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ARTICLE

Monitoring and Quantification of Carbon Dioxide Emissions and Impact of Sea Surface Temperature on Marine Ecosystems as Climate Change Indicators in the Niger Delta Using Geospatial Technology

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ABSTRACT

The Niger Delta marine environment has experienced a series of environmental disasters since the inception of oil and gas exploration, which can be attributed to climate change. Carbon dioxide (CO_2) emissions and sea surface temperature (T) ties associated with burning fossil fuels, such as gas flaring, vehicular traffic, and marine vessel movement along the sea, are increasing. Using data extracted from the NASA Giovanni satellite's Atmospheric Infrared Sounder (AIRS) and Moderate Resolution Imaging Spectroradiometer (MODIS), this study mapped the carbon footprint and T along the coastline into the deep sea from 2003 to 2011, using ArcGIS software. The spatial distribution of CO_2 and T concentrations determined by the inverse distance weighting (IDW) method reveals variations in the study area. The results show an increase in the quantity of the mean tropospheric CO_2 from July 2003 to December 2011, from 374.5129 ppm to 390.7831 ppm annual CO_2 emissions, which also reflects a continuous increase. The average Monthly sea surface temperature had a general increasing trend from 25.79 °C in July 2003 to 27.8 °C in December, with the Pearson correlation coefficient between CO_2 and T indicating 50% strongly positive, 20% strongly negative, 20% weakly positive, and 10% weakly negative. CO_2 levels, like temperature, follow a seasonal cycle, with a decrease during the wet season due to precipitation dissolving and plant uptake during the growing season, and then a rise during the dry season. Carbon capture and storage technologies must be implemented to benefit the marine ecosystem and human well-being.

Keywords: Carbon footprint; NASA Giovanni; Climate change; Coastline; Carbon capture and storage

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1. Introduction

The greatest issue plaguing the 21st century on a global scale is climate change. An increase in the emission of greenhouse gas (GHG) such as methane, nitrous oxide, carbon dioxide (CO_2), and fluorinated gases [1] is the causal effect to which carbon dioxide is the greatest contributor. Though CO_2 is a naturally occurring GHG with a low global warming potential (GWP) of one [2], it is the major culprit due to its longer atmospheric lifespan of 300-1000 years [2-4]. The concentration of carbon dioxide in the atmosphere surpasses all other GHG as a result of human activities, which can be attributed to the increasing population and the consequent need for energy and change in land-use cover [5,6]. CO_2 released from burning fossil fuels can easily be detected as it has a peculiar signature wherein the amount of heavy carbon -13 isotopes in the atmosphere declines, and the ratio of oxygen to nitrogen is reduced [3,7]. This can be related to the increase in global surface temperature over the years as [8] indicates no net increase from solar input [9]. Projected a 130% increase in CO_2 emissions by 2050. The increased human-driven levels of CO_2 emission along the coastline from activities, such as onshore and offshore energy drilling, marine transportation of goods, and resource extraction have resulted in higher atmospheric temperature and consequently, heavier precipitation. The coastal areas are more vulnerable to the dangers of climate change which manifest as flooding, changes in shoreline, higher water table, saltwater intrusion in the aquifer, and oceans acidification [10]. The carbon cycle through which atmospheric carbon dioxide concentrations are regulated involves the carbon sink which includes; forests, ocean, and soil. All these are however under threat from human activities like deforestation, ocean pollution, and oil spill, limiting their ability to absorb free tropospheric CO_2. In recent times there have been frequent flooding episodes, outbreaks of water-borne diseases, and cases of massive dead fish occurring in the coastal states of Nigeria. These necessitate the need for monitoring and mapping our carbon footprint. Remote sensing as a cost-effective method allows consistent, precise, and comprehensive data collection of GHG at a regional and global scale from the Atmospheric Infrared Sounder (AIRS) on the Earth Observing System (EOS) Aqua satellite [11].

2. Study area

The study location is along the Niger Delta coastline. Spanning about 800 km, it cuts across Lagos, Ondo, Delta, Bayelsa, Rivers, and Akwa Ibom states. With a 14% surge in population to over 40 million residents according to the Niger Delta Region survey by the National Population Commission and an estimated land mass of 70,000 km^2, it is densely populated. The study area is located between longitudes 0040 00’0” and 0080 00’0” east of the first meridian and latitudes 040 00’0” and 060 00’0” north of the equator. There are 2 main seasons all year round; a lengthy rainy season which commences from March to October with precipitation of about 4000 mm [12] and the dry season from November to February. The peak of both wet and dry seasons are July and December respectively. This location was chosen because it is highly susceptible to CO_2 emission owing to the fact that the 6 major seaports and all the gas flaring points in the country are distributed within this region (**Figure 1**).

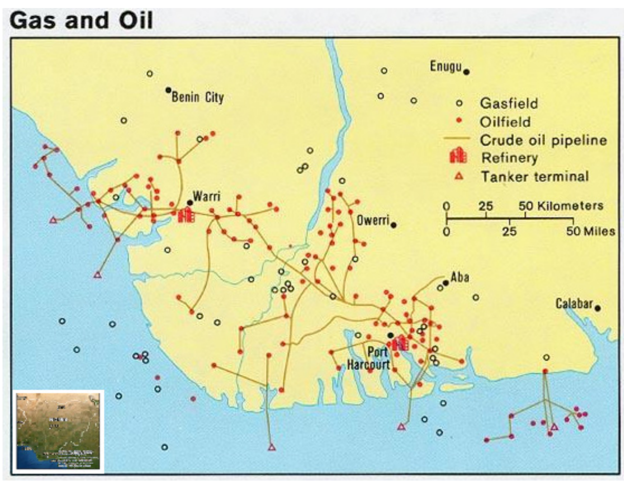


Figure 1. Niger Delta coastal area map with oil and gas fields (about 606 oilfields – 355 onshore, 251 offshore, and 178 gas flare points). Nigerian Oil and Gas Corporation (1997) and Anifowose et al. [13]

3. Materials and method

3.1 Data collection

The remote sensing data utilized in this study are the mean carbon dioxide emissions in ppm acquired from the Atmosphere Infrared Sounder on National Aeronautics and Space Administration (NASA) Giovanni Aqua Satellite and Sea Surface Temperature at 11 microns using Moderate Resolution Imaging Spectroradiometer (MODIS) R2019.0 (https://giovanni.gsfc.nasa.gov/giovanni/) with an accuracy of 20 × 2.50 for selected geophysical parameters, and the map of the Niger Delta coastal area highlighting the oil and gas fields and gas flare points from Nigerian Oil and Gas Corporation (1997) and Anifowose et al. [13]

3.2 Data processing

The monthly average CO_2 and sea surface temperature data were extracted from Giovanni and processed using ArcGIS software with the spatial interpolation method, Inverse Distance Weighting (IDW) from 42 stations from July 2003 to December 2011.

The ArcGIS software was launched and the acquired data prepared in Microsoft Excel sheets and saved in CSV format was imported. The area of interest was delineated in Google earth, saved as kml file, and imported into the ArcGIS software retaining the Projected Coordinate System using WGS UTM 1984 Zone N32 which covers the coastal region in Nigeria, and then converting it to a shapefile on ArcGIS. Google Earth image Subsetting was done using clipping tools in the Arc Toolbox. The editing tool was used to digitize the shoreline boundary creating the shapefile of the area of interest.

Step1: CO_2 processing: Arc Toolbox → Spatial Analyst Tool → Interpolation → Click on the Inverse Distance Weighting (IDW) → Import the CSV File Containing the CO_2 Result of the Area Under Review for July, 2003 → Click on Environment → Processing Extend Select the Shapefile of the Study Area →Click on Spatial Analysis →Click on the Mask and Select the Study Area → Ok. The final result was exported for further analysis. The same process was repeated in December 2003, 2005, 2007, 2009 and 2011. The same process was repeated for the sea surface temperature.

3.3 Inverse Distance Weighting (IDW) technique

Inverse distance weighting is a mathematical means of estimating an unknown value from nearby known values. Based on Toiler's law "everything is related to everything else but near things are more related than distant things", IDW uses the "weight" of the known value(s) which is a function of the inverse distance, to estimate the unknown value. Burrough and McDonnell [14] found that utilizing IDW within a squared distance yields reliable results. To estimate the CO_2 concentration across the marine environment, spatial interpolation of the CO_2 emission collected from 42 stations in the coastal environment for each sampling year is obtained and reclassified into five classes for the period under review. The Inverse Distance formula is given in equation 1:

$$x^* = \frac{w_1 x_1 + w_2 x_2 + w_3 x_3 + \ldots + w_n x_n}{w_1 + w_2 + w_3 + \ldots + w_n} \tag{1}$$

Where x* is the unknown value at a location to be estimated, w is the weight, x is the known point value, and n, is the total number of x.

The weight formula is given in equation 2 as:

$$wi = \frac{1}{d_{lx*}^{P}} \tag{2}$$

Where di is the distance from the known point, P a variable that stands for Power.

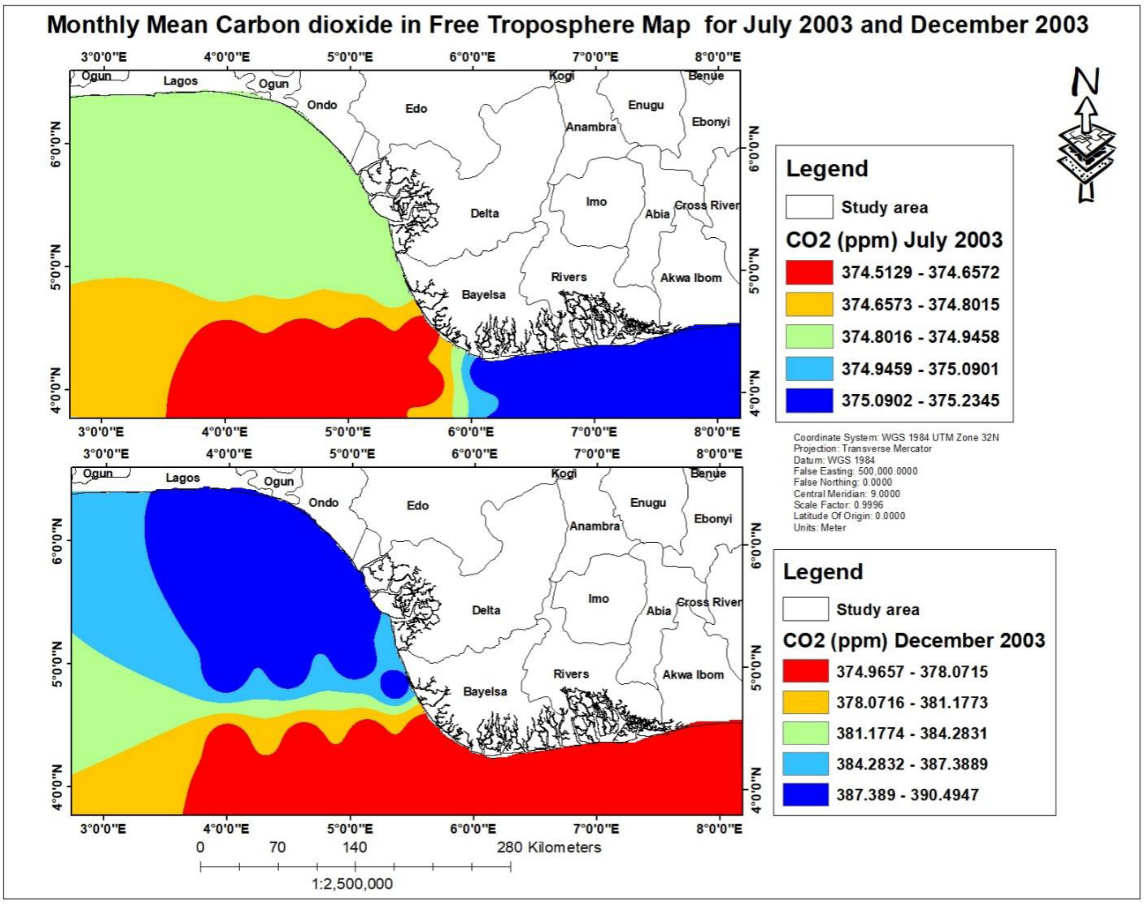
3.4 Data analysis

Step 2: Plotting histogram and line chart with the analyzed statistical data such as mean, minimum, maximum, and percentage of CO_2 using Microsoft excel to estimate the quantity of carbon dioxide emitted each year for both wet and dry seasons and identify the trend. Finally, the relationship between CO_2 and sea surface temperature was established using the Pearson correlation coefficient.

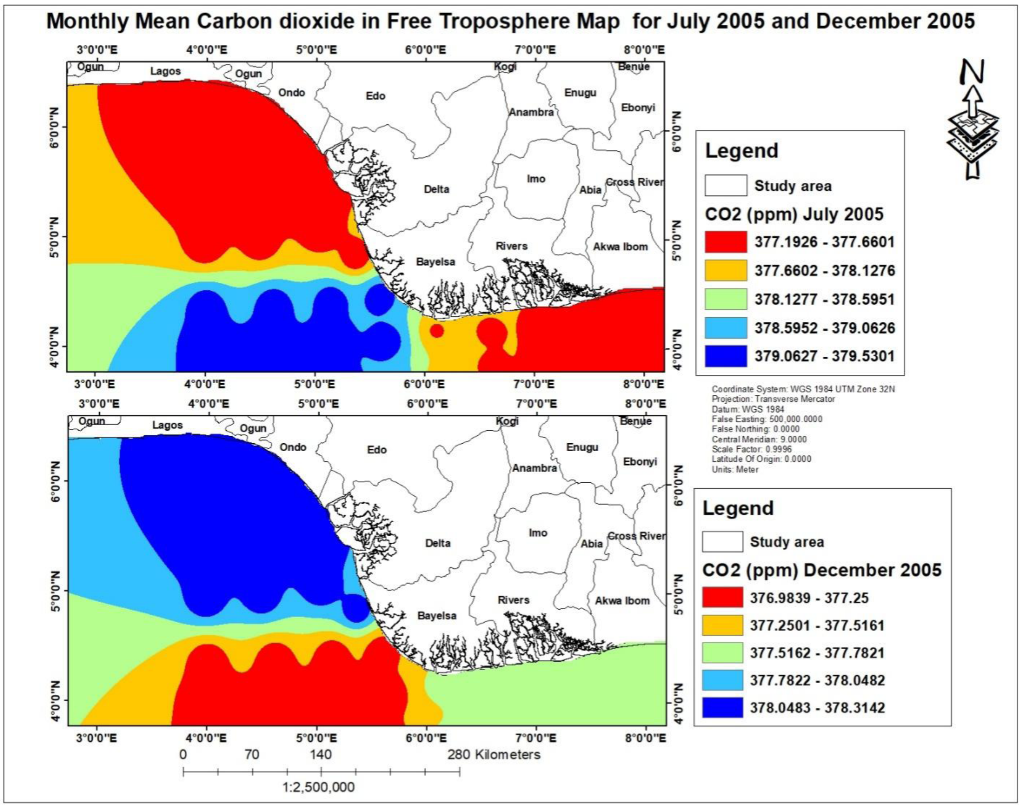
4. Results and discussion

4.1 Monitoring and quantifying carbon footprint

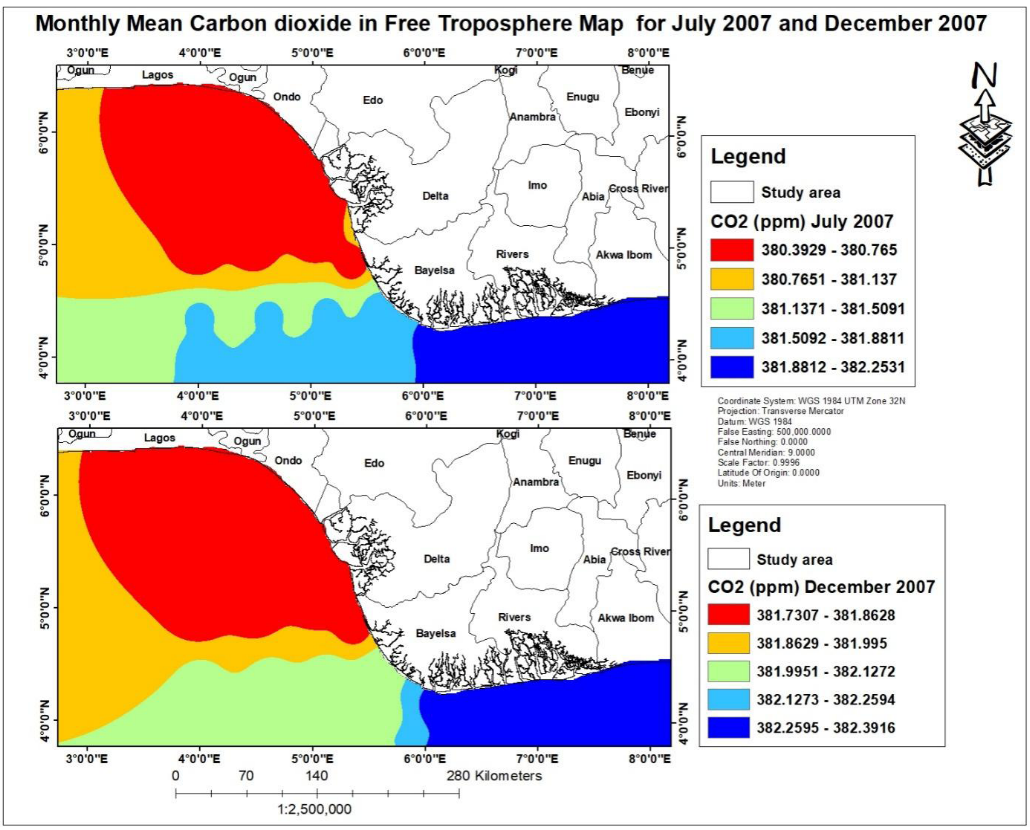
The monthly average CO_2 spatial distribution as seen in **Figures 2a to 2e** and their estimated CO_2 in **Table 1**, is constantly increasing annually for both July and December. This reflects an increase in the amount of carbon dioxide emitted from burning fossil fuels in electric power generating sets, marine vessels, and vehicles associated with the increasing populace. Deforestation for industrial and residential needs as well as agricultural degradation resulting from oil spills typical of the Niger Delta is another likely factor. Most important is the fact that the continuous exploration of fossil fuels and the increasing spate of illegal refineries in the region in response to the ever-increasing need for energy is not abating. December has the highest mean CO_2 concentrations increasing from 376.5186 ppm in 2003 to 390.5302 ppm in 2011. Whereas in July, the lowest values ranging from 374.8737 ppm in 2003 with a continuous increase to 390.1123 ppm are recorded. This contrast represents the different seasons and can be attributed to various factors. Firstly, July is the peak of the rainy season when carbon dioxide is dissolved into carbonic acid during precipitation. Also, December is characterized by hot, dry spells which are grounds for cooling thereby increasing electrical energy consumption and inadvertently increasing the carbon dioxide concentration in the atmosphere. Another vital factor is that the consumption of CO_2 gas by plants for photosynthesis is low in December, thus reducing the use of carbon dioxide.



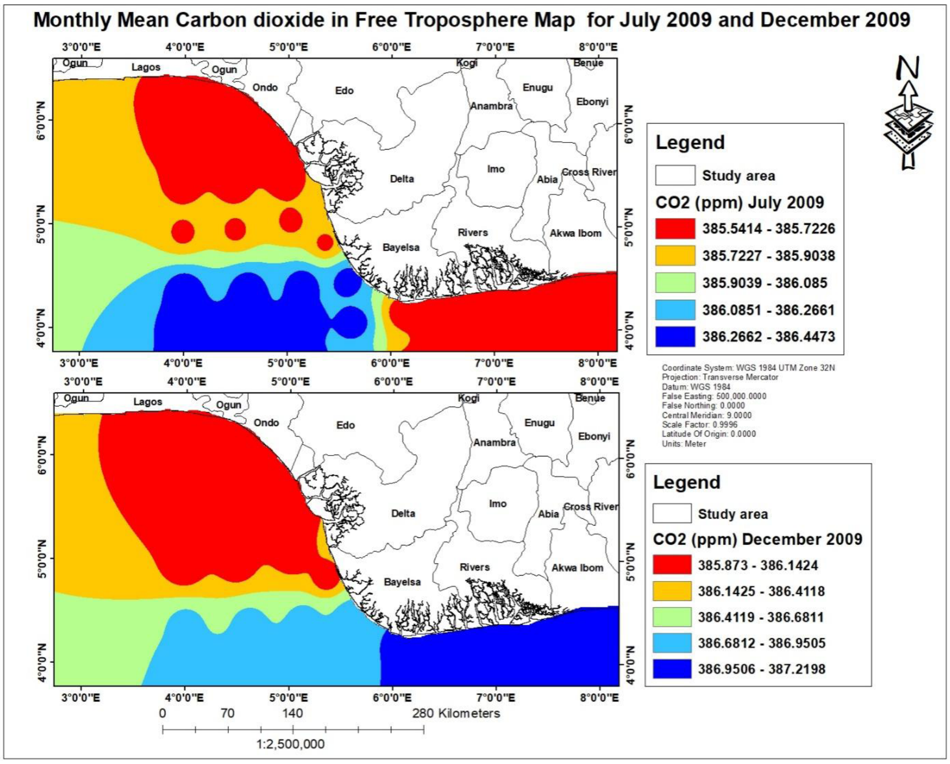
(a)


Monthly Mean Carbon dioxide in Free Troposphere Map for July 2005 and December 2005
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
6°0'0"N
5°0'0"N
4°0'0"N
Ogun
Lagos
Ondo
Edo
Kogi
Benue
Enugu
Ebonyi
Anambra
Delta
Imo
Abia
Cross River
Bayelsa
Rivers
Akwa Ibom
N
Legend
Study area
CO2 (ppm) July 2005
377.1926 - 377.6601
377.6602 - 378.1276
378.1277 - 378.5951
378.5952 - 379.0626
379.0627 - 379.5301
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
Legend
Study area
CO2 (ppm) December 2005
376.9839 - 377.25
377.2501 - 377.5161
377.5162 - 377.7821
377.7822 - 378.0482
378.0483 - 378.3142
0 70 140 280 Kilometers
1:2,500,000

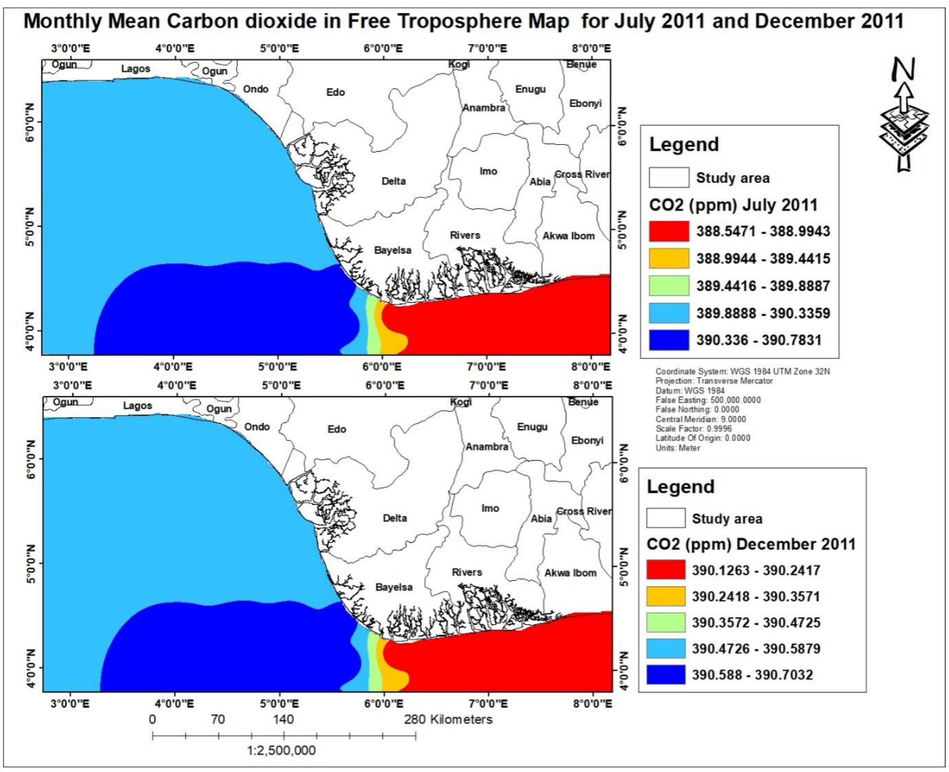
(b)


Monthly Mean Carbon dioxide in Free Troposphere Map for July 2007 and December 2007
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
6°0'0"N
5°0'0"N
4°0'0"N
Ogun
Lagos
Ondo
Edo
Kogi
Benue
Enugu
Ebonyi
Anambra
Delta
Imo
Abia
Cross River
Bayelsa
Rivers
Akwa Ibom
N
Legend
Study area
CO2 (ppm) July 2007
380.3929 - 380.765
380.7651 - 381.137
381.1371 - 381.5091
381.5092 - 381.8811
381.8812 - 382.2531
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
Legend
Study area
CO2 (ppm) December 2007
381.7307 - 381.8628
381.8629 - 381.995
381.9951 - 382.1272
382.1273 - 382.2594
382.2595 - 382.3916
0 70 140 280 Kilometers
1:2,500,000

(c)



(d)



(e)

Figure 2. Monthly mean Tropospheric CO_2 in the marine environment in Nigeria. (a)July 2003 and December 2003, (b) July 2005 and December 2005, (c) July 2007 and December 2007, (d) July 2009 and December 2009, (e) July 2011 and December 2011.

