corrected before. In the Landsat 7 image, there were scanline errors. Scanline error generates as the spacecraft travel. Landsat 7 (along-track) satellite encounters such errors in its flight-line. These are corrected using the 'Landsat Toolbox' available in the ArcMap 10.3.1...
software. Images for 35 years (1989-2019) are downloaded to carry out the study. Satellite data analysis was done in the ArcMap 10.3.1 software. Each band of these satellite images was used separately to calculate the various land surface, vegetation, and built-up area change identifying indices over the study period.

The Landsat 5 TM and 7 ETM+ sensor uses two thermal bands (Bands 6 for Landsat 5, Bands 6.1 and 6.2 for Landsat 7 images), and Landsat 8 OLI/TIRS sensor uses two thermal bands (Bands 10 and 11) to measure the land surface temperature of any area. Landsat 5 and 7 involve similar formulas and steps of calculations behind the image processing. In the case of NDVI determination, Landsat 5 and 7 uses band 4 (NIR) and band 5 (Red), whereas Landsat 8 uses band 5 (NIR) and band 6 (Red). For NDBI calculations, Landsat 5 and 7 use band 5 (SWIR) and band 4 (NIR), while Landsat 8 uses band 6 (SWIR-1) and band 5 (NIR).

3.2. Calculation of LST, NDVI, and NDBI
The LST, NDVI, and NDBI are important indices used to understand the changes in the surface temperature in an area. The materials used and calculations involved here are discussed in details below in equation(1):

3.2.1. Retrieval of LST from Landsat 5 and 7 images (Irish, 2000)[7]:
- Conversion of Digital Number (D.N.) to Spectral Radiance values
  \[ L_\lambda = \frac{(Q_{\text{CAL MAX}} - Q_{\text{CAL MIN}}) + (Q_{\text{CAL MAX}} - Q_{\text{CAL MIN}})}{L_{\text{MAX}} - L_{\text{MIN}}}} \] (1)
  where
  \[ L_\lambda = \text{spectral radiance at the sensor's aperture (watts/ (m}^2 \times \text{ster} \times \mu\text{m})} \]
  \[ L_{\text{MAX}} = \text{spectral radiance scaled to } Q_{\text{CAL MAX}} \text{ (watts/(square. meters))} \]
  \[ Q_{\text{CAL MIN}} = \text{minimum quantized calibrated pixel value (corresponding to } L_{\text{MIN}} \text{) in digital number.} \]
  \[ Q_{\text{CAL MAX}} = \text{the maximum quantized calibrated pixel value (corresponding to } L_{\text{MAX}} \text{) in D.N.} \]
- Conversion of the Spectral Radiance into Brightness Temperature (T) in Kelvin
  \[ T = \frac{K_2}{\ln \left( \frac{K_1}{L_\lambda} \right)} \] (2)
  where,
  \[ T = \text{Effective at-satellite temperature in Kelvin} \]
  \[ K_2 = \text{Calibration constant 2 from metadata} \]
  \[ K_1 = \text{Calibration constant 1 from metadata} \]
  \[ L_\lambda = \text{Spectral radiance in watts/ (sq. m)} \]
- Conversion from temperature in Kelvin to Celsius
  \[ C = T - 273.15 \] (3)
  where, \[ T = \text{Temperature in Kelvin from Landsat 8 images} \]
- Conversion of Digital Number to Spectral Radiance
  \[ L_\lambda = M_x \ast Q_{\text{CAL}} + A_x \] (4)
  where,
  \[ L_\lambda = \text{Top Of Atmosphere (TOA) spectral radiance in (watts/ (meter squared * ster * } \mu\text{m)})} \]
  \[ M_x = \text{Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)} \]
  \[ A_x = \text{Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)} \]
  \[ Q_{\text{CAL}} = \text{Quantized and calibrated standard product pixel values (DN)} \]
- Conversion of the Spectral Radiance into Brightness Temperature (T) in Kelvin: using a similar process as used in Landsat 5 and 7 images (Step 2, equation 2)
- Conversion from the temperature in Kelvin to Celsius: using a similar process as used in Landsat 7 (Step 3, equation 3)
- Conversion of Satellite Brightness Temperature into LST
  \[ T_S = \frac{T}{\left[ 1 + \lambda (T/\rho) \ln \phi \right]} \] (5)
where, \( T_s \) = LST in Celsius (°C)
\( T \) = Brightness Temperature(°C) at sensor
\( \lambda \) = emitted radiance wavelength (\( \lambda = 11.5 \) μm)
\( \rho = h^*c/s \) (1.438 * 10^{-3} m K) where, \( h \) = Planck’s constant (6.626 * 10^{-34} Js), \( s \) = Boltzmann constant (1.38 * 10^{-23} J/K), and \( c \) = velocity of light (2.998 * 10^{8} m/s)
\( \varepsilon_{\lambda} \) = emissivity.