Table 1. Average tropospheric carbon dioxide for the wet and dry seasons from 2003-2011.

YEAR	July Minimum	July Maximum	Mean CO_2	December Minimum	December Maximum	Mean CO_2
2003	374.5129	375.2345	374.8737	374.9657	390.4947	382.73
2005	377.1926	379.5301	378.3614	376.9839	378.3142	377.649
2007	380.3929	382.2531	381.323	381.7307	382.3916	382.061
2009	385.5414	386.4473	385.9944	385.873	387.2198	386.546
2011	388.5471	390.7831	389.6651	390.1263	390.7032	390.415

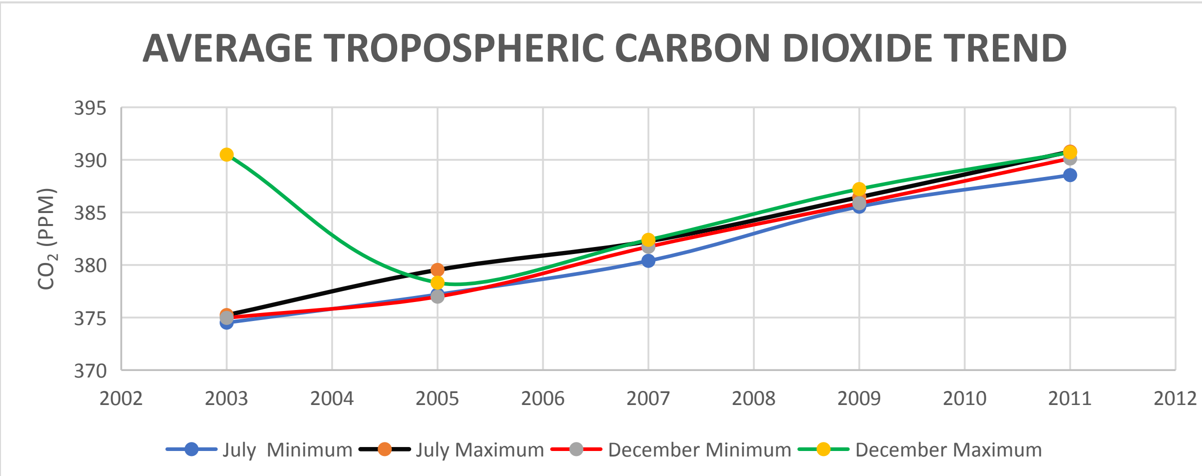


Figure 3. Minimum and Maximum carbon dioxide levels for July and December 2003–2011.

Ideally, higher CO_2 levels are expected in December and lower values in July. However, the trend in **Figure 3** shows a dip in the maximum amount of CO_2 emitted in December 2005 which gradually built up in 2007 corresponding to the drop in the average carbon dioxide level recorded for that month in **Table 1** and **Figures 2a to 2e**. This anomaly could result from wind action or low CO_2 absorption by carbon sink within that period.

Although the mean CO_2 values for December were only lower than that of July in the year 2005 see **Table 1**. The relative frequency of the maximum CO_2 levels between December and July in **Table 2** and **Figure 4** shows a plunge in 2005 from a 0.64% increase in 2003. This dip continually plunges till 2011 when it slowly builds up. In the case of the minimum values, **Table 3** and **Figure 5** indicate a 0.03% increase in December 2007 over July 2007 and a 0.05% increase in December 2011 over July of the same year. Whereas in 2003, 2005, and 2009, the percentage decreased in December and increased in July.

4.2 Comparative analysis of the spatial variation

Figure 2a to 2e a pictorial of the spatial distribution of the monthly carbon dioxide concentrations was derived using the Inverse Distance Weighting (IDW) method. It can be observed that the values show a spatial difference between two major parts of the region; the Northeast (NE) and the Southwest (SW), with variations in the spatial patterns for each season. The highest and lowest monthly average values of 390.5302 ppm in December 2011 and 374.8737 in July 2003 were both recorded in the NE. The significant dip from 380.7649 ppm in July 2007 to 371.8493 ppm in December of the same

Table 2. Percentage change in the maximum carbon dioxide levels for July and December 2003-2011.

YEAR	% July Maximum	% December Maximum	% +/- in Mean CO_2 December from July	Interpretation
2003	19.60	20.24	0.64	Higher in December than July
2005	19.83	19.61	-0.22	Higher in July than December
2007	19.97	19.82	-0.15	Higher in July than December
2009	20.19	20.07	-0.12	Higher in July than December
2011	20.41	20.25	-0.16	Higher in July than December

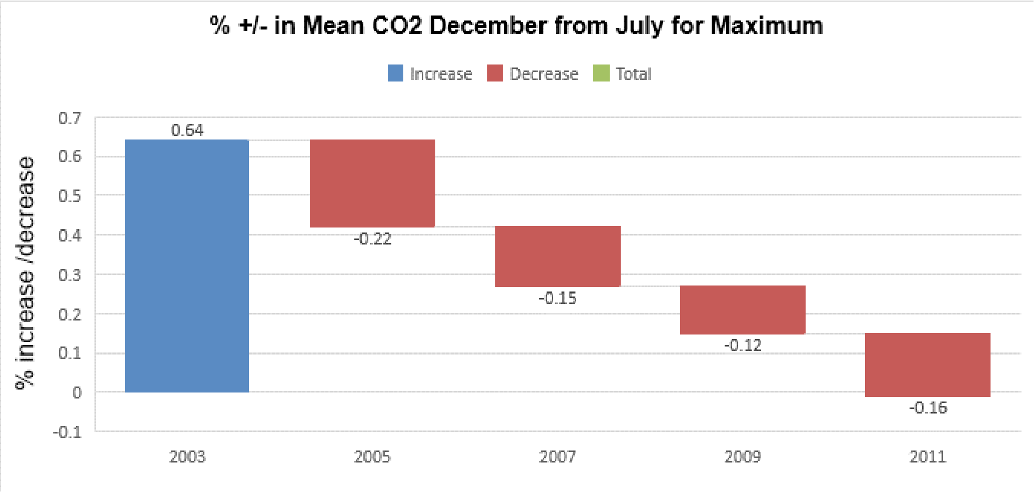


Figure 4. Percentage increase and decrease in the mean maximum carbon dioxide between December and July.

Table 3. Percentage change in the minimum carbon dioxide levels for July and December 2003-2011.

YEAR	% July Minimum	% December Minimum	% +/- in Mean CO_2 December from July	Interpretation
2003	19.65	19.64	-0.01	Higher in July than December
2005	19.79	19.74	-0.05	Higher in July than December
2007	19.96	19.99	0.03	Higher in December than July
2009	20.23	20.21	-0.02	Higher in July than December
2011	20.38	20.43	0.05	Higher in December than July

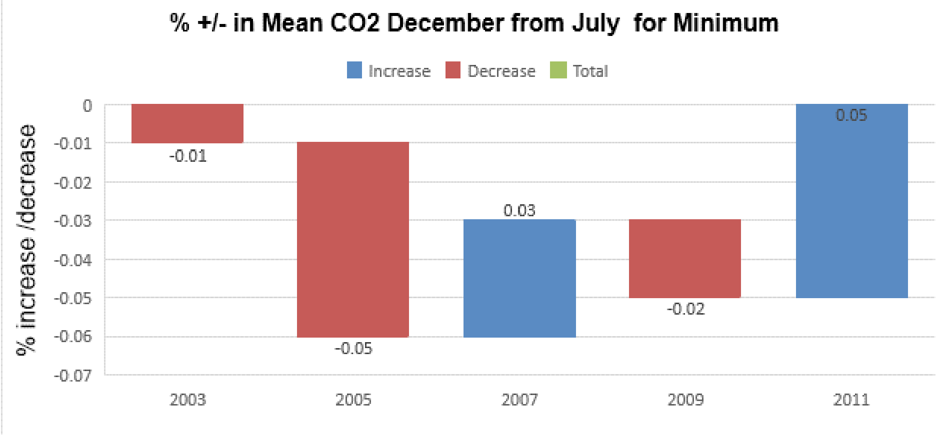


Figure 5. Percentage increase and decrease in the mean minimum carbon dioxide between December and July.

year not with standing, the NE experienced the most elevated concentrations over time with an overall mean CO_2 value of 3823.0911ppm. While the SW with fairly consistent increasing CO_2 values and a negligible drop in rates between July and December 2005 recorded 3823.0596ppm. This is a function of the population, the level of industrialization, urban expansion, and the number of gas flaring points.

The Spatio-temporal carbon dioxide values, for July in **Table 4** and **Figure 6** show that in 2003 and 2007, the NE was lower than the SW by 0.01%. In 2005 and 2009, the percentage of CO_2 across the NE and SW was the same, whereas in 2011, the NE is 0.07% higher than the SW. As a result, the South West emitted more CO_2 than the North East. Factors that could influence CO_2 in the marine environment during the wet season include rainfall and temperature differences, gas flaring activities, marine vessels, and illegal oil bunkering.

For the months of December as shown in **Table 5** and **Figure 7**, in 2003, 2005, and 2011, the NE surpassed the SW by 0.57%, 0.02%, and 0.02% respectively. While in 2007 and 2009, the percentage of CO_2 in the NE decreased by 0.55%, and 0.05%, respectively, implying that CO_2 was higher in the South West than in the North East. This could be a function of temperature and rainfall differences, gas flaring activities, marine vessels, urban expansion, and the level of industrialization.

Table 4. Percentage change in carbon dioxide levels for July 2003-2011 in the NE and SW.

Period	% Northeast Mean CO_2	% Southwest Mean CO_2	% +/- in Mean CO_2 North East from South west	Interpretation
2003 July	19.64	19.65	-0.01	Higher in South West than North East
2005 July	19.78	19.78	0.00	Equal
2007 July	19.94	20.01	-0.07	Higher in South West than North East
2009 July	20.20	20.20	0.00	Equal
2011 July	20.43	20.36	0.07	Higher in North East than South West

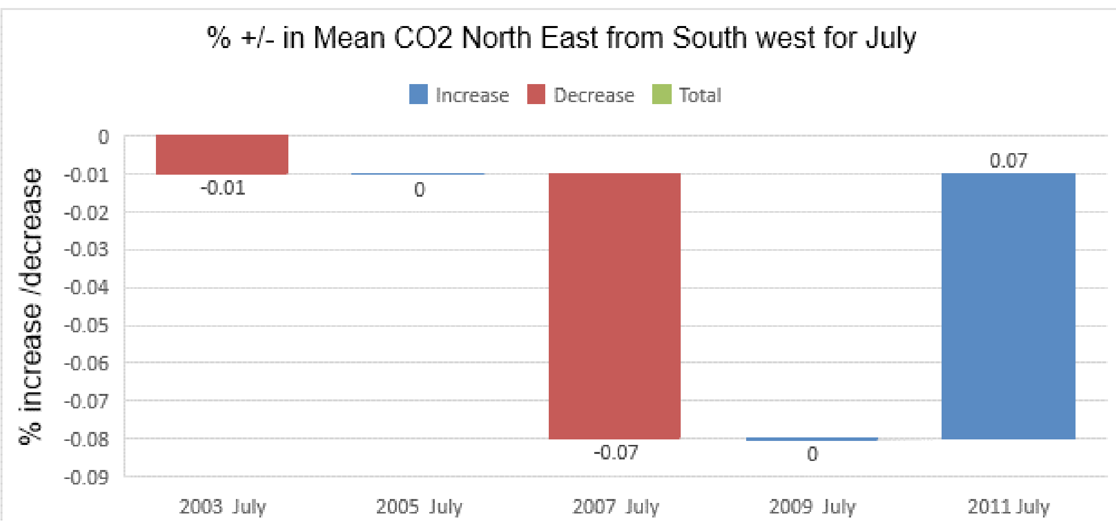


Figure 6. Percentage increase/decrease in Mean CO_2 NE from SW for July.

Table 5. Percentage change in carbon dioxide levels for December 2003-2011 in the NE and SW.

Period	% Northeast mean CO_2	% Southwest mean CO_2	% +/- in Mean CO_2 North East from South west	Interpretation
2003 December	20.24	19.67	0.57	Higher in North East than South West
2005 December	19.76	19.73	0.02	Higher in North East than South West
2007 December	19.43	19.98	-0.55	Higher in South West than North East
2009 December	20.18	20.23	-0.05	Higher in South West than North East
2011 December	20.41	20.39	0.02	Higher in North East than South West

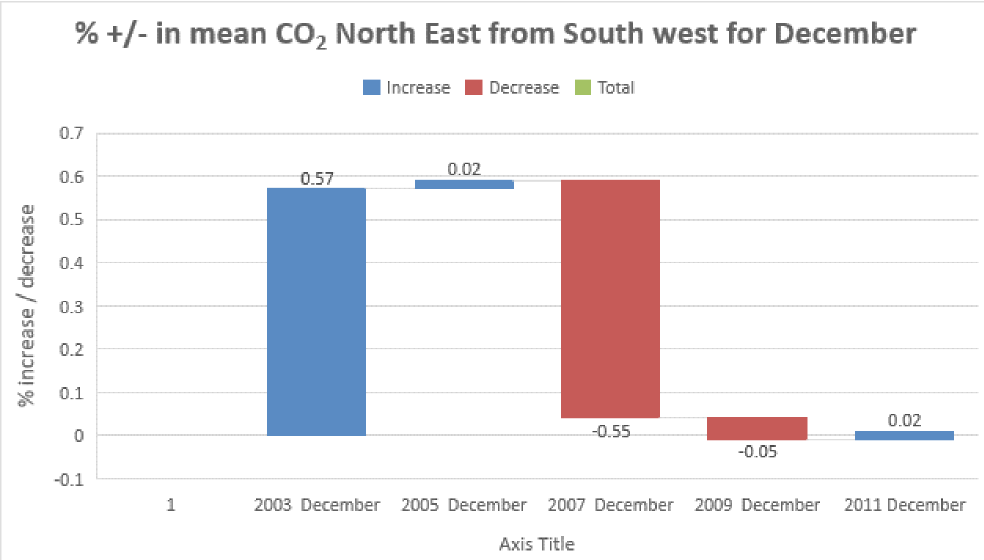


Figure 7. Percentage increase/decrease in Mean CO_2 NE from SW for December.

4.3 Predictions

From the projections made using Microsoft excel, **Figure 8** shows a steep linear trend in the minimum emission for both July and December with higher values in December. While the maximum values show a gradual trend in December, and a steep trend line to about 398ppm in July see **Figure 9**. In July, **Figure 10** and **Table 6** projects a uniform steep trend in the NE and SW whereas there is a variation in December, where the NE has a gradual trend and the SW, has a steep trend in **Figure 11**.

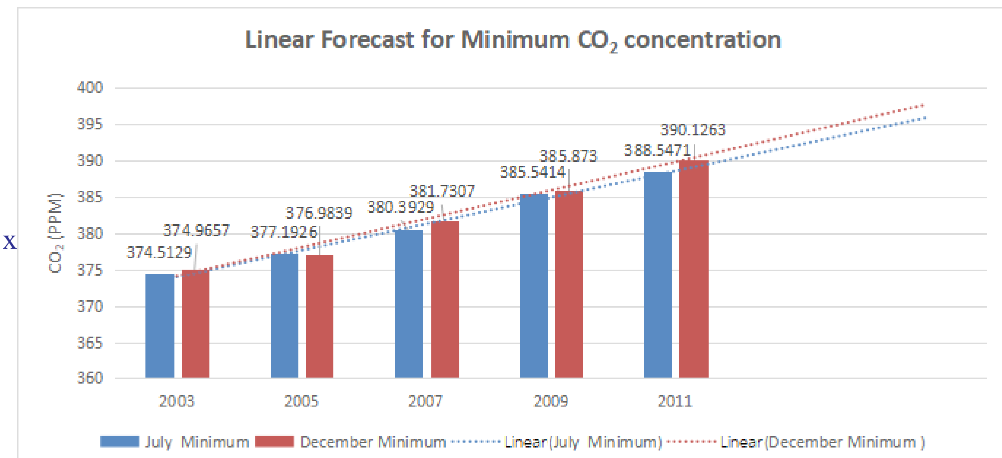


Figure 8. Trend line for the minimum CO_2 concentration.

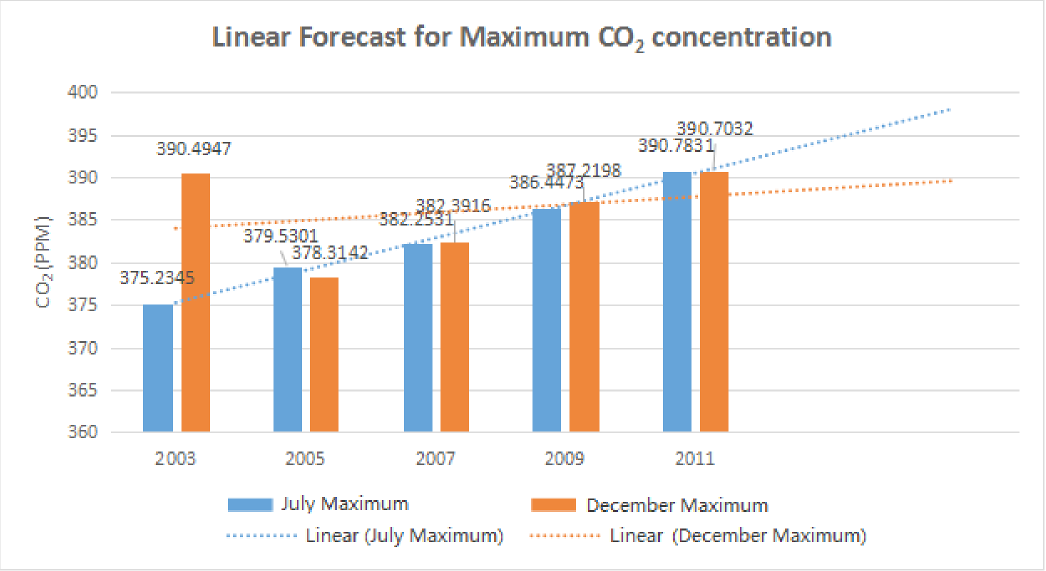


Figure 9. Trend line for the Maximum CO_2 concentration.

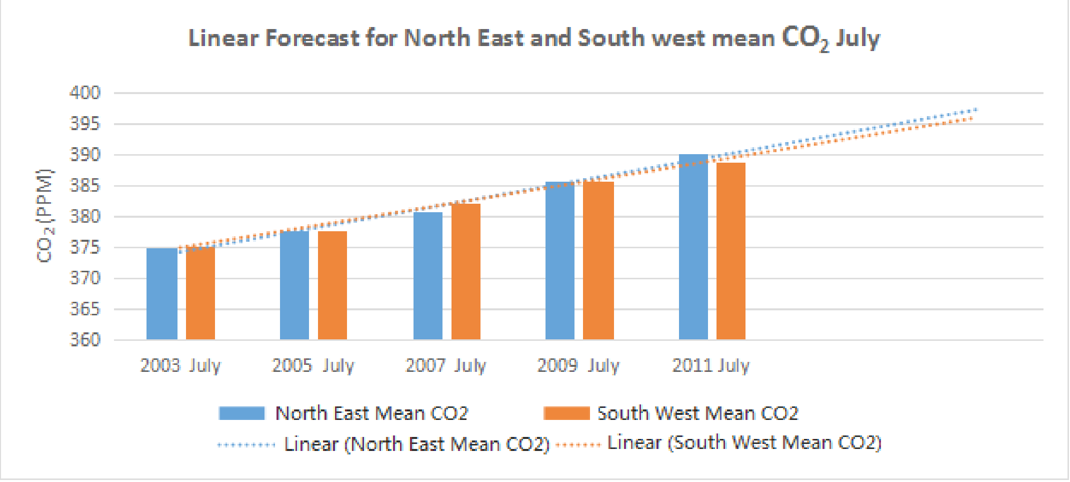


Figure 10. Trend line for the mean CO_2 concentration in the NE and SW for July.

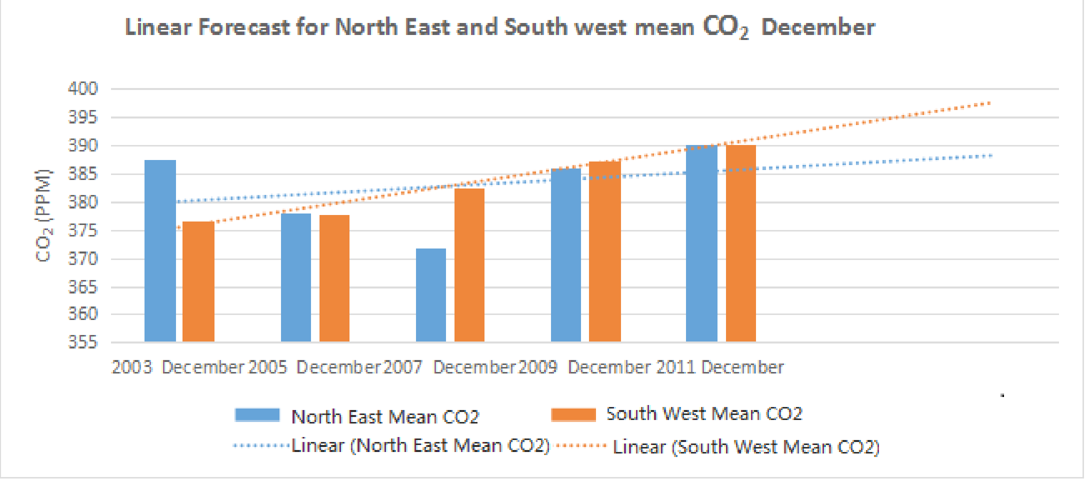


Figure 11. Trend line for the mean CO_2 concentration in the NE and SW for December.

Table 6. Monthly average tropospheric carbon dioxide for the peak wet and dry seasons from 2003-2011 for NE and SW.

Period	North East		South West	
	CO_2 Range	Mean CO_2	CO_2 Range	Mean CO_2
July 2003	374.8016-374.9458	374.8737	375.0902-375.2345	375.1623
December 2003	384.2832- 390.4947	387.3889	374.9657-378.0175	376.5186
July 2005	377.1926-378.1276	377.6586	377.1926-378.1276	377.6601
December 2005	377.7822-378.3142	378.0482	377.5162-377.7821	377.6491
July 2007	380.3929-381.137	380.7649	381.8812-382.2531	382.0671
December 2007	361.7037-381.995	371.8493	382.2595-382.3916	382.3255
July 2009	395.5414-385.9038	385.7226	385.5414-385.7226	385.632
December 2009	385.873-386.4118	386.1424	386.9506-387.2198	387.0852
July 2011	389.8888-390.3359	390.1123	388.5471-388.9943	388.7707
December 2011	390.4726-390.5879	390.5302	390.1263-390.2417	390.1840

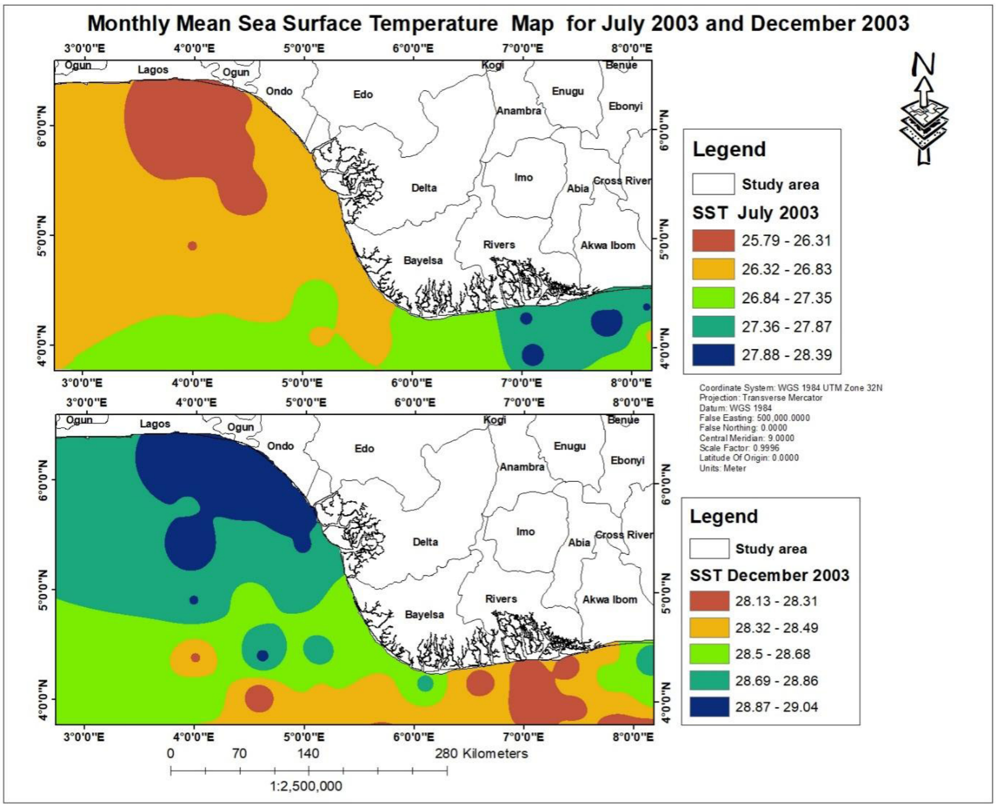
The overall investigation predicts increasing CO_2 emissions in both seasons over the years with higher concentrations in the Southwest if adequate measures are not taken to reduce carbon footprint.

4.4 Sea surface temperature

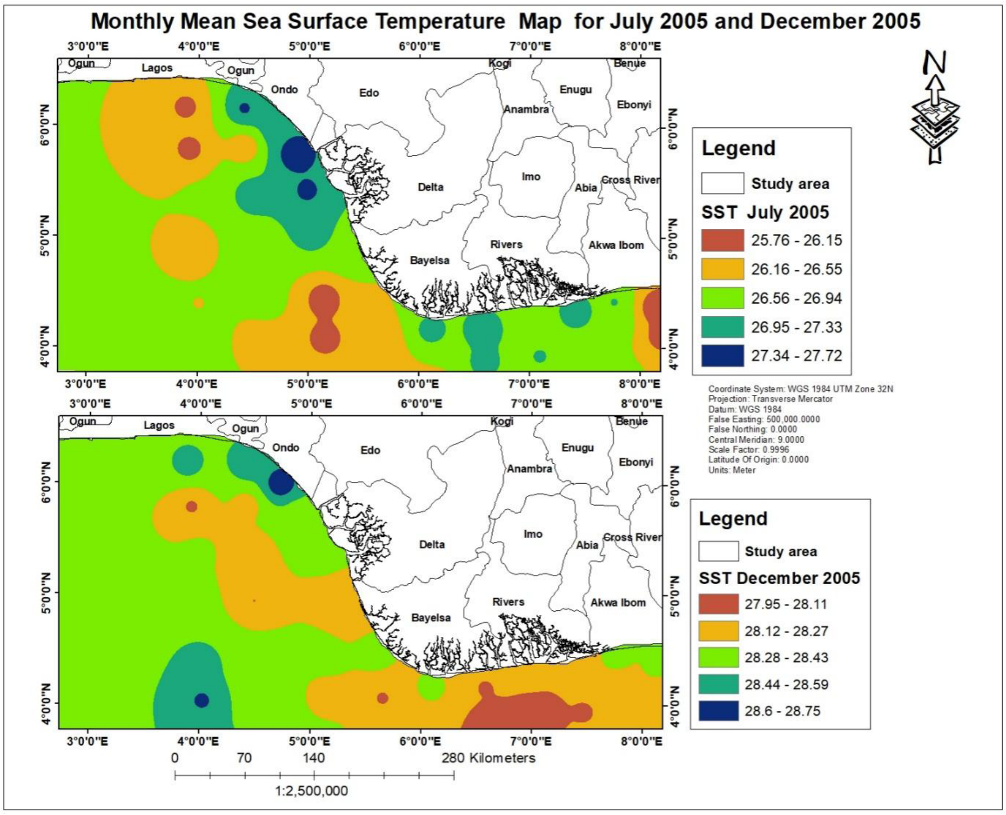
The temperature of the ocean's surface water is an important physical property of the world's oceans. As the oceans absorb more heat, sea surface temperatures rise, and the ocean circulation patterns that transport warm and cold water around the world change [15]. A change in sea surface temperature, according to Ostrander, G. K., Armstrong, K. M., Knobbe, E. T., et al. [16], can affect the marine ecosystem in a variety of ways, including how variations in ocean temperature can affect what species of plants, animals, and microbes are present in a location, alter migration and breeding patterns, endanger sensitive ocean life such as corals, and change the frequency and intensity of harmful algal blooms such as red tide. Long-term increases in sea surface temperature may also reduce circulation patterns that transport nutrients from the deep sea to the surface. Changes in reef habitat and nutrient supply could drastically alter ocean ecosystems and lead to fish population declines, affecting people who rely on fishing for food or a living [17, 18].

The results in **Figure 12**, show that the sea surface temperature was consistently low during the wet season and high during the dry season from 2003 to 2011 and also indicate a spatial variability in the monthly average sea surface temperature across the region.

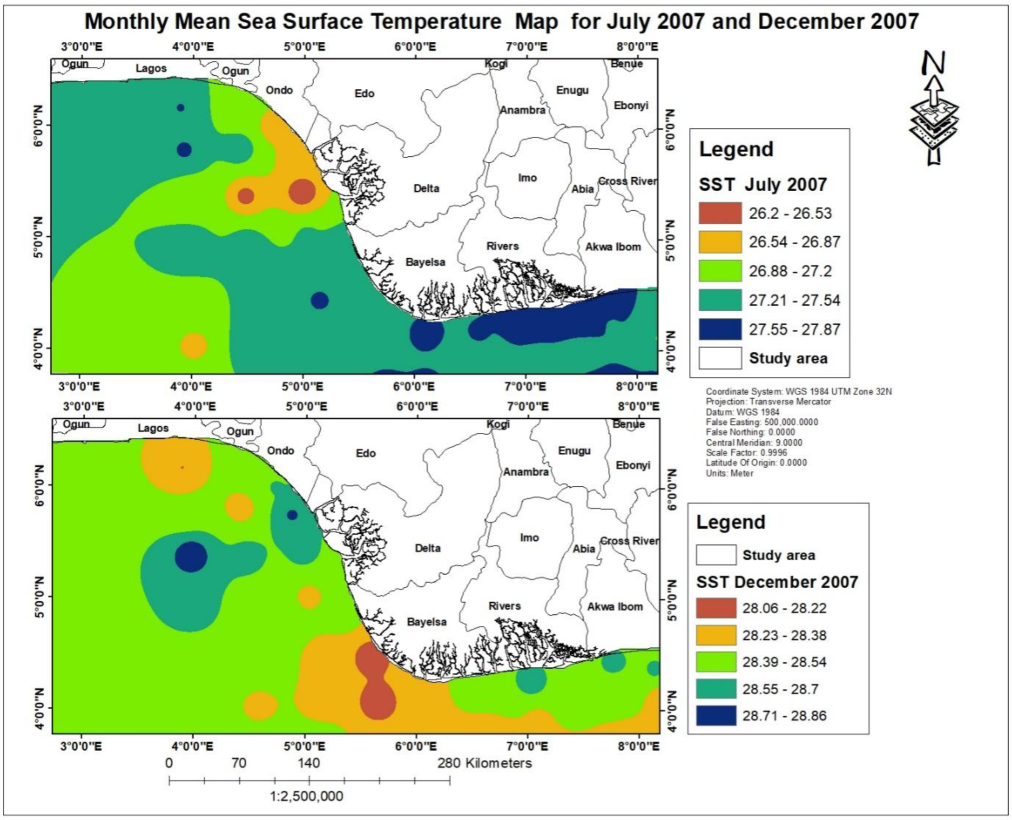
According to Tables 7 and 8, the lowest minimum temperatures for both seasons were recorded in July 2011; 25.7 °C and in December 2011; 27.8 °C. While the highest maximum temperatures of 28.39 °C and 29.27 °C were recorded in July 2003 and December 2009 respectively. The minimum temperature values show a linear trend gradually increasing in July and fairly constant in December in **Figure 13**. While **Figure 14** indicates a reduction in the maximum temperature in July and a fairly constant trend in December. However, the spatial distributions show a general increase in sea surface temperature from 2003 to 2011, and factors that could influence the rise in temperature include oil and gas operations such as gas flaring activities as shown in **Figure 1**, as well as the movement of marine vessels, and bunkering activities.


Monthly Mean Sea Surface Temperature Map for July 2003 and December 2003
Legend
Study area
SST July 2003
25.79 - 26.31
26.32 - 26.83
26.84 - 27.35
27.36 - 27.87
27.88 - 28.39
Legend
Study area
SST December 2003
28.13 - 28.31
28.32 - 28.49
28.5 - 28.68
28.69 - 28.86
28.87 - 29.04
0 70 140 280 Kilometers
1:2,500,000

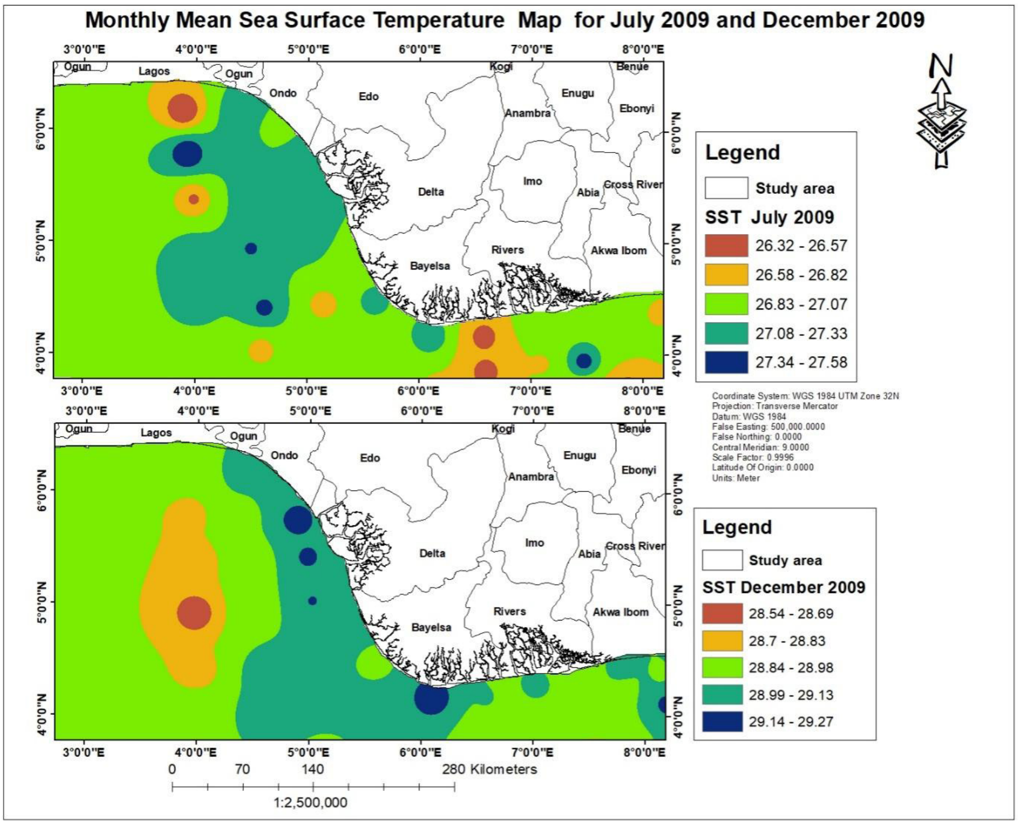
(a)


Monthly Mean Sea Surface Temperature Map for July 2005 and December 2005
Legend
Study area
SST July 2005
25.76 - 26.15
26.16 - 26.55
26.56 - 26.94
26.95 - 27.33
27.34 - 27.72
Legend
Study area
SST December 2005
27.95 - 28.11
28.12 - 28.27
28.28 - 28.43
28.44 - 28.59
28.6 - 28.75
0 70 140 280 Kilometers
1:2,500,000

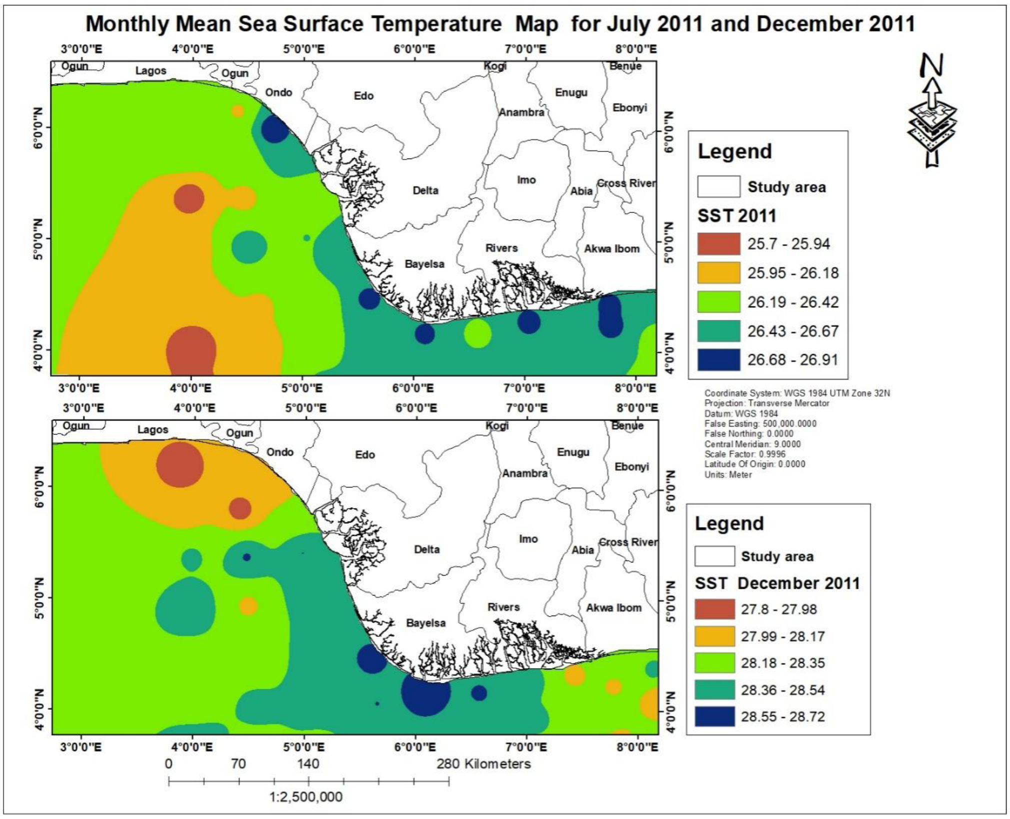
(b)


Monthly Mean Sea Surface Temperature Map for July 2007 and December 2007
Legend
SST July 2007
26.2 - 26.53
26.54 - 26.87
26.88 - 27.2
27.21 - 27.54
27.55 - 27.87
Study area
Legend
Study area
SST December 2007
28.06 - 28.22
28.23 - 28.38
28.39 - 28.54
28.55 - 28.7
28.71 - 28.86
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
0 70 140 280 Kilometers
1:2,500,000

(c)


Monthly Mean Sea Surface Temperature Map for July 2009 and December 2009
Legend
Study area
SST July 2009
26.32 - 26.57
26.58 - 26.82
26.83 - 27.07
27.08 - 27.33
27.34 - 27.58
Legend
Study area
SST December 2009
28.54 - 28.69
28.7 - 28.83
28.84 - 28.98
28.99 - 29.13
29.14 - 29.27
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
0 70 140 280 Kilometers
1:2,500,000

(d)



(e)

Figure 12. Monthly mean Sea Surface Temperature in the marine environment in Nigeria. (a)July 2003 and December 2003, (b) July 2005 and December 2005, (c) July 2007 and December 2007, (d) July 2009 and December 2009, (e) July 2011 and December 2011.

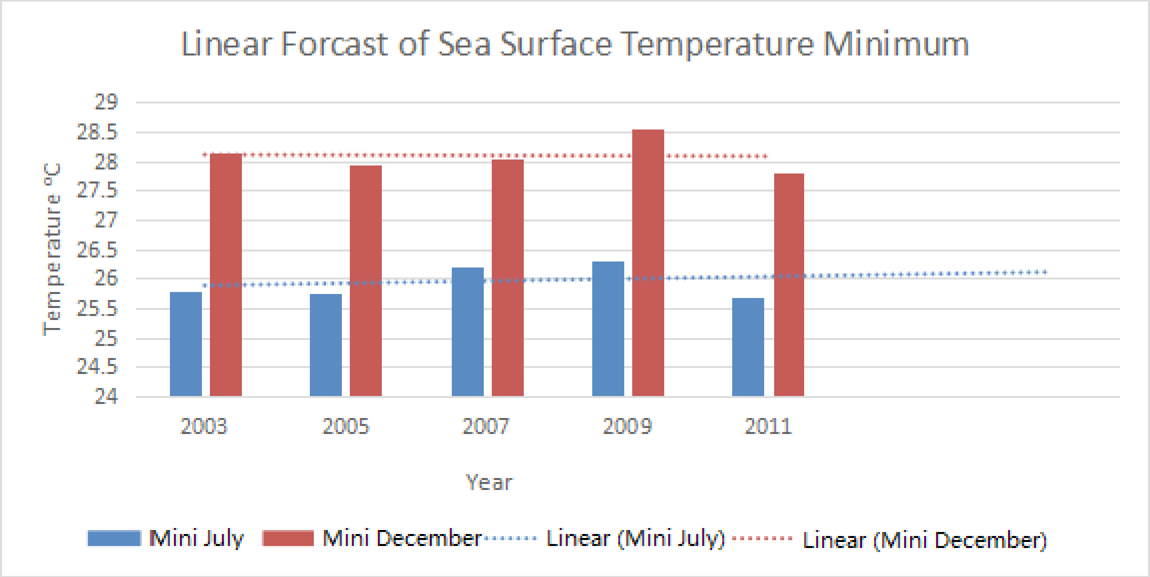


Figure 13. Trend line for the Minimum Sea surface temperature.

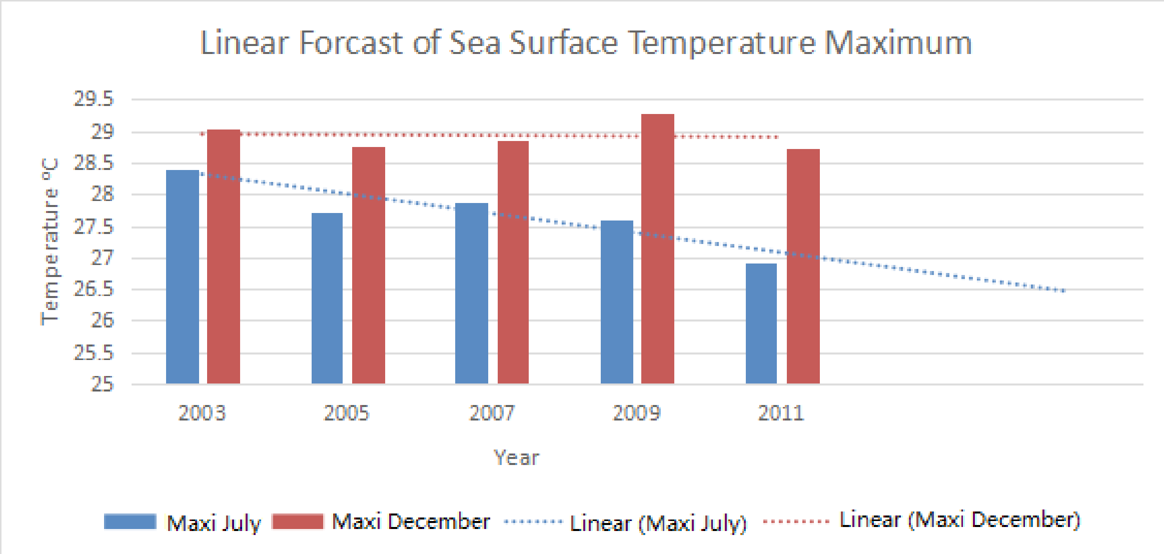


Figure 14. Trend line for the Maximum Sea surface temperature.

Table 7. Sea Surface Temperature for Minimum from 2003-2011.

Year	2003	2005	2007	2009	2011
Mini July	25.79	25.76	26.2	26.32	25.7
Mini December	28.13	27.95	28.06	28.54	27.8

Table 8. Sea Surface Temperature for Maximum from 2003-2011

Year	2003	2005	2007	2009	2011
Maxi July	28.39	27.72	27.87	27.58	26.91
Maxi December	29.04	28.75	28.86	29.27	28.72

4.5 Correlation between carbon dioxide and sea surface temperature

The regional distribution of carbon dioxide revealed that carbon dioxide is continuously increasing as a result of increased combustion of fossil fuels in oil and gas exploration, marine vessel movement, and population density in coastal communities. Consequently, the study area was classified into two: NE and SW for CO_2, based on these activities. The Pearson correlation coefficient was utilized to determine the relationship between the carbon dioxide concentrations and the sea surface temperatures (**Table 9**). The correlation coefficient revealed that 50% of the study stations showed a strong positive relationship between increased carbon dioxide concentrations and high temperatures during both the dry and wet seasons, 20% showed a strong negative relationship, 20% showed a weak positive relationship, and 10% showed a weak negative relationship. As earlier observed, the CO_2 levels are low in July and higher in December. This corresponds with lower sea surface temperatures in July and higher values in December. A scatter plot of correlation coefficients between temperature and carbon dioxide concentrations for July and December from 2003 to 2001 is shown in **Figure 15**.