While in the conversion of satellite brightness temperature into land surface temperature, emissivity calculation has been done from NDVI by using:

\[ \varepsilon_{\lambda} = 0.004 \times \text{PVI} + 0.986 \]

(6)

where \( \varepsilon_{\lambda} \) = emissivity calculated from the Proportional Vegetation Index(PVI) by using:

\[ \text{PVI} = \left( \frac{\text{NDVI} - \text{NDVI}_{\text{min}}}{\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}}} \right)^2 \]

(7)

where the NDVI_{min} and NDVI_{max} are the approach to analyses soil and vegetation pixels.

3.2.2. NDVI calculation from Landsat 7 and Landsat 8 satellite images:

\[ \text{NDVI}_{\text{Band 7}} = \frac{\text{NIR (Band 4)} - \text{Red (Band 3)}}{\text{NIR (Band 4)} + \text{Red (Band 3)}} \]

(8)

\[ \text{NDVI}_{\text{Band 8}} = \frac{\text{NIR (Band 5)} - \text{Red (Band 4)}}{\text{NIR (Band 5)} + \text{Red (Band 4)}} \]

(9)

3.2.3. NDBI calculation from Landsat 7 and Landsat 8 satellite images:

\[ \text{NDBI} = \frac{\text{SWIR (Band 5)} - \text{NIR (Band 4)}}{\text{SWIR (Band 5)} + \text{NIR (Band 4)}} \]

(10)

\[ \text{NDBI} = \frac{\text{SWIR-1 (Band 6)} - \text{NIR (Band 5)}}{\text{SWIR-1 (Band 6)} + \text{NIR (Band 5)}} \]

(11)

3.3. Meteorological Parameters
The meteorological changes significantly affect the climate of an area most vividly and directly. Isohyet maps are prepared in the ArcMap software. The thematic maps for disturbed rainfall patterns are prepared using statistical analysis tools in the Arc Toolbox of the Arc Map 10.1.1 software. Using the annual rainfall data from 1985 to 2019, the variability and irregularity in the rainfall pattern are studied. The change in the rainfall quantities and atmospheric temperature (2 meters above the ground) are studied by preparing graphs over 35 years duration to carry out the climate study of the KMA region.

3.4. Air Quality Index Parameters
The changes in atmospheric components and matters (PM 2.5, PM 10), \( \text{SO}_2 \), \( \text{NO}_2 \) are studied to see their effect on climate change. These are among the four air quality index components. The other components include ozone(\( \text{O}_3 \)) and carbon monoxide (C.O.) levels in the air. The measurements of all the six elements combined in the air give the AQI (Air Quality Index) of any area. The four components analyzed here are among the integrant that affects the area largely.

4. Results and Discussions

4.1. Analyzing the rise in LST affecting the climate of KMA
The changes observed (Figure 3) explain how the surface features have changed over the years, affecting the temperature conditions, which affect the climate. The maps show that the surface temperature has shown an eventual rise and fall over the years. The built-up areas reflect more SWIR than NIR bands, and thus the thermal reflectance is higher (represented in red to yellow in maps) and marks evidence of rising surface temperature.