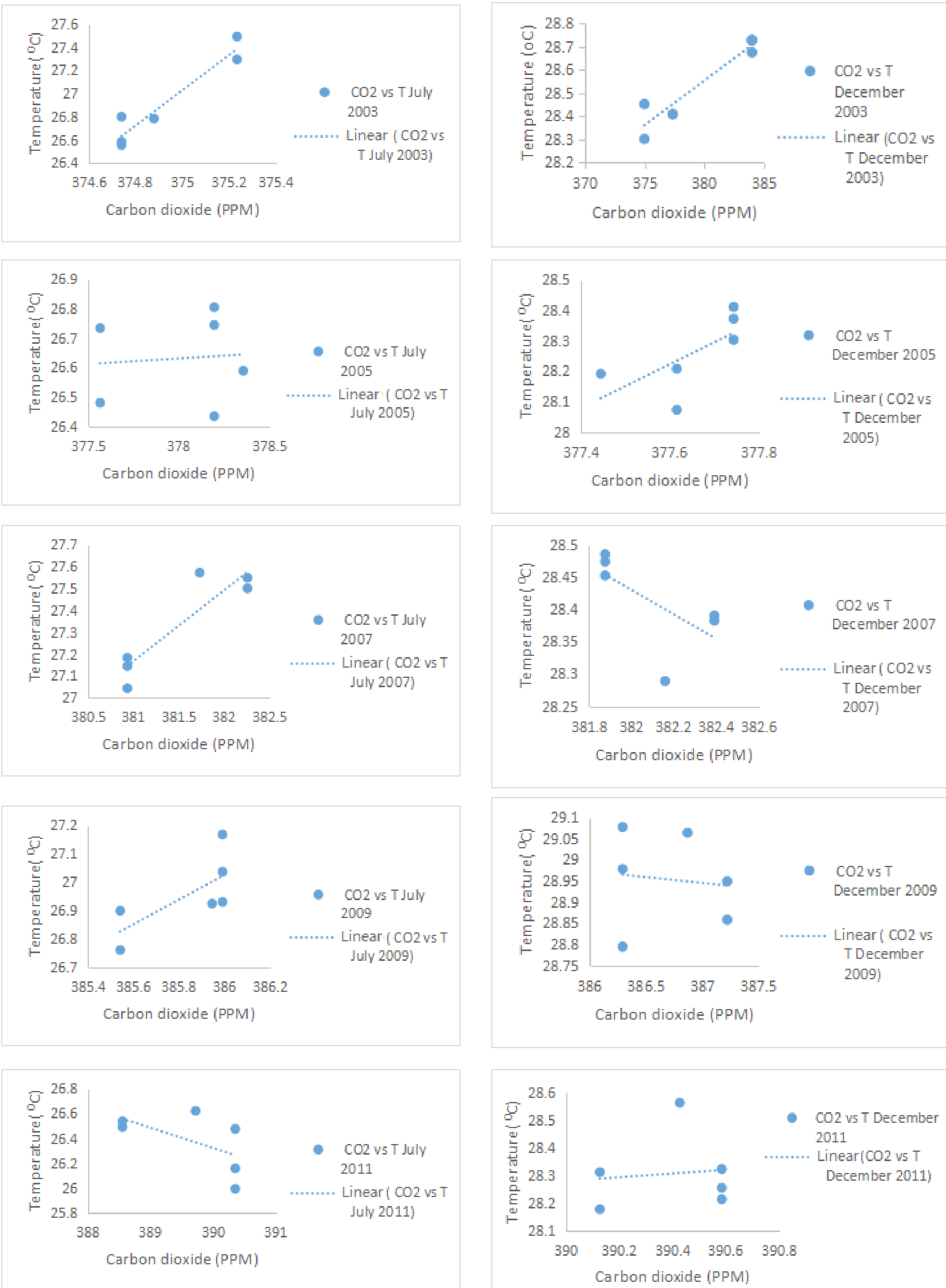


Figure 15. Pearson Correlation coefficient between CO_2 and Sea surface temperature.

Table 9. Pearson correlation coefficient between CO_2 and sea surface temperature.

Year	r (CO_2 vs T July)	Strength	Direction	r (CO_2 vs T December)	Strength	Direction
2003	.96	Strong	positive	0.95	Strong	positive
2005	.09	Weak	positive	0.68	Strong	positive
2007	.91	Strong	positive	-0.65	Strong	Negative
2009	.72	Strong	positive	-0.11	Weak	Negative
2011	-.59	Strong	Negative	0.11	Weak	positive

4.6 Environmental implications

An increase in the levels of carbon dioxide emitted and sea surface temperature leads to Global warming which results in climate change with serious repercussions on the environment. The principal consequence being higher temperatures has a ripple effect beginning with frequent torrential precipitation due to increased evaporation rate and higher water vapour retaining capacity of a warm atmosphere. In addition, sea level rise according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) was expected to rise by 18 to 59 centimeters globally by the end of the 20th century. The Niger Delta coastline is categorized as an extreme hotspot of climate vulnerability by the IPCC and has in recent years experienced a series of coastal inundations, which increased annually during the period under review [19,20], erosion, and increased soil salinity induced by saltwater intrusion depleting the mangrove reserves [21]. Furthermore, the effects include changes in the circulation pattern of coastal waters [22] and warmer ocean water. Warm water holds less oxygen, and CO_2 depletion occurs in the upper 1km where most species live, inducing hypoxia in some species and increasing ocean acidity creating an imbalanced marine ecosystem [23]. In response, marine life either dies or migrate to more conducive waters.

Public health is not spared either, as warm humid climates encourage the breeding of vector-borne diseases like yellow fever and waterlogged areas for breeding mosquitos, carriers of malaria. Hot weather reduces the size of water bodies like lakes. The dry beds resulting from this shrinkage can be sources of air pollution with high levels of arsenic and other toxins which are poisonous to inhale leading to respiratory problems [24]. Poor nutrition of the population, another effect, is a function of poor crop yield and consuming mutated aquatic organisms from the acidic ocean.

5. Conclusions and recommendation

Geospatial Technology has demonstrated that the continuous increase in carbon dioxide concentration in the atmosphere caused by human activities heats up the atmosphere, resulting in heavier precipitation, which exacerbates coastal flooding. Climate change is also causing ocean acidification, shoreline erosion, and saltwater intrusion along the Niger Delta marine environment. Variations in CO_2 concentration and sea surface temperature across the region reflect differences in seasons, weather, and rates of human-driven carbon emissions. The observed trend indicates that carbon dioxide levels will rise with sea surface temperature serving as climate change indicators. It is in man's best interest to mitigate this by reducing our carbon footprint and protecting our carbon sink.

GIS and remote sensing technology should be used to regularly monitor carbon dioxide levels, and all illegal crude oil refineries in the Niger Delta should be decimated. Environmental friendly policies, such as carbon capture and storage, should be developed and implemented to improve the marine ecosystem and residents' quality of life, and thus boost economic activity.

Conflict of Interest

There is no conflict of interest.

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Appendix 1

Carbon dioxide (PPM) July					Sea Surface Temperature (°C) July				
2003	**2005**	**2007**	**2009**	**2011**	**2003**	**2005**	**2007**	**2009**	**2011**
374.7397	378.1945	380.9311	385.9913	390.3538	26.555	26.435	27.18357	26.92857	25.99571
374.7397	378.1945	380.9311	385.9913	390.3538	26.58214	26.74429	27.145	27.16643	26.16
374.7397	378.1945	380.9311	385.9913	390.3538	26.79929	26.80428	27.04357	27.035	26.47643
374.8788	378.3543	381.7284	385.9451	389.7175	26.78214	26.58929	27.57143	26.92286	26.62071
375.2345	377.5654	382.2531	385.5414	388.5471	27.49286	26.73386	27.5	26.89786	26.53714
375.2345	377.5654	382.2531	385.5414	388.5471	27.29571	26.48071	27.54857	26.75929	26.49143

Appendix 2

Carbon dioxide (PPM) December					Sea Surface Temperature (°C) December				
2003	**2005**	**2007**	**2009**	**2011**	**2003**	**2005**	**2007**	**2009**	**2011**
384.0065	377.7441	381.8758	386.2906	390.5842	28.72786	28.41071	28.47429	28.79429	28.25571
384.0065	377.7441	381.8758	386.2906	390.5842	28.67429	28.30286	28.45286	28.97786	28.21429
384.0065	377.7441	381.8758	386.2906	390.5842	28.72643	28.37214	28.48571	29.07714	28.32357
377.3511	377.4448	382.1591	386.8678	390.4262	28.40714	28.19143	28.28929	29.06357	28.56286
374.9657	377.616	382.3916	387.2199	390.1263	28.3	28.07357	28.38286	28.85786	28.31243
374.9657	377.616	382.3916	387.2199	390.1263	28.45071	28.20786	28.39071	28.94857	28.17786

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REVIEW

Global Effect of Climate Change on Seasonal Cycles, Vector Population and Rising Challenges of Communicable Diseases: A Review

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ABSTRACT

This article explains ongoing changes in global climate and their effect on the resurgence of vector and pathogen populations in various parts of the world. Today, major prevailing changes are the elevation of global temperature and accidental torrent rains, floods, droughts, and loss of productivity and food commodities. Due to the increase in water surface area and the longer presence of flood water, the breeding of insect vectors becomes very high; it is responsible for the emergence and re-emergence of so many communicable diseases. Due to the development of resistance to chemicals in insect pests, and pathogens and lack of control measures, communicable zoonotic diseases are remerging with high infectivity and mortality. This condition is becoming more alarming as the climate is favoring pathogen-host interactions and vector populations. Rapid changes seen in meteorology are promoting an unmanageable array of vector-borne infectious diseases, such as malaria, Japanese encephalitis, filarial, dengue, and leishmaniasis. Similarly, due to unhygienic conditions, poor sanitation, and infected ground and surface water outbreak of enteric infections such as cholera, vibriosis, and rotavirus is seen on the rise. In addition, parasitic infection ascariasis, fasciolosis, schistosomiasis, and dysentery cases are increasing. Today climate change is a major issue and challenge that needs timely quick solutions. Climate change is imposing non-adaptive forced human migration territorial conflicts, decreasing ecosystem productivity, disease outbreaks, and impelling unequal resource utilization. Rapid climate changes, parasites, pathogens, and vector populations are on the rise, which is making great threats to global health and the environment. This article highlighted the necessity to develop new strategies and control measures to cut down rising vector and pathogen populations in endemic areas. For finding quick solutions educational awareness, technology up-gradation, new vaccines, and safety measures have to be adopted to break the cycle of dreadful communicable diseases shortly.

Keywords: Global climate change; Biodiversity loss; Loss of life; Habitat; Economic losses; Biomarkers; Challenges and solutions

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1. Introduction

Today's most important challenge is altered climatic conditions at a global level that is imposing adverse effects on human health and the environment. Changing climate is disrupting the economic and social structure of society and breaking the natural association between man and wild animals. There is a tug-of-war between those countries which are producing high emissions and contributing the least to climate control. People are facing growing adversities of climate change, mainly due to shifting weather patterns, rising sea levels, and more extreme weather events such as cyclones, typhoons, and tsunamis. The climate is dynamic and undergoes a natural cycle all the time. Several slow-moving natural forces contribute to climate change. Continental drift, volcanoes, ocean currents, the tilt of the globe, comets, and meteorites are a few of the more noticeable ones. The atmospheric quantities of water vapor, carbon dioxide, methane, and nitrous oxide—all greenhouse gases that help trap heat at the earth's surface—have significantly grown as a result of industrialization, deforestation, and pollution. Carbon dioxide is being released into the atmosphere by humans much more quickly than it can be taken up by plants and oceans. Even if such emissions were stopped today, the atmosphere would still contain these gases for years, which would delay the onset of global warming. Any variation or change in the natural environment brought by human action is referred to as climate change (IPCC). However, it contrasts with the Framework Convention on Climate Change (FCCC), which states that over comparable periods, any change in the composition of the global atmosphere may be caused either directly or indirectly by human activities. From the re-industrial era to 2005, the global atmospheric concentration of carbon dioxide, methane, and nitrous oxide increased, according to IPCC. Global average CO_2 concentrations set a new record of 414 ppm in 2020, 417.2 parts per million (ppm), up 2.5 ppm from 2021 levels [1]. Atmospheric CO_2 concentrations are now 51% above pre-industrial levels [2].

At present world climate system has been altered due to the addition of greenhouse gases and aerosols into the atmosphere. These significant effects are caused due to industrial and automobile emissions, delayed precipitation, massive deforestation, melting of glaciers, and poorly managed land use patterns. All these changes finally affected the balance of the climate system. A deviation in natural incoming and outgoing energy in the earth-atmosphere system has been noted. The increase in global atmospheric temperature is due to accelerating anthropogenic activities. Though, natural factors like extreme radiation and ozone depletion are also responsible for the warming or cooling of the global climate [3]. These are environmental gases that trap long-wave radiation reflected from the earth's surface. These are enhancing the global mean temperature of the atmosphere. This phenomenon is popularly known as the "Greenhouse" effect. Water vapor is by far the most significant greenhouse gas. However, carbon dioxide contributes significantly, and ozone, methane, and nitrous oxide have less of an impact. It is well known that atmospheric levels of carbon dioxide, methane, and nitrous oxide are rising, and in recent years, other greenhouse gases, namely chlorofluorocarbons (CFCs), have been significantly increased [4]. The subsequent climatic impacts are difficult to predict with any degree of certainty. Since 1860, anthropogenic activities have increased greenhouse gases, mostly CO_2 and methane, which have caused an increase in the global mean surface temperature of around 0.5 EC. Based on forecast concentrations, the temperature should be limited to 1.5 °C, and all efforts should be made to it zero by 2050. For this purpose "Global net human-caused emissions of carbon dioxide (CO_2) would need to fall by about 45 percent by 2030 and carry it up to zero in next 20 year" [5]. The maintenance of the environment's temperature is mostly dependent on vegetation and forest cover. Local and regional climate variations have an impact on soil temperature, biological activity, physical composition, nutrient uptake, and plant output. The Amazon basin's forest cover has an impact on the flux of moisture into the atmosphere, regional convection, and regional rainfall. In the majority of

African countries, drought is primarily caused by warmth and the degradation of local vegetation [6].

Today, climate change is a serious problem that requires prompt responses. Climate change is driving inequitable resource use, decreased ecosystem productivity, non-adaptive forced population migration, disease outbreaks, and territorial conflicts. Temperature, precipitation, clouds, and wind are all variables in the annual weather. The weather varies from one year to the next and from one place to another. A few unthinkable changes in air and ocean temperatures have led to an increase in sea level and the rapid melting of pole-located snow and ice caps. Global warming has been occurring for the past 60 years, and the fundamental cause is human interference with the planet's various primary ecological divisions [7].

Marine, aquatic, and terrestrial lives are all being negatively impacted by significant ongoing climate change. Even while there are many consequences already apparent, there may be a few unexpected effects in the future. As a result, each of these consequences has been identified one at a time, and projects have been set up to identify answers. The accumulation of large volumes of carbon dioxide in the atmosphere is the effect that is most obvious. As a result of the greenhouse effect, it is raising the average world temperature and causing unintentional natural disasters everywhere. The survival of terrestrial, freshwater species, primarily planktons and bottom-dwellers, is being hampered; in the marine environment, coral reefs, algae, and fish fauna belong to various taxa. Due to the ocean's inability to absorb additional carbon dioxide, the food chain in the ocean is more likely to be disrupted. Micro-flora and micro-fauna along the seashore are drastically declining. Large-scale disturbances have resulted from it, including biodiversity loss, habitat damage, forest depletion, land degradation, floods, and draughts in terrestrial environments. On the other side, unexpected weather changes can cause permanent damage because of hurricanes, typhoons, storms, lightning, floods, and tsunamis, which are often on the rise [8]. Breakdowns in the economy and the environment are happening more frequently and are lasting longer.

There is a substantial increase in temperature and heat-related deaths in dry and semi-arid regions. Climate change is making people's issues worse as more hurricanes, blizzards, tornadoes, floods, droughts, tornadoes, earthquakes, and losses to human life, health, physical riches, habitat devastation, and resilience occur practically every year. Land degradation, soil erosion, and destructive floods that produce landslides are all increasing dramatically. The biodiversity of hydrophytes, pollinators, symbiotic bacteria, coral reefs, fish, amphibians, reptiles, mammals, and invertebrates—primarily insects—has been severely damaged. Coral bleaching brought on by seawater warming contributes to the mass collapse of corals. The effects of climate change and global environmental stress must be evaluated in terms of their ecological, meteorological, socioeconomic, political, thermal, biophysical, and biological impacts. Action must then be taken to find the best solutions and to mitigate these effects on a worldwide scale.

Long-term changes in weather patterns and extreme weather event frequency are referred to as climate change. It could increase already existing health issues and change the threat to human health. The scientific data on how climate change affects human infectious diseases are examined in this review. Climate change has reached a critical level in recent years, affecting plant and animal species as well as making people more vulnerable and posing possible health risks in numerous eco-climatic zones. To quickly identify answers, it is necessary to investigate the health effects of particular diseases, the shifting spectrum of infectious diseases, and novel clinical and ecological operational approaches. In order to forecast future health effects associated with climate change, current research must concentrate more on the causes of infectious diseases, climate variables, the development of control warning systems, and the use of improved methods [9]. The involvement of human society, the scientific community, economists, stakeholders, healthcare professionals, and policymakers must come together on a single platform to educate the public about how to reduce greenhouse gas emissions and use energy and materials safely in order to find quick solutions [10]. The effect of climate change on seasonality, population biology of parasites, pathogens, and vectors, and their interactions with the environment have all been highlighted in the current review article in an effort to find innovative approaches to the current and foreseeable challenges of communicable diseases. The Coronavirus recently infected a sizable portion of the global population; it struck forcefully and caused millions of fatalities. The recent COVID-19 outbreak has put individuals in danger and had a negative impact on the global economy. The primary challenge is due to massive and multiple pharmaceutical interventions and climatic changes going on in micro-organisms, primarily viruses, and bacteria, which are making genomic changes mainly drug and vaccine resistance nowadays. The second problem is how to combat mixed infections, mostly bacterial and fungal infections. The recent pandemic made it abundantly evident that current clinical and therapeutic approaches are insufficient to manage disease transmission, treatment, and control of an influx of new infectious diseases (**Figure 1**). The main objective of this review is to sketch out possible climatic pressure on the microbial genome to have new changes in DNA or mutations for gearing up new adaptations to ensure their survival in presence of diverse pharmaceuticals and climatic conditions. The main objective of this study is to find out the most appropriate treatment for communicable diseases in the near future. This article emphasizes the need for improvement of the cultural environment, new strategies, and control measures to cut down rising vector and pathogen populations in endemic areas.

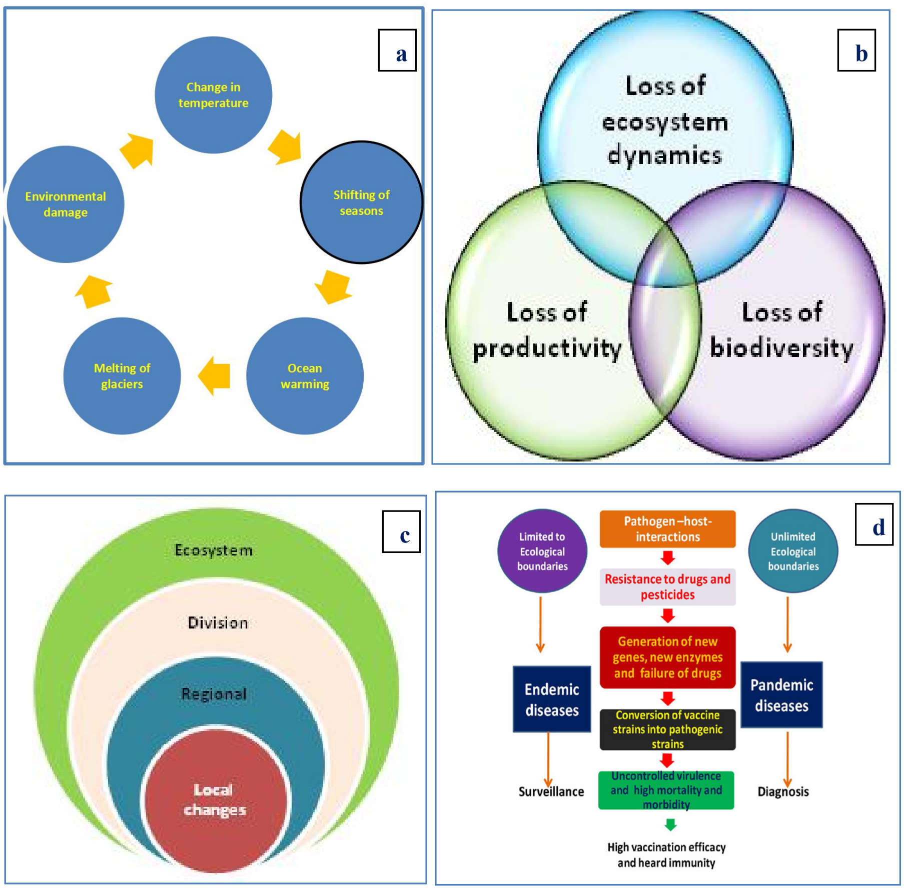

Figure 1. (a) cyclic changes in seasons (b) loss faced due to climate change (c) rising impact of climate change (d) unlimited virulence and infectivity are cause of endemic and pandemic diseases.

Materials and methods

For writing this comprehensive research review on the global effects of climate change on seasonal cycles, vector population, and rising challenges of communicable diseases various databases *were searched*. All concerned information was collected from different reference books, journals, encyclopedias, survey reports, and databases available on world climate and environment were read. For collection of data on climate change and climate-imposed risks, possible levels of gas emissions, and their impact on seasonal cycles and human life Climate Change Knowledge Portal (CCKP) was searched. For a collection of relevant information specific terms "climate change and its impact on the environment and human life were used such as key text words," published till 2022 were used in MEDLINE. Most especially for retrieving all articles about climate-related changes, electronic bibliographic databases were searched and abstracts of published studies with relevant information on the present topic were collected. All important IPCC reports on climate change, climate action plans, impacts, adaptation, vulnerability, Climate Change Statistics, and Indicators were studied. Findings of the Kyoto Protocol & Paris Agreement, United Nations Framework Convention on Climate Change, and Key reports on climate impacts and solutions from around the United Nations are also considered for furnishing more recent information on the present topic of the review article. For updating the information about a subject and incorporating recent knowledge, relevant research articles, books, conference proceedings, and public health organization survey reports were selected and collated based on the broader objective of the review. Three important findings included climate justice and climate ambition and a temperature change of 1.5-degree temperature limit by 2030 and zero up to 2050. Relevant terms were used individually and in combination to ensure an extensive literature *search*. Most relevant information on this topic was acquired from various scientific databases, including SCOPUS, Science Direct Web of Science, EMBASE, Pubmed central, PMC, Publon, Swissprot, and Google Scholar. From this common methodology, discoveries and findings were identified and summarized in this final review.

2. Seasonal cycles

The movement of the earth on its axis at a fixed angle causes seasonal cycles because there are two opposed points. It is decided by the position of the sun which remains year-round in the Northern and Southern Hemispheres. The lengths of the day and night shifts are decided as a result of the earth's rotational motion. Each of the four seasons—spring, summer, fall, and winter—has its own cycle. Weather-based seasons, such as wet or dry ones, also exist on Earth. Similarly to this, tornado and hurricane seasons coincide in some regions with two seasonal changes. The monsoon season in the northern Indian Ocean is caused by this characteristic pattern, which also underlies other periodic cycles.

Droughts and floods are happening more frequently as a result of global climate change. The rotation of the globe has a significant impact on the troposphere's wind patterns. The monsoon season in the northern Indian Ocean is caused by this characteristic pattern, which also underlies other periodic cycles. There are two distinct seasonal cycles: "El Nino", is a warm ocean current that begins in late December. An opposite cycle called La Nino has milder winds. Additionally, La Nino provides stronger trade winds while "El Nino", diminishes them. Because heated air near the earth's surface rises swiftly and moves far, tornadoes also follow a yearly cycle. During the spring and summer, when this hot air becomes actively warm near the surface, it becomes more buoyant and quickly forms tornadoes [11]. Seasonal cycles therefore occur within a calendar year, while spans of time that are shorter or longer than a year are possible. Occasionally throughout the course of a calendar year, regular predictable and unpredictable shifts in climate regimes take place during the varying seasons. Seasonal refers to any predictable variation or pattern that recurs or repeats over the course of a year.

A season can refer to either a commercial season, like the Christmas season or to a calendar season, such as the summer or winter. Changes in the atmosphere caused by eco-climatic factors or variations in the weather have a negative impact on human health, animal behaviour, pathogen-host interactions, and economic growth. Seasonal cycles have an impact on economic, social, biological, and environmental variables. Seasonal cycles periodically fluctuate, which has an impact on animal and plant life. Despite the fact that forecasting techniques and projections are available, loss of life, economic loss, and loss of plant and animal life occur virtually year. Unexpected seasonal changes and difficulties due to any climatic element are the problems. Thermal waves and extreme droughts have a negative impact on the flow of sap and nutrients in sapwood and phloem vessels. The principal effects of seasonal variations have been seen in arid zone plants and plants on hilly slopes. Due to a drastic reduction in water supply brought on by dry lands and poor rainfall, a nutrient concentration is negatively impacted in hot thermal waves [12].