The period from 1985-1990 saw a rising population due to the population's movement in the major cities of the KMA region. This resulted in agglomeration in two major municipalities- Kolkata MC and Howrah MC, where 60% of the region got concentrated (Kumar et al., 2018, pp. 213-214)[8]. In
1989, the mean LST temperature was 21.26°C. It rose to 32.09°C in most areas, especially in Kolkata, Howrah, and Kalyani, by 2006. This constant rise continued until 2014. During 2014-2015, under the Mahatma Gandhi National Rural Employment Guarantee Act 2005, largescale roadside plantations and taking care of cropping and cultivations were exercised in West Bengal (Govt. Of West Bengal, 'MGNREGA,' 2018). From 2016-2017, a new scheme called "SabujtreePrakalpa" was taken up where for each newborn child, the family was given a sapling (WBFD, 'Sabujtree,' 2019)[18]. The surface temperatures saw a steady reduction. By 2019, there was a slight fall in LST mean temperatures (31.52°C). Therefore, the maps of 2015 and 2019 show a steady decrease in their LST values showing growth in the culture of urban plantation activities. But still, the surface temperature shows a rising trend, marking the future trends as the worst effects on climate.

This is more strengthened when the satellite data information and calculated values are studied more keenly. The LST graph's constant rise shows how the surface temperature has continued to follow a rising trend. The surface did not change as the plantation activities were carried out along the urban roads and houses, resulting in a continuous rise in the land surface temperature graph. Table 1 and Figure 4 show the data values and changes more precisely.

![Figure 3: Land Surface Temperature (LST) comparison maps of the KMA region](image)

**Table 1:** Charting the land surface temperature information shown from 1989 to 1999

| Years | Maximum (°C) | Minimum (°C) | Range (°C) | Mean (°C) | Years | Maximum (°C) | Minimum (°C) | Range (°C) | Mean (°C) |
|-------|--------------|--------------|------------|-----------|-------|--------------|--------------|------------|-----------|
| 1989  | 35.65        | 20.62        | 15.03      | 26.21     | 2009  | 40.85        | 19.30        | 21.55      | 30.11     |
| 1992  | 42.96        | 24.11        | 18.85      | 29.71     | 2010  | 36.62        | 15           | 21.62      | 29.85     |
| 1995  | 34.06        | 21.5         | 12.56      | 26.48     | 2011  | 39.12        | 20.38        | 20.38      | 30.00     |
| 2000  | 40.00        | 21.35        | 18.65      | 29.00     | 2012  | 42.70        | 18.40        | 18.40      | 31.84     |
| 2001  | 42.00        | 22.50        | 19.50      | 30.00     | 2013  | 43.07        | 23.77        | 23.77      | 31.79     |
| 2002  | 40.20        | 20.40        | 19.80      | 30.27     | 2014  | 36.00        | 14.20        | 14.20      | 31.50     |
| 2003  | 42.37        | 22.69        | 19.68      | 30.90     | 2015  | 34.02        | 12.62        | 12.62      | 31.69     |
| 2004  | 43.96        | 25.36        | 18.60      | 31.24     | 2016  | 41.32        | 15.09        | 15.09      | 32.51     |
| 2005  | 46.02        | 23.26        | 22.76      | 32.09     | 2017  | 39.27        | 21.73        | 21.73      | 31.85     |
| 2006  | 46.02        | 23.26        | 22.76      | 32.09     | 2018  | 42.95        | 21.20        | 21.20      | 31.87     |
| 2007  | 40.87        | 23.71        | 17.16      | 30.87     | 2019  | 38.08        | 25.51        | 12.57      | 31.52     |
| 2008  | 40.49        | 19.85        | 20.64      | 30.29     |
Note: All the values presented in the table are collected from the satellite image information after calculating LST.

Figure 4: The LST Graph showing the rising trend of the surface temperature

4.2. Analyzing the effects of urbanization and concretization through the comparative analysis of NDVI and NDBI:
The vegetation index (NDVI) shows a negative change (in Table 2) from the beginning of 1985 until 2014. During this time, there has been a steady rise in the built-up area (NDBI). The two indexes are indirectly related, and therefore the human-made impacts and driving forces resulted in the reduction of greenery all over the region. The plantation activities started from 2014 onwards, as discussed earlier. The rising built-up areas now got covered with plant and tree covers. Thus in Figure 5, there is a steep rise and fall in NDVI and NDBI, respectively.

Table 2. The NDVI and NDBI values used in drawing the comparison graphs

| Years | NDVI Mean Value | NDBI Mean Value | Years | NDVI Mean Value | NDBI Mean Value |
|-------|-----------------|-----------------|-------|-----------------|-----------------|
| 1989  | 0.1319          | -0.0006         | 2009  | -0.2094         | 0.1426          |
| 1992  | 0.1892          | -0.0615         | 2010  | -0.1241         | 0.1279          |
| 1995  | 0.1625          | -0.0605         | 2011  | -0.0436         | 0.0872          |
| 2000  | -0.1063         | 0.1165          | 2012  | -0.0597         | 0.1012          |
| 2001  | -0.0749         | 0.1126          | 2013  | -0.1185         | 0.1358          |
| 2002  | -0.1755         | 0.1426          | 2014  | 0.2380          | -0.1074         |
| 2003  | -0.1345         | 0.1027          | 2015  | 0.1656          | -0.0870         |
| 2004  | -0.0822         | 0.1101          | 2016  | 0.2075          | -0.1004         |
| 2005  | -0.0605         | 0.1144          | 2017  | 0.2339          | -0.1123         |
| 2006  | -0.0605         | 0.1144          | 2018  | 0.0956          | -0.0698         |
| 2007  | -0.0674         | 0.1086          | 2019  | 0.0375          | -0.0126         |
| 2008  | -0.0648         | 0.1040          |

Note: All the values presented in the table are collected from the satellite image information after calculating NDBI and NDVI values.
Figure 5: The comparison graphs studying change in NDVI and NDBI

4.3. Analysing the disturbed rainfall pattern in the region

Rainfall in India is very uncertain and is characterized by constant disturbances and irregularities. In 1995, the monsoons arrived with a difference. This was the year when the KMA region witnessed urban floods of a devastating kind. Between 1905 and 1980, the monsoon’s pattern was marked by monsoon’s outbreak on 26th May in 1937, and the delay was encountered to be on 25th June in 1976 (Ghosh, n.d., p. 3)[5]. This has, over time, shifted during the 1980-2009 period. It almost became a trend over the years.

Figure 6: Disturbed rainfall pattern in the KMA

Delayed monsoon ramifies extreme events such as a condition of flooding due to unexpected rain surges, in other scenarios causes widespread crop failure in West Bengal and the KMA suburbs. Figure 6 clearly shows the rain variations with the help of isoclines that marks the areas of the same rainfall. It can be analyzed that the maps show great variations in the amount of rainfall received by
the area over the years. 1985 receives very less rainfall amount which is less than 960.03mm, while it rises to more than 2000mm annual rainfall eventually. Comparing 2003 and 2013 maps, it is seen that there exists a reverse in the isoclines pattern. There remains no parity in the distribution of rainfall over the years as well.

4.4. Analyzing the change in the quantity of rainfall in the KMA region

The major cities as selected over the six districts have received the same quantity of rain. However, following the annual rainfall distribution graph (Figure 7), there is a fall in the rainfall quantity received in the areas. From 1985 to 1990, there remained a low annual rainfall range ranging between 900 to 1500mm. This increased later from 1991 to 1998. The period from 2003 to 2008 received rainfall ranging from 2000 to 2500 mm rainfall. This reduced to a range from 1000 to 1500mm rainfall annually during 2017, 2018, and 2019. This essentially shows the average fall in the quantity of rainfall affecting the region's climate, resulting in sudden outbursts of monsoon with no consistency and even dry spells that affect the residents' livelihood and lives.