Conifers and flowering vegetable plants' leaves display dehiscence and wilting symptoms including sunburn and significant soil water loss. High temperatures have a significant impact on juvenile meristematic tissues in buds, tendrils, stem tips, plumules, cambia, and roots as well as on growing seeds. In dry soil, it causes a 90% crop loss. Due to the impact of the aquatic and marine environment surface temperature, rising temperatures and scorching winds also enforce tidal energy and enclosing waves. Every season's fall brings changes in the wind's direction, the amount of sunlight, the humidity, and the surrounding temperature. Typhoons, tides, and seasonal and diurnal cycles all have an impact. Seawater and air interface temperature differences of 1°C between day and night are also noted [13]. Diurnal cycles in the upper ocean are being impacted by rising sea surface temperature, which has a significant impact on the diversity of plankton, corals, mollusks, and fish. Due to the increase in temperature, similar effects have been observed in estuaries or in shallow river waters. It causes the sea level to rise, which is one of the main reasons for the loss of biodiversity and productivity (**Figure 1**).

3. Effect of seasonal cycles on soil climate, fauna and flora

Soil formation takes thousands of years, and most soils are still developing following changes in some of these soil-forming factors, particularly climate and vegetation, over the past few decades. Though, it depends on so many interactions and a number of forces, including climate, relief, parent material, and organisms, all acting over time. Climate is one of the most important factors affecting the formation of soil with important implications for its development, use, and management perspective. Climate severely affects soil functions like a significant change in organic matter turnover and CO_2 dynamics. The impact of climate change on soils is a slow complex process because soils not only are strongly affected by climate change directly. For example effect of temperature on soil organic matter decomposition and indirectly, for example, changes in soil moisture via changes in plant-related evapotranspiration but also can act as a source of greenhouse gases and thus contribute to the gases responsible for climate change.

Most soils are currently evolving as a result of changes in some of these soil-forming elements, particularly temperature and vegetation, over the past few decades. Soil development takes thousands of years. Although, it depends on a variety of elements that participate throughout time, such as the climate, relief, parent material, and organisms. One of the most significant elements influencing soil formation is climate, which has significant implications for their development, usage, and management. Climate has a considerable impact on soil processes like CO_2 dynamics and organic matter turnover. Because soils are indirectly influenced by climate change in addition to being directly affected, the impact of climate change on soils is a slow, complex process. Indirectly, for instance, changes in soil moisture due to variations in plant-related evapotranspiration), but they can also operate as a source of greenhouse gases and so contribute to the gases that are responsible for climate change (**Figure 1**).

Climate change is affecting soil formation, torrent rains and accidental floods are depleting the upper layer of fertile soil with massive soil erosion in semi-arid and agricultural fields and hilly areas. The final impact of all these physical and chemical factors is affecting soil microbial nutrient availability and loss of productivity year after year. Due to anthropogenic interventions and carbon inputs to the soil from crop biomass decreasing with massive changes in soil climate, and rate of organic matter digestion has been decreased due to rising temperature and shifting of seasonal cycles in subtropical climatic areas. Water availability to forest soil in hot summer and dry winter is unbalanced which is hard heating on CO_2 dynamics and O_2 release from photosynthetic plants (**Figure 1**).

Massive soil erosion in semi-arid, agricultural fields and hilly places is a result of climate change, which also affects the formation of soil. Torrential rains and unintentional floods are removing the top layer of fertile soil. The cumulative effect of all these physical and chemical factors affects the availability of nutrients for soil microbes and their productivity loss year after year. The rate of organic matter digestion has decreased due to rising temperatures and shifting seasonal cycles in subtropical climate zones due to anthropogenic interventions and carbon inputs to soil from crop biomass, which is decreasing with significant changes in soil climate. Unbalanced water availability to forest soil throughout the hot summer and dry winter has a negative impact on the dynamics of CO_2 and the release of oxygen from photosynthetic plants.

As constant inputs to the soil from vegetation depend on temperature, precipitation, and evaporation. More often, losses of soil carbon affect soil functions like soil structure, stability, topsoil water holding capacity, nutrient availability, and erosion. The loss of soil carbon is also accelerated by the increase in temperature. Further, climate also indirectly affects changes in growth rates or water-use efficiencies, through sea-level rise, through climate-induced decrease or increase in vegetative cover, or anthropogenic intervention. Soil pollution interaction of the various soil-forming processes, particularly biological ones, makes it difficult to quantify the changes (**Figure 1**). Increased rainfall could increase atmospheric N deposition to soils, and may promote soil disturbances, flooding, and subsidence which changes in wetland and waterlogged habitats and also enhance soil erosion, potentially leading to the pollution of surface waters. Increased rainfall enhances bypass flow and downward movements. Increased environmental temperature affects evapotranspiration and photosynthesis in C3 plants. Increased CO_2 affects fertilization and flowering in both C3 and C4 plants. Both climatic warming and rising CO_2 levels in the atmosphere will enhance tree growth in the short term.

Temperature, precipitation, and evaporation are all constant inputs to the soil from vegetation. More frequently, soil functions like soil structure, stability, topsoil water holding capacity, nutrient availability, and erosion are impacted by losses of soil carbon. The rise in temperature also hastens the loss of soil carbon. Additionally, changes in growth rates or water usage efficiency are indirectly impacted by climate through sea level rise, changes in vegetation due to the climate, anthropogenic interference, or both. It is challenging to measure the changes as a result of soil pollution since different soil-forming processes, particularly biological ones, interact with one another. Increased precipitation has the ability to increase atmospheric nitrogen (N) deposition on soils, encourage soil disturbances, flooding, and subsidence, which can affect wetland and waterlogged habitats. It can also increase soil erosion, which has the potential to pollute surface waters. Rainfall that is more abundant is enhanced by downward movements and pass flow. Elevated ambient temperature has an impact on C3 plants' evapotranspiration and photosynthesis. Both C3 and C4 plants' fertilization and flowering are impacted by increased CO_2. In the short term, both climate warming and growing CO_2 levels in the atmosphere will promote tree growth (**Figure 1**).

4. Factors responsible for communicable diseases

In the last twenty years series of virus generated infectious diseases have been emerged and re-emerged. The zoonotic microbes are continuously evolving and acquiring adaptations, and showing high infectivity and mortality at global level. Severity and risks of communicable diseases have been increased due to human movement, trade, recreation activities and dense population structures. Presence of pathogens in human community and its easy exposure is providing new hosts while eco-climatic conditions favoring microbial growth, transmission and infectivity. Further, evolution of new mutant variants of these pathogens has acquired high infectivity and generating catastrophic effects in human population. There are rising incidences of virus generated disease, flu, dengue, hepatitis, chikungunya, rabies, polio, gastroenteritis and encephalitis throughout the globe (**Figure 1**).

There are external factors that support disease occurrence, among them few important factors are heavy rains, water logging, high humidity, temperature difference, urbanization, deforestation, human migration, settlement of slums, relief camps, and nomadic movements. There is a lack of clean drinking water, cooking, and washing. Lack of sanitation, presence of disease vectors, and contaminated food and waste disposal are responsible for the spread of communicable diseases. Among non-communicable diseases, diabetes is one of the important diseases that kill roughly 30 million people per year worldwide. Three major challenges are i.e. development of insecticidal resistance in insects/vectors of potentially communicable diseases, and drug resistance in microbes and parasites. Cases of lung infection, liver, kidney, and gastrointestinal tract, and child diarrhea are rapidly increasing in developing [14]. Besides, this incidence of child diarrhea [15], neonatal jaundice Click et al., 2013 [16], Collier J et al., 2010 [17], and helminths parasitic infections are spreading in developing and in third-world countries.

Some infectious disorders caused by viruses have originated and returned throughout the past twenty years. The zoonotic microorganisms exhibit significant infectivity and mortality on a global scale as well as ongoing evolution and adaptation. Human migration, trade, recreational activities, and dense population patterns have all contributed to an increase in the severity and hazards of communicable diseases. As new hosts are being created by diseases in the human population and their ease of exposure, microbial development, transmission, and infectiousness are encouraged by the eco-climatic conditions. Furthermore, these infections have evolved novel mutant versions with great infectivity that has disastrous impacts on the human population. Around the world, there are increasing numbers of viral illnesses such as the flu, dengue, hepatitis, chikungunya, rabies, polio, gastroenteritis, and encephalitis. There are environmental factors that encourage the spread of disease. A few of the most significant ones are heavy rainfall, standing water, high humidity, temperature variations, urbanization, deforestation, and human migration, as well as the establishment of slums, relief camps, and nomadic movements. Cooking, washing, and access to clean drinking water are all lacking. The causes of the spread of communicable diseases include poor sanitation, the existence of disease vectors, contaminated food, and improper waste disposal. Diabetes is one of the major non-communicable diseases that kill about 30 million people worldwide each year. The development of insecticidal resistance in insects and possible disease vectors, as well as medication resistance in bacteria and parasites, are three key challenges. In emerging nations, cases of child diarrhea, and liver, kidney, and gastrointestinal tract infections are rising quickly. In addition, helminths parasitic infections, newborn jaundice, and infant diarrhea are all on the rise in third- and developing-world nations.

Due to climatic effects and drug resistance and new mutations in pathogens disease burden has been exacerbated enormously at the global level. In all cases, helminths, protozoans, fungi, bacteria, virus pathogens, and parasite's available drug structure seem to be failed or their usefulness has been much reduced due to the evolution of new mutant variants with multiple drug resistance. There are serious failures at the level of operation, management, and control of the disease. The utmost failure is due to a lack of appropriate vaccines, drug regimens, clinical care, and awareness among people. These are major reasons that are why diseases become uncontrolled and unmanageable. Year after year new mutant variants or climate-induced microbial pathogen genotypes are emerging; these are not only challenging existing drugs but also challenging vaccine efficacy. This disastrous situation can be overcome by having new potential drug structures, control strategies, and methods. For finding quick solutions all biomedical researchers should arrange drug repurposing, testing, diagnosis, and treatment methods with a focus on major human parasitic and microbial diseases. In this article, major zoonotic infections/communicable diseases have been explained with their specific etiology, transmission and epidemiology, and control/preventive measures. More specifically effect of climate on disease occurrence, vector population, drug and insecticide resistance, and generation of new genotypes of microbial pathogens and parasites have been described.

The disease burden has significantly increased globally as a result of climate effects, treatment resistance, and new pathogen mutations. Helminthes, protozoans, fungus, bacteria, virus pathogens, and parasites all appear to be resistant to the available drug structures, or at least their efficacy has been greatly diminished as a result of the emergence of novel mutant versions with multiple drug resistance. At the level of operation, management, and disease control, there are significant problems. The greatest failure is brought on by the absence of the proper vaccine, drug regimens, clinical care, and public awareness. These are the main causes of diseases becoming unmanageable and out of control. Every year, new mutant variants or genotypes of climate-induced microorganisms pose a threat to the efficiency of vaccines as well as to the effectiveness of currently available medications. By coming up with new prospective medicine structures, control tactics, and methodologies, this dreadful scenario can be remedied. All biomedical research should set up drug repurposing, testing, diagnostic, and treatment procedures with an emphasis on the most common human parasite and microbial disorders in order to identify speedy fixes. Major zoonotic illnesses and communicable diseases have been described in this article along with details on their genesis, transmission, epidemiology, and control/preventative strategies. The impact of climate on the occurrence of disease, the population of disease-carrying vectors, drug and pesticide resistance, and the emergence of new genotypes of microbial diseases and parasites have been documented in more detail.

5. Seasonal climate changes and disease occurrence

Global health largely depends on seasonal changes felt and faced during the calendar year. Temperature variability, rainfall, and sunlight put a direct impact on human health [18]. Mostly increased cases of leptospirosis, campylobacter infections and cryptosporidiosis have been noted after devastating floods. Global warming affects water heating, rising the transmission of water-borne pathogens. Pathogens transmitted by vectors are particularly sensitive to climate change because they spend a good part of their life cycle in a cold-blooded host invertebrate whose temperature is similar to the environment (**Figure 1**). A warmer climate presents more favorable conditions for the survival and the completion of the life cycle of the vector, going as far as to speed it up as in the case of mosquitoes. This is the main reason for the upspring of malaria and other viral diseases. Tick-borne diseases have increased in the past years in cold regions because rising temperatures accelerate the cycle of development, the production of eggs, and the density and distribution of the tick population [19].

Seasonal changes experienced and confronted over a year have a significant impact on global health. The direct effects of temperature variation, rainfall, and sunlight on human health are also observed [20]. Following disastrous floods, a rise in leptospirosis, campylobacter infections, and cryptosporidiosis cases has been seen. Water heating is impacted by global warming, which increases the spread of water-borne infections. Because they spend a significant portion of their life cycle in a cold-blooded host invertebrate whose temperature is similar to the environment, pathogens spread by vectors are especially vulnerable to climate change. A warmer environment offers better chances for the vector to survive and complete its life cycle, even hastening it as in the case of mosquitoes. This is the primary cause of the spread of viral infections like malaria. Cold regions have seen a rise in tick-borne infections in recent years because warming temperatures speed up the tick life cycle, egg production, density, and distribution [19].

Most pandemics and endemic diseases happen in favorable climates and seasons to disease vectors. Climate induces reproduction in adults of vectors and infectivity in the human population. In the rainy season, more cases of Cholera, malaria, diarrhea, and dysentery rise at their peak while, cough cold and asthma, chicken pox, and smallpox in the winter and spring season. Thus both regular seasonal cycles and weather factors play either direct or indirect roles in disease occurrence and infection rate [20-23]. Cholera cases shoot up during rainy or monsoon season when river water level and surface area get increased [24]. During the rainy season sudden rise in vector population primary transmission of *Vibrio cholerae* from an aquatic environmental reservoir get increased manifold in endemic regions [25]. It also varies due to physical and biological parameters [26,27]. Warm temperature, sunlight, nutrients and winds in the aquatic environment influence the growth of phytoplankton and aquatic plants. These factors alter dissolved O_2 and CO_2 content and pH of the surrounding water and help to accelerate *Vibrio cholerae* growth rate and transmission. High phytoplankton production produces food for zooplankton, to which V. cholerae attaches for protection from the external environment and proliferates.

The majority of pandemics and endemic diseases occur during times of the year when disease vectors thrive. Climate influences adult vector reproduction and human population infectiousness. Cholera, malaria, diarrhea, and dysentery cases increase significantly during the rainy season, whereas cough, cold, asthma cases, chicken pox, and smallpox cases peak in the winter and spring.

6. Multiplication of vector and pathogen population

Reproduction and development of disease vectors widely depend on climatic conditions, and changing weather conditions significant effect on risk from vector-borne diseases. Disease occurrence is climate-dependent as it is proved by recent climate change. It is very difficult to enumerate both the over- and underestimated effects of climate change on pests. In a few parts of the world, the insect pest population is uncontrolled the best examples are mosquitoes, house flies, termites, and locusts. Few direct effects of climate on pesticides are responsible for resistant pest populations. The recent corona pandemic, monkeypox, dengue, and malaria are the best examples of vector-borne diseases due to climate change. Climate-independent factors or dependent factors are directly related to changing risk of climate change [28]. These significant regional changes in vector and pathogen occurrence are mostly seen in Arctic, tropical, temperate, peri-Arctic and subtropical climatic zones. In future there is a possibility that both climate changes and human behavior will result in more conflicts within the society and rest of the animal world as pressure is heavily targeting wildlife and forests.

Climate has a big impact on how disease vectors develop and reproduce, and shifting weather patterns have a big impact on the risk of contracting diseases spread by vectors. Recent climate change has demonstrated that disease occurrence is climate-dependent. It is highly challenging to list both overestimated and underestimated pest consequences of climate change. The best examples of an unregulated insect pest population are mosquitoes, house flies, termites, and locusts. The population of pests that are resistant to pesticides is caused by a few indirect effects of climate. The best examples of vector-borne diseases caused by climate change are the recent corona pandemic, monkey pox, dengue, and malaria. Changes in risk from climate change are directly correlated with factors that are reliant or independent of the climate [28]. The Arctic, tropical, temperate, peri-Arctic, and subtropical climatic zones are where these notable regional differences in the occurrence of vectors and pathogens are most prevalent. As pressure intensifies on wild life and forests, it is possible that both climate change and human behavior could lead to increased conflicts within humanity and among other animals in the future.

Shrinking resources, habitat destruction, and changes in soil, water, and aerial climate are making the condition more intolerable. All physical factors like light, temperature, and winds are creating accidental disturbances that are making a loss of life, goods, agriculture, economy, and people are forced to migrate. The demand for commodities is increasing while the risks of natural calamities are increasing. There is a significant alteration in disease occurrence, fatalities, and morbidities in marginal agriculture-based societies. Recent genetic resistance in insect pests and pathogens defeated the drugs and clinical treatments, loss of action in broad-spectrum drugs, incidence rate, and sudden pandemics have destroyed public services, human behavior; and political stability and conflicts. Recent challenges related to drug and insecticide resistance, and the resurgence of the pest population are on the rise, however, to control the existing and emerging communicable diseases, more funds and grants are required with new pharmaceuticals and clinical facilities at the global level [29].

Resources are being depleted, habitats are being destroyed, and soil, water, and aerial climate changes are making the situation increasingly untenable. All physical conditions, including light, temperature, and winds, cause unintentional disturbances that result in the loss of life, property, agricultural production, the economy, and the need for population migration. Commodity demand is rising, and so are the chances of natural disasters. In marginal agriculture-based cultures, disease incidence, mortality, and morbidities have significantly changed. Recent pandemics are going on due to genetic resistance to infectious agents and insect pests. These changes have resulted in the loss of efficacy of broad-spectrum medications and devastated public services, human behavior, political stability, and conflicts. However, additional funding and grants are needed for new medications and clinical facilities at a global level to manage to exist and emerging communicable illnesses. Recent issues connected to drug and pesticide resistance, and a rebound of the pest population are on the rise [29].

Changing weather conditions are imposing direct and indirect impacts on human health and increasing risks. Climate-sensitive infections pose a disproportionate burden and ongoing risk to both smaller and large human communities, hence, surveillance, diagnosis and prevention of diseases become highly important to minimize or prevent infections [30]. Severe risks of infectious disease are also made after forced displacement due to disasters from rural sites to urban-poor areas; labor migration and illegal human trafficking add new types of risks. Therefore, disease diagnosis and treatment are highly essential for migrants, because, in lack of these, they convert into epicenters of epidemic diseases. Hence, the administration should try to understand and respond to the health impacts of all infectious disease cases found in migrant populations and host communities [31]. All three parameters changing ecology and transmission dynamics of infectious disease and treatments methods available must be rechecked and advanced.

The risks associated with changing weather are rising and having both direct and indirect effects on human health. Smaller and larger human societies are equally in danger from climate-sensitive illnesses, making disease surveillance, diagnosis, and prevention crucial for reducing or eliminating infections [30]. After forced relocation from rural sites to urban-poor areas owing to disasters, labor migration, and any illicit human trafficking add additional sorts of risks, severe infectious disease risks are also created. For this reason, sickness diagnosis and treatment are absolutely crucial for migrants, as without them, they become the centers of epidemic diseases. As a result, management should attempt to comprehend and address the health implications of all infectious disease cases discovered in migrant groups and host communities [31]. All three variables, which include the dynamics of evolving infectious disease ecology and transmission, as well as current treatment options, need to be reviewed and improved.

6.1 Flies as vectors

Arthropods mainly spiders, scorpions, ticks, and mites; lice, fleas, bedbugs, flies, bees, and ants, these insects impose allergies, morbidity, and mortality in human beings worldwide [32]. Bites of these insects are major mode of transmission of disease pathogens, their stings cause allergies and impose life threatening physiological and biochemical changes. Flies are known vectors for a variety of infectious diseases mainly Aleutian disease in animals. *Fannia canicularis* (L.) (Diptera: Muscidae) is a vector of Aleutian mink disease virus in mink farms [33]. *Cochliomyia hominivorax* is a fly that causes oral myiasis or fly-blown disease that is found in tropical and subtropical areas [34]. This disease is characterized by symptoms of severe pain, swelling, itchy sensations, and the feeling of something moving in the mouth [35]. Japanese encephalitis (JE) is a viral disease predominantly located in South East Asia. It is transmitted by the mosquito *Culex tritaeniorhynchus*. The disease is causing severity due to geography, climate change, and urbanization [36]. Trachoma is a keratoconjunctivitis caused by flies *Chlamydia trachomatis*, in Botucatu Sao Paulo State, Brazil. This is a leading cause of blindness in the world [37].

Insect stings can trigger allergies and have potentially fatal physiological and biochemical effects. Insect bites are a significant way that disease infections are transmitted. Humans develop allergic reactions when some insects including bugs, fleas, mites, and ticks are present, and their salivary proteins do the same. The class Arachnida of arthropods, which includes spiders, scorpions, ticks, and mites, and the class Insecta, which includes lice, fleas, bedbugs, flies, bees, and ants, are responsible for a significant portion of sickness and mortality among humans worldwide [32].

Flies have known vectors for a variety of infectious diseases mainly Aleutian disease in animals. *Fannia canicularis* (L.) (Diptera: Muscidae) is a vector of the Aleutian mink disease virus in mink farms [33]. Oral myiasis or fly-blown disease is caused by *Cochliomyia hominivorax* a fly that is found in tropical and subtropical areas [34]. The main symptoms of oral myiasis are severe pain, swelling, itchy sensation, and the feeling of something moving in the mouth [35]. Japanese encephalitis (JE) is a viral disease predominantly located in South East Asia. It is transmitted by the mosquito *Culex tritaeniorhynchus*. The disease is causing severity due to geography, climate change and urbanization [36]. In Botucatu, Sao Paulo State, Brazil, flies carrying the keratoconjunctivitis virus *Chlamydia trachomatis* are the source of trachoma. According to Meneghim et al. [37], this is a major cause of blindness worldwide.

Cattle hypodermis (warble fly infestation) is a notorious veterinary problem throughout the world. Larvae of Hypoderma species cause subcutaneous myiasis in domesticated and wild ruminants. This disease is caused by, *Hypoderma bovis, Hypoderma lineatum* in cattle whereas, *Hypoderma diana*, *Hypoderma actaeon*, and *Hypoderma tarandi*, affect roe deer, red deer, and reindeer, respectively. Adults of the cattle grub are commonly known as heel flies, warble flies, bomb flies or gad flies. The biology of hypodermis is complex because it passes through ecto- as well as endoparasitic stages in the life cycle [38]. Myiasis caused by Hypodermatinae flies is an economically important disease affecting domesticated and wild ruminants in countries of the Mediterranean and Indian subcontinent. Adult female insects lay eggs on the coat of animals. *Hypoderma* spp. primarily lay their eggs on cattle, buffalo, roe deer, red deer and reindeer, while Przhevalskiana spp. lay eggs on the coat of goats [39]. *Hypoderma tarandi* larvae infect early-age calves of reindeer Rangifer *tarandus tarandus* skin of the back [40]. Dengue hemorrhagic fever (DHF) virus or Dengue virus (DENV) is a mosquito-borne virus mainly *Aedes* sp. mosquitoes from an infected host to non-infected [41,42].

A well-known veterinary issue worldwide is cattle hypodermis (infestation with warble flies). Domesticated and wild ruminants that are exposed to Hypoderma species' larvae develop subcutaneous myiasis. *Hypoderma diana, Hypoderma actaeon*, and *Hypoderma tarandi*, which affect roe deer, red deer, and reindeer, respectively, are the causes of this disease in cattle. Hypoderma bovis and Hypoderma lineatum are the causes of the condition in humans. Heel flies, warble flies, bomb flies, or gad flies are common names for the adults of the cattle worm. The life cycle of hypodermis includes both ecto- and endoparasitic stages, which complicates its biology [38]. Myiasis, a disease brought on by Hypodermatinae flies, affects both domesticated and wild ruminants in the Mediterranean and Indian subcontinent nations. On the fur of animals, adult female insects deposit their eggs. While Przhevalskiana spp. lay eggs on the coat of goats, *Hypoderma* spp. primarily lay their eggs on cattle, buffalo, roe deer, red deer, and reindeer [39]. The skin on the back of young calves of reindeer Rangifer tarandus is infected with *Hypoderma tarandi* larvae [40]. The virus that causes dengue hemorrhagic fever (DHF) or dengue (DENV) is spread by mosquitoes, primarily *Aedes* sp. mosquitoes, from an infected host to an uninfected host [41,42].

Francisella tularensis is a bacterium that causes Tularemia an endemic zoonotic infection mostly seen in North America and parts of Europe and Asia. This disease is transmitted by ticks and deer flies [43]. Similarly, sleeping sickness or trypanosomiasis is a vector-borne disease caused by a protozoan parasite *Trypanosoma brucei, T gambiense*, Human African trypanosomiasis. This disease is caused by bites of tsetse flies Glossina palates. Infection with *Trypanosoma brucei rhodesiense* leads to the acute, zoonotic form of Eastern and Southern Africa [44]. Arthropod vectors transmit African and American trypanosomiases, and disease containment through insect control programmes is an achievable goal [45]. Cutaneous leishmaniasis is a disease caused by various *Leishmania spp*., which are transmitted by phlebotomine sand flies. This fly has seven species, with *Phlebotomus perniciosus* (76.2%), *Ph. papatasi* (16.7%) and Ph. sergenti (5.0%) being the most common species, representing together 97.9% of the collected specimens. The remaining specimens were identified as *Sergentomyia minuta, Se. fallax, Ph. longicuspis and Ph. perfiliewi* [46].

In North America, some regions of Europe, and Asia, *Francisella tularensis* is a bacterium that causes tularemia, an endemic zoonotic infection. Ticks and deer flies are the carriers of this disease [43]. In a similar vein, trypanosomiasis, also known as sleeping sickness, is an infection brought on by the protozoan parasites *Trypanosoma brucei, T gambiense*, human African trypanosomiasis. The tsetse fly, *Glossina palalis,* which transmits this disease, bites humans. The acute, zoonotic variant of Trypanosoma brucei rhodesiense infects people in Eastern and Southern Africa [44]. African and American trypanosomiases are transmitted by arachnid vectors, making disease containment through insect control programs a realistic objective. In 2003, *Leishmania* sp., which is spread by phlebotomine sand flies, cause cutaneous leishmaniasis, a disease [45]. There are seven different species of this fly, with *Phlebotomus perniciosus* (76.2%), *Ph. papatasi* (16.7%), and *Ph. sergenti* (5.0%) making up the majority and accounting for 97.9% of the specimens gathered. *Sergentomyia minuta, Se. fallax, Ph. longicuspis*, and *Ph. perfiliewi* were named for the remaining specimens [46].

6.2 Tick vectors

Ticks (Acari: Ixodida) are ectoparasites that rely on a blood meal from a vertebrate host at each developmental stage for the completion of their life cycle. Ticks are serious health threats to humans and both domestic and wild animals in tropical and subtropical areas. These cause severe economic losses both through the direct effects of blood-sucking and indirectly as vectors of pathogens. Tick feeding causes transmission of pathogens and evokes severe infections, morbidity, and immune reactions in man. Feeding by large numbers of ticks causes a reduction in live weight gain and anemia among domestic animals, while tick bites also reduce the quality of hides. However, the major losses caused by ticks are due to the ability to transmit protozoan, rickettsial and viral diseases of livestock, which are of great economic importance worldwide [47].

Ectoparasite ticks (Acari: Ixodida) require a blood meal from a vertebrate host at each stage of development to complete their life cycle. Ticks are serious health threats to humans and both domestic and wild animals in tropical and subtropical areas. Ticks are responsible for severe economic losses both through the direct effects of blood-sucking and indirectly as vectors of pathogens. Animal health is impacted by the tick feeding cycle because it results in hide damage, secondary infections, immunological reactions, and diseases brought on by the spread of pathogens. Domestic animals who are heavily tick-fed experience reduced weight gain and anemia, and the quality of their hides is also compromised by tick bites. The ability of ticks to transmit livestock diseases including protozoan, rickettsial, and viral infections, which are extremely important economically around the world, is what causes the majority of losses [47].

Brown tick Ixodes hexagons live on the bodies of domestic and wild animals and vegetation. It transmits *Theileria parva* a protozoan parasite, which causes the tick-transmitted disease East Coast fever in cattle mainly in ruminants [48]. Tick-borne anaplasmosis and ehrlichiosis are clinically important emerging zoonoses of ticks belonging to three genera (*Rhipicephalus, Hyalomma,Haemaphysalis*).Tick-borne relapsing fever in North America is primarily caused by the spirochete *Borrelia hermsii.* Babesial vector tick defensin against *Babesia sp*. parasites [48]. Ticks possess sticky nature and ixodid ticks stick over the body of migratory birds, particularly passerines, infected with tick-borne pathogens, like *Borrelia spp., Babesia spp., Anaplasma*, Rickettsia/Coxiella, and tick-borne encephalitis virus. The prevalence of ticks on birds varies over years, seasons, locality and different bird species. Adult *Ixodes ricinus* is red-brown, but the female ticks are light gray when engorged. Before feeding, sheep tick males are approximately 2.5-3 mm long and females 3-4 mm long. When they are engorged, the females can be as long as 1 cm. Their palps are longer than the base of the gnathostome.

Black ticks live on the bodies of both domestic and wild animals as well as on flora, Ixodes hexagons are. It spreads the protozoan parasite Theileria Parva, which is the primary cause of East Coast fever in cattle and other ruminants [48]. Emerging zoonoses ticks from three genera are clinically significant carriers of anaplasmosis and ehrlichiosis. In North America, the spirochete Borrelia hermsii is the main cause of tick-borne relapsing fever, Babesial vector tick defensin against Babesia sp. parasites Ixodid ticks, which carry infections like *Borrelia spp., Babesia spp., Anaplasma*, *Rickettsia/Coxiella*, and tick-borne encephalitis virus, adhere to the bodies of migratory birds, especially passerines. Tick prevalence in birds varies depending on the year, season, location, and type of bird. *Ixodes ricinus* adults are red-brown, whereas engorged female ticks are pale gray. Male sheep ticks are roughly 2.5-3 mm long, whereas females are 3-4 mm long before feeding. The females can grow up to 1 cm long when they are engorged. Their palps extend farther than the gnathostome's base.

Ixodes ricinus is a major pest of sheep, cattle, deer, dogs and humans. A few medically important ixodid ticks include *Amblyomma*spp, *Anomalohimalaya*spp, *Bothriocroton*spp, *Cosmiomma*sp, *Dermacentor*spp, *Haemaphysalis* spp, *Hyalomma*spp, *Ixodes*spp, *Margaropus*spp, *Nosomma*sp, *Rhipicentor*spp, and *Rhipicephalus*spp.*Ixodesricinus* a free-living tick has been intensively studied [49,50]. The nymph of the western black-legged tick (*Ixodes pacificus*) is an important bridging vector of the Lyme disease spirochete (*Borrelia burgdorferi*) to humans in the far-western United States [51]. These show horizontal and vertical movements of host-seeking *Ixodes pacificus* (Acrii Ixodidae) nymphs in hardwood forests.

Ixodes ricinus is a serious pest to humans, dogs, cattle, sheep, and deer. *Amblyommaspp, Anomalohimalayaspp, Bothriocrotonspp, Cosmiommaspp, Dermacentorspp, Haemaphysalisspp, Hyalommaspp, Ixodesspp, Margaropusspp, Nosommasp, Rhipicen-*

torsspp, and *Rhipicephalusspp* are a few ixodid ticks that are significant medically. In-depth research has been done on the free-living tick *Ixodes ricinus* [49,50]. In the far western United States, the nymph of the western black-legged tick (*Ixodes pacificus*) is a crucial bridging vector of the Lyme disease spirochete (*Borrelia burgdorferi*) to humans [51]. These depict the movements of host-seeking Ixodespacificus (AcriiIxodidae) nymphs in a hardwood forest in both the horizontal and vertical planes.

Mites, nematodes and spirochaetes, feed on ticks, as they carry diseases as the primary hosts of pathogens. These organisms could not reach their secondary hosts. The diseases caused may debilitate their victims, and ticks may thus be assisting in controlling animal populations and preventing overgrazing [52]. Ticks remain attached to the body of mobile hosts and reach new far distant locations, best example is bird hosts, which even carry ticks across the sea. The infective agents can be present not only in the adult tick but also in the eggs produced plentifully by the females. Many tick species have extended their ranges as a result of the movements of people, their pets, and livestock. With increasing participation in outdoor activities such as wilderness hikes, more people and their dogs may find themselves exposed to attack [53]. Lyme disease transmission cycles are maintained by different vector species *Ixodes scapularis* and *Ixodes pacificus*, respectively. Though these show differences in transmission efficiency can be used to identify vector competence contributes to variable Lyme disease risk [54].

Since ticks are the main hosts for the pathogens that cause diseases, mites, nematodes, and spirochaetes prey on them. The secondary hosts of these organisms were out of reach. Ticks may be helping to manage animal populations and prevent overgrazing because the diseases they spread may render their victims helpless [52]. The longer period that a tick remains attached, during which the mobile host can be transported across great distances or, in the case of hosts that are birds, across the ocean, enhances the spread of the disease. The infectious pathogens can be found in both the adult tick and the female ticks' copious amounts of eggs. Because of the mobility of people, their pets, and cattle, many tick species have expanded their geographic ranges. As more people engage in outdoor activities like wilderness hikes, more people and their dogs may become vulnerable to attack [53]. Lyme disease transmission cycles are maintained by different vector species *Ixodes scapularis* and *Ixodes pacificus* respectively. Though these show differences in transmission efficiency can be used to identify vector competence contributes to variable Lyme disease risk [54].

6.3 Mosquito vectors

Malaria is a worldwide disease; the spectrum of this disease is increasing at the global level. Global warming induced by human activities has increased the risk of vector-borne diseases such as malaria. During the last three decades, its incidences have enormously increased in South East Asian countries, African countries, and Australia as changing climates have favored the reproduction and survival rate in vector populations. Rising temperature, rainfall, presence of host and parasite enhanced epidemiological risks of malaria. In the last two decades, the human malaria parasite has rapidly changed its genome according to the type of human host and vector population and ongoing climatic variations. Anopheline mosquitoes have developed resistance against variations in temperature, salinity, pesticides, and against plasmodium the malaria parasite [55]. There are four strains of malaria parasite infections with *Plasmodium falciparum, Plasmodium yoelii* and *Plasmodium berghei* parasites among which newly emerged Plasmodium knowlesi disease is more fatal, its natural primate hosts are *Macaca fascicularis, M. nemestina, M. inus, and Saimiri scirea.* All these are transmitted by 70 species of mosquitoes among which 41 are more prominent and dominant vectors which that transmit the malaria parasite [55]. The reason behind rising cases of malaria is genetic resistance developed by the parasite, human migration, failure of drug formulae, eco-climatic changes, poor health policies, human migration, and pesticide resistance in malaria vectors [55]. The rise in the anopheline mosquito population are floods, urbanization, hygiene, tropical forests, and humidity. Insecticide resistance is the main problem and hurdle that is lowering the effectiveness of vector-borne disease management [56]. However, molecular investigations are required to diagnose mechanisms involved in the development of the parasites in New World vectors [57]. The intensity of transmission is dependent on the vectorial capacity and competence of local mosquitoes (**Table 1**) [55].

Malaria is a disease that affects people all around the world and its range is expanding globally. The likelihood of vector-borne illnesses like malaria has increased due to global warming brought on by human activity. Because of the changing climate, the vector population's survival and reproduction rates have increased significantly during the past three decades in South East Asian, African, and Australian nations. Increasing temperatures, precipitation, the presence of a host and a parasite, and malaria

Table 1. Major communicable diseases with their vector and reservoir hosts.

Diseases	Vector	Infected Population	Main Reservoir	Affected Area
Dengue Fever	Ades	Human	None (Primates)	Africa Asia America (Inter -tropical zone)
Yellow Fever	Ades	Human	Monkey	Africa, America (Inter -tropical zone)
West Nile encephalitis	Ades, culex	Human (Horse)	Birds	Africa,Middle East Southern Europe, America
Tick-borne encephalitis	Ticks	Human	Wild Animals cervids, Rodents	Central Europe Scandinavia
Japanese encephalitis	Ades, culex	Human (Pigs)	Birds (Pigs)	Far East
Chikungunya fever	Ades	Human	Monkey	Africa,South Europe,
RVF Virus (Phlevo virus)	Ades	Human (Sheep,cattle,goat, canines,felines)	Sheep,cattle	Equatorial Africa
Hantavirus	Rodents	Human	Rodents	Asia (Hantaan virus) America (Sin Nombre Virus)
Lymphatic filariasis	*Culex/ Anopheles*	Human	Human	Sub-Saharan Africa
Rift Valley fever	*Aedes*	Human	Mosquitoes	eastern and southern Africa, sub-Saharan Africa, Madagascar, Saudi Arabia and Yemen.
Zika	*Anopheles*	Human		Africa to Asia
Malaria	*Anopheles*	Human		North America
Onchocerciasis (river blindness)	Blackflies	livestock such as cattle, sheep, goats, buffalo, and camels.	Human	Africa, with additional foci in Latin America and the Middle East.
Plague (transmitted from rats to humans)	Fleas	Human	Rats	Africa, Asia and the United States
Tungiasis	Fleas	Human	pigs	Mexico to South America, the West Indies and Africa.
Typhus	Lice	rats, cats, or opossums	Human	Southeast Asia, Japan, and northern Australia
Louse-borne relapsing fever	Lice	Human	Dog	north-eastern Africa
Leishmaniasis	Sandflies	Human		Mexico, Central America, and South America
Sandfly fever (phlebotomus fever)	Sandflies	Human	rodents,	Mediterranean, Middle East, northern African and western Asian countries

Table 1 continued

Diseases	**Vector**	**Infected Population**	**Main Reservoir**	**Affected Area**
Crimean-Congo haemorrhagic fever	Ticks	wild and domestic animals, such as cattle, goats, sheep and hares	Hard ticks	the Mediterranean, in northwestern China, central Asia, southern Europe, Africa, the Middle East, and the Indian subcontinent
Lyme disease	Ticks	wild and domestic animals, such as cattle, goats, sheep and hares	white-footed mouse (Peromyscusleucopus)	Northeast, mid-Atlantic, upper Midwest, and West Coast.
Relapsing fever (borreliosis)	Ticks	wild and domestic animals, such as cattle, goats, sheep and hares	Human	North America, plateau regions of Mexico, Central and South America, the Mediterranean, Central Asia, and much of Africa.
Rickettsial diseases (eg: spotted fever and Q fever)	Ticks	wild and domestic animals, such as cattle, goats, sheep and hares	Human	Hawaii, California, and Texas.
Tularaemia	Ticks	wild and domestic animals, such as cattle, goats, sheep and hares	rabbits, hares, and muskrats	south central United States, the Pacific Northwest, and parts of Massachusetts, including Martha's Vineyard.
Chagas disease (American trypanosomiasis)	Triatome bugs	wild and domestic animals, such as cattle,	Human	Americas
Sleeping sickness (African trypanosomiasis	Tsetse flies	wild and domestic animals, such as cattle,	Human	central Africa and in limited areas of West Africa

epidemiological risks. The human malaria parasite has quickly altered its genome during the past 20 years in response to the many human hosts, vector populations, and ongoing environmental changes. Anopheline mosquitoes have evolved resistance to insecticides, plasmodium, temperature fluctuations, and salinity changes [55]. There are four different types of malaria parasite illnesses, including *Plasmodium berghei, Plasmodium yoelii,* and the recently discovered *Plasmodium knowlesi* disease, which is more deadly and has *Macaca fascicularis* as its natural monkey host. M. Nemestine as well as Saimiri science. All of them are spread by 70 different kinds of mosquitoes, of which 41 are the most common and effective vectors for the malaria parasite [55]. The parasite's genetic resistance, human movement, medication formula failure, eco-climatic changes, inadequate health policies, human migration, and pesticide resistance in malaria vectors are all contributing factors to the increase in instances of malaria [55]. Floods, urbanization, sanitation, tropical forests, and humidity all contribute to an increase in the anopheline mosquito population. The primary issue and roadblock limiting the efficiency of managing vector-borne diseases is insecticide resistance [56]. However, to identify the processes involved in the growth of the parasites in New World vectors, molecular analyses are necessary [57]. The competence and vectorial potential of the local mosquito population determine how intense the transmission will be [55] (**Table 1**).

6.4 Pesticide resistance in insect vectors

Resistance to currently-used insecticides varied greatly between the four-vector species. While no resistance to any insecticides was found in the two Aedes species, bioassays confirmed multiple resistance in *Cx. p. quinquefasciatus* (temephos: ~20 fold and deltamethrin: only 10% mortality after 24 hours). In *An. gambiae*, resistance was scarce: only moderate resistance to temephos was found (~5 fold). resistance levels of four major vector species (*Anopheles gambiae*, *Culex pipiens quinquefasciatus*, *Aedes aegypti* and *Aedes albopictus*) to two types of insecticides: i) the locally currently-used insecticides (organophosphates, pyrethroids) and ii) alternative molecules that are promising for vector control and come from different insecticide families (bacterial toxins or insect growth regulators) [58]. The emergence of genetic engineering is used to improve human health using genetic manipulation techniques in a clinical context. Gene therapy represents an innovative and appealing strategy for the treatment of human diseases, which utilizes vehicles or vectors for delivering therapeutic genes into the patient's body. However, a few past unsuccessful events that negatively marked the beginning of gene therapy resulted in the need for further studies regarding the design and biology of gene therapy vectors, so that this innovating treatment approach can successfully move from bench to bedside (**Table 1**) [59].

6.5 Insect vectors that exhibit pesticide resistance

The four-vector species showed very different levels of pesticide resistance. The two *Aedes* species had no pesticide resistance, while bioassays showed that Cx had multiple insecticide resistance. *P. quinquefasciatus* (mortality after 24 hours for temephos was 20-fold lower than for deltamethrin) In *An. gambiae*, resistance was limited; only a mild resistance to temephos (5-fold) was discovered. *Anopheles gambiae, Culex pipiens quinquefasciatus, Aedes aegypti*, and *Aedes albopictus* are four major vector species. Resistance levels to two types of insecticides have been studied: The locally prevalent organic phosphates and pyrethroids and alternative molecules that are promising for vector control and come from different insecticide families (bacterial toxins or insect growth regulators). Through the use of clinically relevant genetic alteration techniques, the development of genetic engineering is being used to enhance human health. Gene therapy, which uses carriers or vectors to transport therapeutic genes into patients' bodies, is a cutting-edge and alluring approach to treating human ailments. However, a few prior instances of failure that adversely affected the development of gene therapy necessitated additional research into the design and biology of gene therapy vectors in order for this ground-breaking therapeutic strategy to successfully transition from bench to bedside [59].

6.6 Drug resistance in microbes

In normal environmental conditions mainly temperature imposes mutations that confer resistance to a drug that is rare and undetected. The genetic switches found in bacteria are more susceptible to altering the behavior of genes accordingly as the target drug is set right and its action is foiled in two steps. In an environment with the addition of drugs, the drug-resistant mutants favored and replaced the normal bacteria. There occurs directive selection in bacteria that non-pathogenic strains are converting into pathogenic and later on into resistant one. It might be thought that the mutations conferring resistance are caused or induced by the drug, but this is not true. It is a natural phenomenon that drug-resistant mutations occur in bacterial cells irrespective of the presence or absence of the drug. This is the nature of bacterial cells that mutation occurs simultaneously without drug exposure. This is an open race between man and microbes to sabotage each other to acquire fitness through natural selection. Both shield and attack are becoming more advanced and are proving lethal tools for each other. Though, in the past and even today microbes have attained the required resistance against thousands of synthetic drugs by making changes in the genetic system. Microbes are UN-conquered warriors on this earth because of their adaptations, flexibility in the mode of feeding, and behavioral and genetic selection than any other organism. It has also ascertained their survival in extreme climatic conditions both outside host or exotic conditions. Among microbes most of the species belong to various groups which are pathogenic to man and their ultimate survival comes through the creation of a pathogen city to the host.

Mutations that confer drug resistance are uncommon and go undiscovered in typical environmental conditions, when the temperature is the dominant environmental constraint. The genetic switches present in bacteria are more likely to change gene behavior as the target drug is corrected and its function is thwarted in two steps. The regular bacteria were preferred and replaced by drug-resistant mutants in an environment where drugs were added. Directive selection occurs in bacteria, resulting in the transformation of non-pathogenic strains into pathogenic and then resistant ones. Contrary to popular belief, the medication does not actually cause or trigger the mutations that confer resistance. Regardless of whether a medicine is present or not, drug-resistant mutations in bacterial cells are a common occurrence. Bacterial cells naturally undergo simultaneous mutations without being exposed to drugs. Mankind and germs are engaged in a competitive race to sabotage one another in order to improve their fitness through natural selection. Shield and assault are both evolving and proving to be deadly instruments for one another. However, both in the past and in the present, bacteria have developed the necessary resistance to countless man-made medications by altering their genetic makeup. This is a reality that infectious agents have increased their selection against existing drugs and vaccines available and becoming unbeatable combatants on our planet. Additionally, it has been demonstrated that they can survive in hostile environments or under ideal conditions regardless of the climate. Most microbe species belong to groups that are harmful to humans, and they ultimately survive by developing pathogen cities in their hosts.

There is a strong tug-of-war between pathogenic genes and medicine mainly broad-spectrum chemical agents. It is the finest work of pharmacists and chemists but has a worthless future. There is negative and positive selection seen in newly altered genes due to mutations providing strong biological scissors against bacterial pathogens in spite of the fact that new medicines are coming generation after generation with much-enhanced lethality. There is no drug that can absolutely kill drug-resistant bacterial strains. This is because microbes are developing resistance through evolutionary selection patterns and new enzyme system is becoming stronger and stronger. Are we ready to fight against nature-supported microbes as we are opting for artificial selection and losing our own fitness and adaptation by living in artificial conditions? For nature man is a societal wise animal that is living luxurious life without knowing its consequences and is facing many risks, there is no way to make protection against the sudden evoking of pathogenic endemics. Man has self compromising genetic system, and having noncompromising attitude toward nature and her organisms. A large pile of the drug has been proven worthless and it could not able to kill even a single resistant strain of bacteria, viruses, fungi, PPLOs, and Prions.

Pathogenic genes and largely broad-spectrum chemical drugs are engaged in a fierce battle. Despite being a pharmacy and chemist's finest achievement, it has little future value. Despite the fact that new medications are being developed every generation with significantly increased lethality, there is still negative and positive selection found in newly altered genes as a result of mutations that gave strong biological scissors against bacterial infections. Drug-resistant bacterial strains cannot be completely eradicated by any medication. This is due to the fact that novel enzyme systems are getting increasingly potent and that microorganisms are evolving resistance through patterns of evolutionary selection. Are we prepared to fight back against the germs that nature supports, as we are choosing the artificial selection, losing our own fitness, and failing to adapt to our environment? Since man is a socially intelligent animal who leads a lavish lifestyle without considering the implications and is exposed to numerous risks, there is no way to be protected from the rapid emergence of pathogenic endemics. Man has a genetic system that compromises him, and he has a non-compromising attitude toward nature and her creatures. Numerous drugs have been shown to be useless and unable to eradicate even one resistant strain of bacteria, virus, fungus, PPLOs, or Prions.

It is considerable truth that seventh-generation anti-microbials are highly lethal to microbes, but microbes generated the capability to gain resistance by employing genes to synthesize new enzymes to cleave drug formulae. Only very few allelopathies we intake in daily meals hence, could not achieve sizable resistance. In other words, we receive all utilizable from 30-40 plant species but bacteria have interacted with thousands of plants and animal species and have generated more sensitivity and identification capacity against medicinal molecules which could be sued by a human being as a drug.

Seventh-generation anti-microbials are undoubtedly effective tools for controlling microorganisms, but they also use a genetic system that coordinates thousands of genes to produce new enzymes. Only a very small number of the allelopathy we consume daily might thus not generate significant resistance. In other words, we get what we need from 30-40 plant species, whereas bacteria have interacted with thousands of plant and animal species, increasing their sensitivity to and the ability for identifying drugs that humans might use.