4.5. Analyzing the change in the temperature (2 meters above ground) in the KMA region

The average annual temperature (Figure 8) shows a rise in yearly temperatures. From 1985 to 2003, the temperatures varied from 25°C to 26.5°C on average, with slight falls in some years in between. In recent years, from 2016 to 2019 reaches more than 26.5°C to 27°C. This minute change, although sounding insignificant, creates a huge impact on the climate of the region. The monthly temperatures have also risen. At the beginning of the 35 year time, the highest temperature reached not more than 29°C to 30°C. However, later, these values increased to 35°C and sometimes reach up to 40°C in cities like Kolkata, Haora, and Chandannagar, where pollution rates are also very high due to the pressure transports and industrial pollutants. SubhroNiyogi talks about a rise of 4°C in the temperature over the 20 years reaching up to 44°C of highest atmospheric temperature accounted and eight °C in 50 years reaching a scorching 48°C of temperature which is the same as the Sahara Desert in The Times of India article (Niyogi, 2012, para. 4)[11].An article by Skymet Weather states that the neighboring states like Odisha and Bihar are also steaming with heatwaves, making the temperature rise more evident in these areas ('Here's Why Kolkata Is As Hot As An Oven Right Now,' 2016, para. 5)[16].

Figure 7: Change in rainfall quantity over 35 years.
4.6. Analyzing the changes in particulate matters and atmospheric components

The region reports a major part of it to be exposed to various types of pollution. The atmospheric compositions are thus, largely influenced by the changes in the various air constituents. According to Chapter 6 of the economic Review’ Article, the industrial production overall in West Bengal rose from 115.7 (2007-08) to 147.7 (2011-12) [Economic Review, 2012-2013].

Table 3: Charting four out of six AQI levels over the years in the KMA study region

| Indices | 2005  | 2010  | 2015  | 2019  |
|---------|-------|-------|-------|-------|
| PM 2.5  | 32.60 | 41.90 | 44.26 | 45.90 |
| PM 10   | 57.33 | 81.60 | 100.00| 105.50|
| SO₂     | 6.25  | 6.70  | 6.90  | 7.35  |
| NO₂     | 35.00 | 36.50 | 43.90 | 54.90 |

From Table 3, it is evident that the particulate matter 10 shows the maximum rise over the years. These are particles that are large in diameters. These, in combination with particulate matter 2.5, are responsible for the pollution of air. Both SO₂ and NO₂ account for the creation of secondary pollutants in the air, such as aerosols and particulate matter. The sulfur with the water in the atmosphere can cause acid rain, which causes deforestation and harms plant lives, which disrupts any area's climatic balance. Kolkata Metropolitan area faces the maximum pollution in SPMs (suspended particulate matter) and other polluting agents. This effect of pollution is immense on the climatic constraints faced in the region.

5. Conclusion

The climatic disorders in the KMA region are not a recent problem. The study of it, therefore, becomes of vital necessity. From the land surface temperature analysis, the constant urbanization and urban agglomerations develop a state of the rising trend in the land surface temperature of the area. The vegetation and built-up area changes moreover support these facts. The SAPCC was prepared in West Bengal in 2012, since which the climatic conditions showed slight progress in little limited spheres through the plantation of trees and plants all over the cities and the study area expanse. The atmospheric temperature, in general, shows a rising trend. This has its effect on the change of climate.
Over the 35 years of analysis, the temperature values initially showed a slow rise. However, this temperature rise is higher, reaching scorching 44°C and more during the summers.

Rainfall is reduced in recent periods as a result of the decrease in South West Monsoon Winds bearing moisture-laden clouds by the effect of the temperature difference between land and ocean "due to rapid warming in the Indian Ocean and relatively subdued warming over the subcontinent." (Roxy et al., 2015)[14]. Nevertheless, due to the rapid decline in the East Kolkata Wetlands, Kolkata and its surrounding cities are now more vulnerable to the effects of floods, from sudden heavy rain or any cyclonic events (Dhara, 2019)[2]. Based on the recent rainfall patterns, it can be said that KMA is more vulnerable than ever in terms of urban flooding and is prone to floods.

The atmospheric conditions state that greenhouse gas concentrations lead to a direct climate change over the 35 years. The present air quality of Kolkata as of 2018 suggests a condition even worse than Delhi, the most polluted state in India. The region also includes industries. Over the 35 years study period, industries have been rising to a large extent. This results in climate change hugely. The various industrial laws are not maintained, resulting in automatic, consistent poor air, water, and land quality.

Quiet studies efficiently show that the Kolkata Metropolitan area is at vital risk from a climatic perspective. At the regional levels, work towards environmental issues has seen some progress in reducing carbon emissions in the environment. However, much more requires to be done at all levels.

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