6.7 Gene transfer, virus vectors and drug resistance

Viral vectors are promising gene carriers for cancer therapy. These new genes delivered for therapeutic purposes are increasing safety risks to human health [60]. Adeno-associated virus (AAV) vectors are important delivery platforms for therapeutic genome editing but are severely constrained by cargo limits [61]. These Ad vectors evade pre-deployed immunity. There is a need to make genetic and chemical modifications capsid for modulation of vector–host interactions of Ad-based vectors [62]. Transgenesis and paratransgenesis are highly important molecular methods to control insect-borne diseases. These methods easily decrease insect vectorial capacity, and break the transmission of pathogens such as *Plasmodium sp., Trypanosoma sp*., and Dengue virus. Vector transgenesis relies on direct genetic manipulation of disease vectors making them incapable of functioning as vectors of a given pathogen. In addition, genetically modified insect symbionts are also used to express molecules within the vectors that are deleterious to pathogens they transmit [63]. Finally new genetic additions may induce linear functional responses from hosts and vectors that might increase disease transmission potential in vectors and longevity in the pathogen cycle within the body of hosts. But for control of transmission of the behavioral ecology of insects, molecular changes in pathogens must be studied [64]. Further, the use of virus vectors for the transfer of silencing genes preferable integration sites must be searched with stable expression models [65,60]. For increasing translation efficiency there is a need to improve the quality of oversized vectors [66].

Over one million people die each year as a result of nearly 20% of infectious diseases that are vector-borne. Recently, a few virus-based vectors were employed to create possible vaccines to fight the COVID-19 disease and protect people's immune systems. Finally, new genetic additions might cause hosts and vectors to respond linearly, which could increase the possibility of disease transmission in the vectors and lengthen the pathogen cycle within the body of the hosts. However, molecular modifications in the pathogen must be investigated to control the transmission of insect behavioral ecology [64]. Additionally, stable expression models must be used to search for the best integration locations when using viral vectors to deliver silencing genes [65,60]. It is necessary to raise the caliber of large vectors to increase the translation efficiency of these [66].

The capacity of lentiviral protein transfer vectors (PTVs) for targeted antigen transfer directly into APCs and thereby induction of cytotoxic T cell responses. PTVs can be used as safe and efficient alternatives to gene transfer vectors or live attenuated replicating vector platforms, avoiding genotoxicity or general toxicity in highly immunocompromised patients, respectively. Thereby, the potential for easy envelope exchange allows the circumventing of neutralizing antibodies, e.g., during repeated boost immunizations [67]. The integrated vector management plan, including all the good practices, learned from previous experiences [58]. Almost 20% of all infectious human diseases are vector-borne and, together, are responsible for over one million deaths per annum. Recently few of the virus-based vectors were used for the generation of potential vaccines to fight against COVID-19 disease, the immune safety of people.

Lentiviral protein transfer vectors' (PTVs') ability to transfer specific antigens directly into APCs and consequently trigger cytotoxic T-cell responses.

PTVs can be employed as effective and safe substitutes for live attenuated replicating vector platforms or gene transfer vectors, preventing genotoxicity or general toxicity in severely immunocompromised individuals, respectively. As a result, the possibility of simple envelope exchange enables the avoidance of neutralizing antibodies, for instance, during repeated booster immunizations [67]. A comprehensive vector management strategy that takes into account all the wise decisions made in the past [58]. Almost 20% of all infectious human diseases are vector-borne and, together, are responsible for over one million deaths per annum. Recently few of the virus-based vectors were used for the generation of potential vaccines to fight against COVID-19 disease, the immune safety of people.

6.8 Drug resistance, virus vectors, and gene transfer

Promising gene carriers for cancer therapy are viral vectors. These spread genes for therapeutic purposes but raise security concerns and bring about the emergence of new virus strains as a result of gene fusion and conversion [60]. Although cargo restrictions severely restrict the use of Adeno-Associated Virus (AAV) vectors as therapeutic genome editing delivery platforms [61]. These advertisement routes avoid deployed immunity. Ad-based vectors' capsids require genetic and chemical alterations in order to control the interactions between the vector and the host [62]. Insect-borne disease control uses transgenesis and paratransgenesis, two crucial molecular techniques. These techniques can reduce the ability of insects to transmit disease and stop the spread of viruses like the Dengue virus, Trypanosoma species, and Plasmodium species. By directly altering the genetic code of disease vectors, vector transgenesis renders them unable to spread a specific pathogen. The goal of paratransgenesis is to use genetically altered insect symbionts to express chemicals that are harmful to the infections they transmit within the vector [63].

7. Host immunity and pathogen antigens

New interactions between plasmodium and mosquito vectors have been observed related to the mechanism of innate immune defense responses in anopheline mosquitoes. The body of these mosquitoes makes an innate immune defense and is applied to confine and kill malaria parasites under migration and development. It could be used as one of the effective strategies to control malaria vectors [68]. Mosquitoes and other insects lack adaptive immune defense but they respond to different bacteria and fungi with the same innate immune system by using different defense peptides. Anopheles gambiae mosquito vector contains transition stages of midgut invasion and relocation of sporozoites from the oocysts to the salivary glands. After invasion mosquito innate immune system is activated that kills plasmodium parasite inside salivary glands [69].

The mechanism of innate immune defense responses in anopheline mosquitoes has revealed new interactions between the plasmodium and insect vector. These mosquitoes' bodies produce an inherent immune defense that is used to contain and eliminate malaria parasites while they are migrating and developing. It could be one of the most successful methods for controlling malaria vectors [68]. Although mosquitoes and other insects lack adaptive immune protection, they nonetheless use the same innate immune system to respond to various bacteria and fungus by employing various defense peptides. The mosquito vector Anopheles gambiae has intermediate stages of midgut invasion and sporozoites that go from the oocysts to the salivary glands. Following the invasion, the innate immune system of the mosquito destroys the parasite plasmodium inside the salivary glands [69].

There is one important question Anopheles mosquitoes have developed mechanisms to confront Plasmodium infections during feeding, if vector immune competence may be explored it will help to prevent pathogen transmission [70]. There are three important points seasonal variations, new variants of parasites, and new defense molecules in vectors are favored by a climate that leads to increased transmission, high infectivity, and mortality in hosts even after clinical care and vaccine-based prophylaxis. Further, climatic and other environmental factors affecting biological systems and inducing molecular changes in parasites and vectors towards a more resistant life, while almost no change or slow changes in hosts are the main driving forces that have increased resistant malaria across different Spatio-temporal regions [71]. Infection by extracellular bacteria induces the production of humoral antibodies, which are ordinarily secreted by plasma cells in regional lymph nodes and the sub-mucosa of the respiratory and gastrointestinal tracts. The humoral immune response is the main protective response against extracellular bacteria. The antibodies act in several ways to protect the host from the invading organisms, including the removal of the bacteria and the inactivation of bacterial toxins. Extracellular bacteria can be pathogenic because they induce a localized inflammatory response or because they produce toxins.

One crucial issue is how Anopheles mosquitoes combat Plasmodium infections during feeding; if vector immune competence can be investigated, it will aid in preventing pathogen transmission [70]. There are three crucial reasons. Climate-favored seasonal changes, novel parasite variants, and novel vector defense molecules result in increased transmission, high infectivity, and mortality in hosts even in the presence of medical care and vaccine-based prophylaxis. Additionally, climatic and other environmental conditions have an impact on biological systems and cause molecular changes in parasites and vectors that make them live longer and more robustly. While modest or nearly no changes in hosts are the primary factors that have increased malaria resistance across various spatiotemporal regions [71]. Humoral antibodies are often released by plasma cells in local lymph nodes and the sub-mucosa of the respiratory and gastrointestinal tracts in response to external bacterial infection. The primary defensive reaction against extracellular germs is the humoral immune response. The antibodies have a variety of protective effects on the host, including the elimination of pathogens and the inactivation of bacterial toxins. Because they trigger a localized inflammatory response or because they produce toxins, extracellular bacteria have the potential to be harmful.

Need of most appropriate vaccines

Today risk of microbial infection has been increased due to a lack of control of pathogens and vectors. Both transmissions of pathogen and host availability become easier. These are the main reasons for the spread of deadly pathogens which are causing malaria, diarrhea, Ebola, meningitis, tuberculosis, HIV/AIDS, and many other viral, parasitic and fungal infections. Poor countries are major victims of these diseases as inappropriate health services and lack of prophylactic vaccinations are two major issues related to clinical care [72]. On the other side, those countries which have done prophylactic vaccination are free of these diseases or kept under control. Vaccination has helped in the eradication of diseases like polio, hepatitis, diphtheria, meningitis, and measles in most developed countries [73]. Despite irrational and dangerously erupting anti-vaccine movements that fuel the dwindling public confidence [74], therapeutic vaccines have also been effective at the intersection of infections and cancer [75], as shown by the successful human papilloma virus vaccine [76]. However, screening, testing, diagnosis and vaccination are major facts to adopt rather than adopting medicine of the medieval ages [74]. However, both traditional and new vaccination technologies [77] are to be required to establish herd immunity for wider protection of the people [78] for preventing the speedy expansion of local infectious diseases and their conversion into global pandemics [79,80]. For successful vaccination disease status, infection rate, eco-climatic changes, geographical, seasonal infectious disease epidemiology and mathematical analysis of routine and pulse vaccination programmes must be done [81].

Today risk of microbial infection has been increased due to a lack of control of pathogens and vectors. Both transmissions of pathogen and host availability become easier. Malaria, diarrhea, Ebola, meningitis, TB, HIV/AIDS, and several other viral, parasite, and fungi infections are just a few of the devastating diseases that hold less developed nations prisoner. The measles' spectacular recent resurgence, even in affluent nations, shows that health authorities have been ineffective in educating the public about the benefits of preventative and prophylactic immunization [72]. The success of prophylactic immunization over 200 years makes a strong case for the advantages. In most affluent nations, vaccinations have eliminated diseases including polio, hepatitis, diphtheria, meningitis, and measles [73]. Therapeutic vaccinations have also been successful at the nexus of infections and cancer [75], as proven by the successful human papilloma virus vaccine, despite irrational and dangerously exploding anti-vaccine movements that fuel the waning public confidence [74,76]. However, anti-vaccine campaigns have frequently been louder than scientific evidence and have demonstrated how harmful "alternative facts" communication tactics can persuade even intelligent people, sometimes regressing medicine to the Middle Ages [74]. Traditional and modern immunization methods are significant [77] and will be necessary to build herd immunity, a crucial barrier to preventing the spread of regional infectious illnesses into worldwide pandemics [78]. To combat drug-resistant tuberculosis, the tuberculosis vaccine is crucial [79,80]. According to Nicholas C. Grassly and Christophe Fraser, mathematical analysis of routine and pulse vaccination programs must be done in order to determine illness status, infection rate, eco-climatic variations, geographical, seasonal infectious disease epidemiology, and vaccine success.

8. Migration of people

The worst condition of human social groups is climate-induced forced migration. Changing weather conditions, on two sides of the world are alarming, on one side there is ice shelling in Northern American countries, and people are facing super cool temperatures while in Australia there are no rains, and people are facing longer droughts and rising temperatures. Such climate-related population displacements have been seen in the Caribbean basin where people are facing negative climatic exposure. Artificial physical structural dependence makes the system less sensitive to the environment. Because of rising sensitivity and minimum adaptive capacity anthropogenic climate changes, have increased the vulnerability and given rise to territorial conflicts. Over-industrialization has changed the scenario as the climate-based weather cycle has changed the life of the people and all-around pollution and global effects of rising temperature have imposed climate-related migration. Today these effects are vulnerable but in the future, these will become more hazardous, and anthropogenic climate change will displace people in spite of their economic richness. Hence future population movements will be riskier as random territorial conflicts will be increased.

Forced migration brought on by climate change is the worst situation for human social groups. Awkward weather changes are occurring on opposite ends of the globe. In northern American countries, people are dealing with extremely cold temperatures, while in Australia, where there have been no rains, people are experiencing extended droughts and rising temperatures. In the Caribbean basin, where people are exposed to adverse climate conditions, such population displacements connected to climate change have been seen. As a result of artificial physical structural dependence, the system is less environment-sensitive. Anthropogenic climate change has raised vulnerability and led to territorial conflicts due to rising sensitivity and low adaptive capability. Over-industrialization has altered the situation just as people's lives have been altered by the climate-based weather cycle, and global warming's effects on pollution and pollution everywhere have forced people to migrate. These effects are already dangerous, but as anthropogenic climate change displaces people regardless of their economic wealth, future population movements will become riskier as the number of sporadic territorial conflicts rises.

Post-migration establishment also depends on climate-based stimulus-response, the interaction of environmental changes or events with human social, economic, and cultural processes [82,83]. In the field of climate change research, interactions between climate and migration are increasingly situated within the context of human vulnerability to climate change, which is in turn identified as being a function of exposure to the impacts of climate change, the sensitivity of communities or socioeconomic systems to such impacts, and the capacity of those exposed to adapt. Migration responses to climate change may therefore be treated as one of the ranges of possible ways by which people may adapt to the adverse impacts of climate change or take advantage of resultant opportunities. Though there are migrations in the long historic past that were not so destructive because the need of people was minimum, post-industrialization has increased the population pressure because of development.

Climate-based stimulus-response, the interaction of environmental changes or occurrences with human social, economic, and cultural processes, and post-migration settlement are all factors that influence [82,83]. Climate and migration interactions are increasingly seen in the context of human vulnerability to climate change in the field of climate change research. This vulnerability is then understood to be a function of exposure to the impacts of climate change, the sensitivity of communities or socioeconomic systems to such impacts, and the capacity of those exposed to adapt. Therefore, one of the many potential means by which individuals may cope with the negative effects of climate change or seize associated possibilities is through migration responses to that change. Migration has existed for a very long time, but it was not as harmful then since there were fewer needs for people. However, post-industrialization has increased population pressure due to development.

There are both spatial and temporal patterns of climate-related migration. Displaced people need, societal well-being in a new environment, but it is only possible if state policy is inclusive. If it is not inclusive then in such a condition more vulnerable groups will be formed. Hence, extremes of climate change possibilities kept in mind before making any policy. All climates-induced adverse effects and extremes need more prompt actions to find timely solutions. Besides, ecological factors human interaction in groups, and their living in different social systems, communities, and households within particular systems also shape few differences. These differences are shaped by a variety of factors including the particular nature of climate impacts; the degree of exposure to such impacts; the sensitivity of human systems to such changes; and the capacity of the exposed population and its socioeconomic systems to adapt [84,85]. For abatement of climate-related effects and controlling disease incidences ecological effects related to human behavior and climate must be studied in a broad sense [86-88]. All climate-related environmental issues which are affecting human health and socioeconomic systems must be resolved early as possible to save humanity. More often, include poor countries which have agricultural and natural resource dependence and living in low-lying coastal areas, small island states, and other settings where exposure to climate-related risks is high and human livelihood possibilities are limited should give priority [89,90].

Migration that is influenced by the climate has both spatial and temporal trends. In order for society to thrive in its new surroundings, displaced individuals must be included in state policies. If it isn't inclusive, more vulnerable groups will develop as a result. Therefore, before implementing any policies, the extremes of possible climate change were considered. More immediate steps are required to address the negative effects and extremes that climate change has caused. In addition, ecological factors influence how people interact in groups, how they live in various social systems, and how communities and households differ within certain systems. These disparities are influenced by a number of variables, such as the specific nature of climatic impacts, the extent of exposure to such impacts, the sensitivity of human systems to such changes, and the adaptability of the exposed population and its socioeconomic systems.

Some socioeconomic systems are intrinsically more susceptible to changes in the environment brought on by climate change, which increases the likelihood of adaptive migration. These include those in low-lying coastal areas, tiny island states, and other environments where danger from climate change is high and human livelihood options are constrained. These systems are characterized by a reliance on agriculture and natural resources.

9. Induction of communicable diseases

9.1 Protozoan diseases

Protozoans are unicellular organisms most of them are internal parasite infections of man. Rotozoa is single-celled organisms classified as eukaryotes (organisms whose cells contain membrane-bound organelles and nuclei. These accidents directly or indirectly reach the human host and evoke dreadful diseases. In the past, the most prevalent and deadly human diseases were caused by protozoan infections. These dreadful diseases are African sleeping sickness, amoebic dysentery, and malaria. Common infectious diseases caused by protozoans include Malaria, Giardia, and Toxoplasmosis. These infections are found in very different parts of the body. There are drug resistant strains of *Entamoeba histolytica*. It is a major health problem in the whole of China south-east and Western Asia and Latin America, especially Mexico. It is generally agreed that amoebiasis affects about 15 percent of the Indian population. An estimated 10% of the world's population is infected with E histolytica. The highest prevalence is in developing countries with the lowest levels of sanitation. This results in 50-100 million cases of colitis or liver abscesses per year and up to 100,000 deaths annually (**Figure 2**).

Filariasis is seen mainly in developing countries. Lymphatic filariasis is often associated with urbanization, industrialization, illiteracy, poverty and poor sanitation. The migration of people favored the spread of filariasis. *Giardia lamblia* starts its invasion in gut toxoplasmosis can be found in lymph nodes, the eye, and also (worrisomely) the brain. After ingestion of mature cysts (infective dose varies from 10-100 cysts) via contaminated water or food, the trophozoite emerges in the small intestine, rapidly multiplies, and attaches to the small intestinal villi [91]. Trophozoites do not survive outside the body. Another intracellular parasite of the genus Leishmania attacks macrophage cells and causes leishmaniasis or Kala Azar. The parasite is transmitted by a variety of sand fly species belonging to subfamily Phlebotominae. This parasite largely affects macrophages and causes enlargement of the spleen and liver (**Figure 2**).

Most protozoans, which are unicellular creatures, infect people as internal parasites. As eukaryotes (animals whose cells have membrane-bound organelles and nuclei), protozoa are single-celled organisms. These unintentionally reach the human host, either directly or indirectly, and cause terrible diseases. The most common and lethal human diseases in the past, including malaria, amoebic dysentery, and African sleeping sickness, were brought on by protozoan infections. Malaria, Giardia, and toxoplasmosis are a few common infectious disorders brought on by protozoans. These infections can be seen in many different body parts. *Entamoeba histolytica* strains exist that are resistant to medication. It is a significant public health issue throughout all of China, south and west Asia, and Latin America, particularly Mexico. It is the cause of amoebiasis. It is commonly accepted that roughly 15% of Indians are affected by amoebiasis. The prevalence of *E histolytica* is highest in poorer nations with the poorest sanitation, where it affects an estimated 10% of the world's population. This causes up to 100,000 fatalities annually and 50 to 100 million instances of colitis or liver abscesses (**Figure 2**).

Most cases of filariasis occur in underdeveloped nations. Lymphatic filariasis is frequently linked to industrialization, urbanization, poverty, illiteracy, and inadequate sanitation. The spread of filariasis was aided by population migration. The infection of *Giardia lamblia* begins in the intestines. The lymph nodes, the eye, and (worrisomely) the brain can all be affected by toxoplasmosis. The trophozoite emerges in the small intestine, multiplies quickly, and attaches to the tiny intestinal villi following ingestion of mature cysts (infective dose varies from 10-100 cysts) through infected water or food. Trophozoites are incapable of surviving outside of the body. Leishmaniasis or Kala azar is caused by an additional intracellular parasite of the species Leishmania that attacks macrophage cells. A variety of sand fly species belonging to the subfamily Phlebotominae transmit the parasite. This parasite mostly affects macrophages and results in spleen and liver enlargement (**Figure 2**).

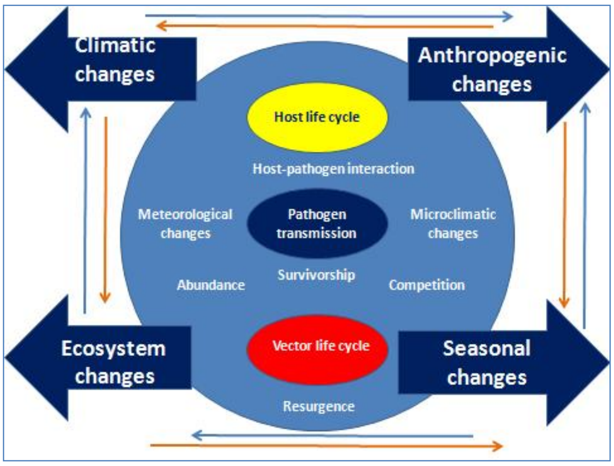

Figure 2. Inter-relationship of anthropogenic and climate change on ecosystem dynamics and host pathogen interactions.

Malaria is a very dreadful protozoan disease caused by a ciliate i.e. Plasmodium, its five species (Plasmodium falcipa-rum, Plasmodium knowlesi, Plasmodium malariae, Plasmodium ovale, and Plasmodium vivax) are identical but it's environmental induced variants are different according to eco-climatic zones. Parasite shows high antigenic variation and acquired both climatic adaptations and drug resistance against the conventional drug spectrum. The level of parasitemia varies according to region, person and endemicity. The disease is controlled but its reemergence is occurring at an interval of two-three years. There is two-way problem; on one side mosquitoes have developed resistance against insecticides and parasite has developed resistance against anti-malarial drugs. In both cases changing climatic conditions, urbanization, migration and slums have supported the severity of incidence. A new species *Plasmodium knowlesi* has been identified during the last decade in Malaysia [92]. Its natural hosts or reservoir hosts are monkeys *Macaca fascicularis, M. nemestina, M. inus*, and *Saimiri scirea* [92]. This shows increased disease severity and parasitemia. This seems to be co-evolved due to vectorial competence and climatic adaptability [57].

Although the five Plasmodium species (*Plasmodium falciparum*, *Plasmodium knowlesi*, *Plasmodium malariae, Plasmodium ovale*, and *Plasmodium vivax* species) are identical, their environmental variants vary depending on the eco-climatic zones, making malaria a highly terrible protozoan disease. In addition to acquiring ecologic adaptations and therapeutic resistance against the standard treatment spectrum, the parasite exhibits considerable antigenic variation. The severity of parasitemia varies by area, individual, and endemicity. Although the condition is under control, it reemerges every two to three years. On one side, parasites have become resistant to anti-malarial medications, and on the other, mosquitoes have become resistant to insecticides. Slums, urbanization, migration, and changing climatic circumstances have all contributed to the severity of the incidence in both cases. Over the past ten years, Malaysia has seen the discovery of new Plasmodium species hosts or reservoir hosts [92]. This demonstrates increasing parasitemia and illness severity. Due to vectorial competency and environmental adaptation, this appears to have co-evolved (**Figure 2**) [57].

African sleeping sickness is caused by T. brucei gambiense and T. brucei rhodesiense in man. The vector which transfers this parasite from an infected person to an unaffected person is tsetse fly. Another species of trypanosome causes T. cruzi American trypanosomiasis or chagas diseases. This disease is spread by vector bugs of the genus Rhodnius and other arthropods such as lice. Sleeping sickness vector is reported in 36 countries, the disease causes serious neurologic effects. Protozoan parasites have different modes of transmission.-Balantidium, Giardia, Entamoeba, Cryptosporidium, Toxoplasma, Cyclospora, Microsporidia show Enteric transmission while Trichomonas transmitted sexually. Babesia, Plasmodium, Leishmania, Trypanosoma is transmitted by insect vectors. Toxoplasma is the only pathogenic fecal-oral transmitted protozoa that have not been associated with gastroenteritis. Trophozoite-staged organisms are more dangerous rather than Spore-forming protozoa (Goodgame RW.). B hominis is pathogenic only when present in large numbers in the intestine. Three distinct morphologic stages are recognized: vacuolar, granular, and ameboid. B hominis inhabits the large intestine and has no evident life cycle in humans (**Figure 2**) (**Table 1**).

T. brucei gambiense and *T. brucei rhodesiense* are the human causes of African sleeping sickness. The tsetse fly is the vector that spreads this parasite from an infected person to an unaffected person. T. cruzi American trypanosomiasis and chagas illnesses are caused by a different species of trypanosome. Rhodnius vector bugs and other arthropods, like lice, are the main carriers of this disease. 36 countries have recorded cases of sleeping sickness, which has devastating neurologic consequences. There are various ways that protozoan parasites are transmitted. Trichomonas does not exhibit enteric transmission, although Balantidium, Giardia, Entamoeba, Cryptosporidium, Toxoplasma, Cyclospora, and Microsporidia do. Insect vectors are used to spread Babesia, *Plasmodium, Leishmania, and Trypanosoma* diseases. The only pathogenic protozoa that are transferred by feces and saliva that has not been linked to gastroenteritis is toxoplasma. Infants have *Trichomonas hominis*. Rather than spore-forming protozoa, organisms in the Trophozoite stage are more hazardous (Goodgame RW.). Only when B hominis is prevalent in high concentrations in the intestine is it harmful. Vacuolar, granular, and ameboid are characterized as three separate morphologic stages. B hominis lives in the large intestine and doesn't appear to have a typical life cycle in people (**Figure 2**).

9.2 Bacterial infections

Several factors lead to the development of bacterial infection and disease. The environment also plays a role in host susceptibility. Air pollution as well as chemicals and contaminants in the environment weakens the body's defenses against bacterial infection. Fouling or an unhygienic environment is the first factor that sets in and favors pathogen multiplication. Second is the presence of a host and transmission vector or any agent. These critically determine whether the disease will develop following transmission of a bacterial agent. Another factor is the number of susceptible and exposed individuals in a population group. The health status of the host is one of the important factors that decide the spectrum of pathogenicity caused by an infectious organism. Pathogenic bacteria evade the body's protective mechanisms and use its resources, causing disease. Finally, virulence shows internal changes occurred in physiological pathways inside the organism's body, and its propensity to cause disease. Among internal factors, toxins released by bacteria decide invasiveness and the level of morbidity caused. Other important factors are genetic constitution, nutritional status, age, duration of exposure to the organism, and coexisting illnesses [93]. There are different bacterial species i.e. *Bacillus anthracis, Brucella sp*, *Coxiella burnetii*, *Francisella tularenis, Leptospira*, *Mycobacterium tuberculosis* complex, *Yersinia pestis* major lethal disease. Due to environmental impact as well as high transmission rate they become uncontrolled and unmanageable (**Figure 2**).

Several things can cause bacterial infections and diseases. In addition, the host's environment affects susceptibility. The body's defenses against bacterial infection are weakened by environmental pollutants, toxins, and air pollution. The first element that develops and promotes disease growth is a foul or unsanitary environment. The existence of a host, a transmission vector, or any agent comes in second. These are crucial in determining whether sickness will manifest itself after bacterial agent transmission. The number of vulnerable and exposed people within a population group is another issue. One of the key variables that determine the range of pathogenicity a given infectious bacterium can cause is the health level of the host. The disease is brought on by pathogenic germs that make use of the body's resources while evading its defenses. Last but not least, virulence demonstrates intrinsic changes in physiological pathways within the organism's body as well as its potential to spread disease. Toxins secreted by bacteria determine the degree of morbidity induced, among other internal factors. The genetic make-up, nutritional status, age, length of exposure to the organism, and co-occurring disorders are additional crucial variables. *Bacillus anthracis, Brucella sp., Coxiella burnetii, Francisella tularensis, Leptospira, Mycobacterium tuberculosis* complex, and Yersinia pestis are only a few of the numerous deadly bacterial species. They become uncontrollable and unmanageable due to the high transmission rate and environmental damage (**Figure 2**).

Climate change, lead to an increase in severe weather events resulting in frequent and more severe flooding and surface water contamination. Because flood water carries lots of untreated waste that contains typhoid pathogens in large numbers and disease spreads easily through the environment. Its causative organisms are acquired via ingestion of food or water, contaminated with human excreta from infected persons. Antibiotic resistance is reported in Salmonella typhi which causes typhoid fever [94]. A cholera epidemic is largely supported by climate and changes its rhythms according to environmental variables, as low precipitation and high temperatures in warmer months bacterial replication occurs faster than in other months [95]. Tuberculosis is a disease more likely to develop due to poor nutrition, overcrowding, and low socio-economic status. Control of multidrug-resistant TB (MDR TB) is the biggest challenge as it becomes resistant to more than one anti-TB drug and imposes more severe multiple pathological changes in patients and results in high mortality [96]. A different condition is with Pertussis is a severe respiratory infection caused by Bordetella pertussis. *Corynebacterium diphtheriae*, Shigellosis is an infection of the intestine; it is caused by a group of bacteria called Shigella, M. *leprae* has acquired multidrug resistance, Anthrax is a zoonotic disease, that is transmitted from animals to humans. Plague is a disease that affects humans and other mammals. It is caused by the bacterium, Yersinia pestis (formerly *Pasteurella pestis*). It is caused by a Gram-positive rod-shaped bacterium *Bacillus anthracis*, transmitted by a bite of an Oriental rat flea (*Xenopsylla cheopis*) (**Table 1**) (**Figure 2**).

Surface water contamination and frequent, more severe flooding are outcomes of climate change, which causes an increase in extreme weather occurrences because typhoid bacteria are abundant in untreated sewage carried by floodwater, and because the disease is readily contagious. The organisms that cause it can be consumed through drinking or eating things that have been contaminated with human excreta from sick people. Typhoid fever is brought on by Salmonella typhi, which has been linked to antibiotic resistance. Because of limited precipitation and high temperatures in warmer months, bacterial reproduction happens more quickly than in other months, which supports the cholera outbreak in a major. Poor nutrition, overcrowding, and low socioeconomic position are the three main risk factors for the disease tuberculosis. The main problem is controlling multidrug-resistant tuberculosis (MDR-TB), which is resistant to various anti-TB drugs, causes severe numerous pathological alterations in patients, and has a high mortality rate. The severe respiratory infection pertussis is brought on by *Bordetella pertussis*. Shigellosis is an intestinal infection brought on by a collection of bacteria known as *Shigella, M. leprae* has developed multidrug resistance, and *Corynebacterium diphtheriae*. The zoonotic illness anthrax spreads from animals to people. Both humans and other mammals can contract the plague. Yersinia pestis, a bacteria, is the culprit (formerly *Pasteurella pestis*) *Bacillus anthracis*, a Gram-positive rod-shaped bacteria that causes it, spreads through the bite of an Oriental rat flea (*Xenopsylla cheopis*) (**Figure 2**).

9.3 Fungal infection

Fungi are especially sensitive to climate extremes. Persistently warmer temperatures at increasingly higher latitudes are contributing to the ongoing expansion of the geographic ranges of known fungal pathogens. Alongside fungal species' advancement into new territories, many can develop thermotolerance. Different types of fungus cause a variety of fungal infections in monsoon season. Fungal spores and mycelia normally grow in high humidity and on unclean surfaces. Opportunistic fungal infections happen due to the massive use of antibiotics. These fungi are nonpathogenic but grow in the upper respiratory tract flora or ear of the immunocompetent host; Aspergillosis is an infection that affects the respiratory system. It is caused by a type of mold (fungus) *Aspergillus*. Mucormycosis (previously called zygomycosis) is a serious but rare fungal infection [97]. This is an invasive opportunistic fungal disease caused by a group of molds (mucormycetes) Rhizopus species, Mucor species, Rhizomucor species, Syncephalastrum species, Cunninghamella bertholletiae, Apophysomyces species, and Lichtheimia (formerly Absidia) species [98]. Other invasive fungal diseases like pneumocystosis, cryptococcosis, histoplasmosis, and coccidioidomycosis are also most frequently seen in autoimmune or immune-deficient patients. These are also evoked all of sudden due to immunological defects and/or concomitant immunosuppressive therapies [99]. Fungi dermatophytes parasitize the horny cell layer which results dermatophytosis. The most common dermatophytes are *Trichophyton rubrum* and *Trichophyton mentagrophytes*. Candidiasis is an infection caused by a yeast (a type of fungus) called Candida (**Table 1**) (**Figure 2**).

Extremes in climate can be particularly harmful to fungi. The geographic ranges of recognized fungal diseases are continuing to expand as a result of consistently warmer temperatures at higher and higher latitudes. Many fungal species have the ability to develop thermotolerance, which helps them spread into new areas. Various fungal infections are caused by various species of fungus during the monsoon season. Mycelia and fungal spores typically flourish on dirty surfaces with high humidity levels. Antibiotic overuse leads to opportunistic fungal infections. Aspergillosis is an infection that affects the respiratory system; nonetheless, these fungi flourish in the upper respiratory tract flora or in the ears of immunocompetent hosts despite being nonpathogenic. Aspergillus is a type of mold (fungus) that causes it. A dangerous yet uncommon fungal infection called mucormycosis (formerly known as zygomycosis) [97]. A group of molds (mucormycetes) including the Rhizopus species, Mucor species, Rhizomucor species, Syncephalastrum species, *Cunninghamella bertholletiae*, Apophysomyces species, and Lichtheimia (previously Absidia) species is responsible for this invasive opportunistic fungal illness [98]. Pneumocystosis, cryptococcosis, histoplasmosis, and coccidioidomycosis are some other invasive fungal illnesses that are most frequently observed in autoimmune or immune-compromised patients. These can also appear suddenly as a result of immunological issues and/or concurrent immunosuppressive treatments. The horny cell layer that arises from dermatophytosis is parasitized by fungi dermatophytes. Trichophyton rubrum and Trichophyton mentagrophytes are the two most typical dermatophytes. The yeast (or fungus) called Candida is the source of the infection known as candidiasis (**Figure 2**).

9.4 Virus generated diseases

Many of the root causes of climate change also increase the risk of virus or bacterial pandemics. Climate change is directly or indirectly responsible for global environmental change and zoonotic disease emergence. This is massively affecting human health in Europe, Asia and Africa where so many hotspots of the virus, protozoan and bacterial deadly diseases have been identified. Climate change mainly shifting seasonal cycles has increased the risk of emerging infectious diseases propagating from animals to humans, from humans to animals or vice versa over the last several decades, including the flu, HIV, Ebola and coronavirus. The virus is finding and establishing itself in new hosts with new epidemiological routes of infection. Most of the virus-generated diseases have been evoked due to climatic effects, drug regimens, and resistance acquired by their circulating strains. Most viruses such as Rhinovirus, Respiratory Syncytial Virus, Herpes Simplex Virus, Adenovirus, cytomegalovirus, influenza virus Type A, Type B, parainfluenza virus, SARS corona virus, poliovirus, HTLV-1, gastroenteritis virus, adenovirus, rotavirus, Norovirus, Astrovirus, coronavirus, pancreatitis coxsackie virus, Hepatitis virus A, B, C, D, E, dengue, and West Nile Virus, Rabies generated disease are on the rise because of attainment of new genetic variations and resistance to therapeutic drugs and vaccines [93]. Recently, WHO has alarmed many countries about new waves of infection caused by Ebola virus, Hantavirus associated with HCPS, Hendra virus, highly pathogenic virus H5N1, Lassa fever virus, lymphocyte choriomeningitis virus, monkeypox virus, Nipah virus, Rabies and Rubella, Rotavirus B, Chikungunia virus and Yellow fever virus. Since 2000 many virus diseases have re-emerged after a prolonged time. Every year incidence rate of sexually transmitted diseases, Herpes simplex virus type 2, human papillomavirus, SARS and H1N1 is increasing. All these viruses changed the intensity of infection, morbidity and mortality rate; even despite clinical and therapeutic care, the mortality rate is not coming down. The major reason for the occurrence of virus and protozoan diseases is the induction of disease transmission vectors in endemic areas. Though no direct evidence of the effect of climate on the transmission of coronavirus has been identified it is well known that climate is supporting vector and pathogen populations and natural boundaries of disease occurrence are extended from endemic to non-endemic areas (**Figure 2**).

Many of the underlying factors contributing to climate change also raise the danger of bacterial or viral pandemics. Environmental change on a global scale and the emergence of zoonotic diseases are caused by climate change, either directly or indirectly. In regions where lethal viral, protozoan, and bacterial illnesses have been identified as hotspots, such as Europe, Asia, and Africa, this is having a significant negative impact on human health. Over the past few decades, climate change has raised the possibility of developing infectious illnesses including the flu, HIV, Ebola, and coronavirus spreading from animals to humans, from humans to animals, or vice versa. With the help of new epidemiological pathways of infection, the virus is locating and establishing itself in new hosts.. The majority of viral diseases have been brought on by treatment regimens, environmental factors, and resistance developed by circulating strains. The majority of viruses, including the rhinovirus, respiratory syncytial virus, herpes simplex virus, adenovirus, cytomegalovirus, influenza type A, type B, parainfluenza virus, poliovirus, HTLV-1, gastroenteritis virus, rotavirus, norovirus, astrovirus, coronavirus, pancreatitis coxsackie virus, hepatitis virus A, B, C, Recent outbreaks of infection brought on by the Ebola virus, Hantavirus associated with HCPS, Hendra virus, highly pathogenic H5N1, Lassa fever virus, lymphocyte choriomeningitis virus, monkeypox virus, Nipah virus, Rabies and Rubella, Rotavirus B, Chikungunya virus, and Yellow fever virus have alarmed many nations, according to the World Health Organization. Numerous virus-related diseases have returned in large numbers since the year 2000. Sexually transmitted illnesses, human papillomavirus type 2, SARS, and H1N1 all have risen incidence rates each year. Even with clinical and therapeutic treatment, the mortality rate is not decreasing because all these viruses altered the severity of infection, morbidity, and fatality rates. The introduction of disease transmission vectors in endemic areas is the main cause of the occurrence of viral and protozoan infections. Although there is no clear proof that the climate affects coronavirus transmission, it is well-recognized that the climate supports the populations of pathogens and vectors and that the natural bounds of disease occurrence stretch from endemic to non-endemic locations (**Figure 2**).

10. Results and discussion

Climate changes have increased the risk of infections. Diseases most likely to increase in their distribution and severity have three-factor (agent, vector, and human being) and four-factor (plus vertebrate reservoir host) ecology. *Aedes aegypti* and *Aedes albopictus* mosquitoes may move northward and have more rapid metamorphosis with global warming. These mosquitoes transmit the dengue virus, and *Aedes aegypti* transmits the yellow fever virus. Climate change has increased the chances of cross-species viral transmission risk [100]. The faster metamorphosis and a shorter extrinsic incubation of dengue and yellow fever viruses could lead to epidemics in North America [101]. For example temperature-sensitive mutants of Japanese encephalitis virus, Dengue fever, H1N1, Hepatitis B have been detected. Heat-sensitive strains of rotaviruses are causing life-threatening dehydrating gastroenteritis in children and animals.

10.1 Molecular alterations in host-pathogen interactions

For finding quick solutions detailed study of "host-pathogen" interactions is highly important. For this purpose all ecological, physiological and molecular reasons are explored to find out the reasons for disease outbreaks, their progression and the outcome of infections. There is a gap in host-parasite interaction about the origin and route of infection, transmission, latency time, progression, host immunity and defense acquired by viral, parasitic and zoonotic pathogens. For solving the pathogenesis and disease occurrence host immunity [102] growing resistance in pathogens and co-evolution of microbial antigens and host receptor interactions must be explored [103]. This is also important for discovering rapid remedies.

Exploring "host-pathogen" interactions will be more useful for understanding the causes, course, and effects of infectious diseases. It will also help in finding the level of host immunity to disease pathogenesis and inadvertent incidences occurring year after year [102], as how does host immune alterations affect stopping pathogens to invade the host [103]. During the COVID-19 pandemic, there have been many improper responses that have been observed, either delayed or early [103]. As a result, there has been an increase in fatalities, economic loss, and clinical health harm.

Host vector interactions and environmental responses must be gauzed for disease transmission by infected and non infected vector population in natural ecological divisions. In addition, all effects related to physiology, behavior, and evolution of human disease vectors must be checked according to genomic data available to map the global health of people (Rinker, David C., 2016). In order to prevent disease transmission by infected and non-infected vector populations in naturally occurring ecological divisions, host vector interactions and environmental reactions must be considered. the host models are required to predict future disease occurrence, epidemiology, genetic invasion of the host and length of pathogen life cycles. Additionally, in order to map the worldwide health of people, all consequences linked to the physiology, behavior, and evolution of human disease vectors must be evaluated [104]. To forecast future disease occurrence, epidemiology, genetic host invasion, and pathogen life-cycle length, computer-based models are necessary.

10.2 Future planning and solutions

Climate change is an emerging disastrous problem that is creating adversities not only for nature but it is a great challenge to human life and well-being. As seasonal climatic variations occur with the changing weather conditions and the seasonal cycle completes almost every year. Climate change is creating human health-related issues mainly incidences of communicable diseases have increased. Significant elevation in the level of environmental pollutants and their regular exposure caused many human health-related risks. Global climate has severely affected human behavior. Due to contact with contaminated air, water, and food untimely diseases, pathogenic morbidities, gastric problems, and psychosocial stress have increased the vulnerability of humans to pollutants/chemicals. Unfortunately, on one side climate change has increased the chances of droughts that are happening around the globe and developing countries suffering at higher rates. Droughts are highly problematic for all farmers. On the other side, there is simultaneous happening of floods that are affecting agriculture production that resulted in price hike in food commodities and putting a large section of people at higher risk of hunger. Climate change is threatening the world's food production and supply. Heavy rains and floods also forced people to migrate. It results in the degradation of farmlands, and loss of seed and crop production. It leads to competition over precious natural resources. Over time, social conflicts displaced entire communities and thrashed to live under life-threatening hunger. Increasing temperature, unavailability of water, and massive hunting are depleting wildlife, deforestation is also very high, and habitat and species loss are on high stakes. Increasing temperatures are problematic for those who own livestock. Year after year sequential cumulative effects of climate change on ecosystem production are worsening; there is devastation due to heavy floods or heavy draughts in croplands (**Figure 3**). This is the main cause of price hikes, poverty, crime, and human migration. This wide impact is increasing in agrarian societies because of the loss of fertile lands and low crop yield. Higher temperatures make it harder for animals to live; if farmers cannot provide enough fresh water to keep their livestock hydrated, they can become diseased or die of dehydration. Loss of glaciers is an important alarm that the earth atmospheric temperature is on the rise and it is causing global warming and showing multiple effects on both human, animal, and plant life (**Figure 3**).

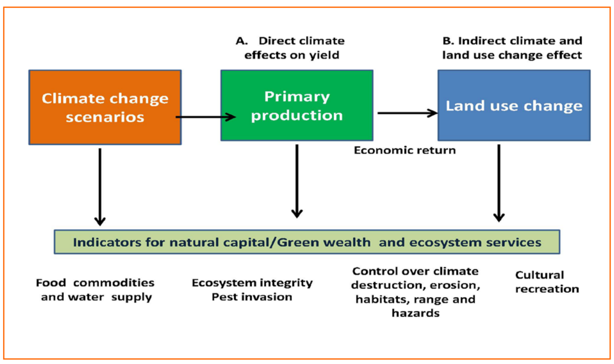

Figure 3. Sequential effects of climate change on ecosystem production and land use.

Climate change is disturbing atmospheric temperature hydro-biological cycle as torrent rains and heavy floods or longer draughts have been seen in so many parts of the world. Due to lesser downpours and precipitation, rainwater, underground water, and hydrologic aquifers are drying out. Agriculture is drying out and irrigated crops are diminishing at a high rate. Due to rising diesel prices, farming becomes more expensive and difficult for poor farmers. In all regions, traditional agriculture is no longer practiced because of changing weather conditions and rising temperatures.

For making human society pollution free, cut down all types of pollutants by making source-level inhibition. For prompt action policy, an action plan and budgetary provisions are to be made to solve the problem. Use the most recent technology for automobile vehicles to minimize diesel exhaust particles, carbon monoxide, and particulate pollutants in the air. For vertical mixing of pollutants uses precipitators and power air filters to minimize the air pollution levels in urban cities. To minimize the gaseous air pollutants such as oxides of sulfur, nitrogen and carbon, hydrogen sulfide, hydrocarbons, ozone and other oxidants, fine technology network system and fuel options be made. Maximize the use of electric, solar and nuclear power-operated vehicles. There must be a ban on the production of single-use polymers which are un-biodegradable, polymers, pollutants, toxic gases, and coal ashes.

For economic well being of farmers search, develop and use resistant plant varieties or cultivars by incorporating the genes causing the leaf surface to become coated in wax crystals, repelling water and decrease evapo-transpiration. Search more genes to increase long-term flood tolerance, make CO_2-smart plants to cut down carbon level in atmosphere. Replace synthetic antibiotics by searching new plant origin bio-organic chemicals to end the problem of drug resistance and vicious cycle of remerging communicable diseases. Increase carbon mineralization across the forest communities by using bacterial population to fix more carbon other than large plant species. Grow new perennial forests and convert land use pattern for long sustainable use, cut down use of synthetic pesticides, fertilizers, weedicides, and apply safe integrated agro-ecosystem practices for control of insects, parasites, and predators.

Make policies to facilitate resource-sharing agreements and promote cooperation between communities to reduce conflict, providing a space for people living there to pursue new types of work such as cooking, cleaning, or construction. Form green governance, and collaborate with local and national governments to improve their ability to manage and prepare for weather-related risks. The income of farmers should increase and they should not give up agriculture in search of other ways/means to bring income to their families. Favor people for learning new technologies, and redesigning their farmland to maximize land productivity and protect the soil in the face of increasingly severe and frequent droughts. Make more adaptation strategies for the operational management of aging dams in a changing climate, together with adequate and timely maintenance. Therefore, long-term policy frame work and environmental management and planning must be made to save the life of the future generation. Therefore, for displaced vulnerable populations proactive adaptive capacity should be made by generating funds and green policies, practices, and laws.

To control ongoing and projected damage to ecosystems and human communities, global warming keeps to a maximum of 2 ºC over pre-industrial levels, more than this will threaten human health, water supplies and ecosystems more vulnerable, hence, a warming of at least 1 ºC appears unavoidable (**Figure 3**). The main reason for this warming is man-made emissions of carbon dioxide and other heat-trapping gases. These gaseous clouds have made a thick blanket over the earth and are trapping extra sunlight and strong rays are reverting. It resulted in temperatures rising. To find quick solutions there must be a ban on coal-based manufacturing units, and other sources of greenhouse gas emissions must be controlled with efforts to minimize the anticipated effects of climate change. Hence, for developing new safe gourds CO_2 emissions should be minimized and forest cover is being increased to minimize adverse episodic changes in the atmosphere and their impact on human health.

The more suggestible point is to immediately check the combustion of fossil fuels such as coal, oil, and natural gas. Coal is particularly damaging, as it produces 70% more CO_2 emissions than natural gas for the same energy output. Electricity generation is the single largest source of manmade CO_2, amounting to 37% of worldwide emissions. Efforts of United Nations environmental protection programs are directing every nation to replace CO_2-releasing industrial units with electric power that should be generated from noncoal sources sector to become CO_2-free. It is mandatory for developed, developing, and underdeveloped countries. Organizations responsible for the assessment and management of health risks of chemicals, therefore, need to be more proactive and consider the implications of GCC for their procedures and processes.

For mitigation of automobile-generated aerosols and particulate matter, air purifies and uses alternative sources of fuel other than gasoline and hydrocarbons. Eco-friendly alternatives are CNG, electric vehicles, solar power vehicles, and ethanol as fuel. Automobile engine design and filters can also save environmental oxygen. Cut down the use of CFCs in air conditioners, freezers, and other appliances. Stop using heat-generating plants and think about low-energy processors and liquid fuels which convert into a gas at low ignition temperatures. Utilities can support meaningful global warming legislation, to improve the energy efficiency of power plants, increase their use of renewable energy sources, and halt investment in new coal plants and coal mining. Electricity consumers should opt for “green power” where it is available, demand this choice where it is not, and invest in highly efficient appliances. Policymakers must ease the transition to a carbon-free energy industry by passing legislation that creates favorable market conditions, shaping new frameworks for change, and ensuring that the Kyoto Protocol, the world’s primary legal tool to combat global warming, enters into force as soon as possible.

Ecological modeling, farm track engineering, and urban forestry could play an important role in finding solutions to air pollution soil, erosion control, and noise. Technological development is required to manage industrial wastes, emissions, and wastewater treatment for environmental safety. Pilot projects are required for the management of good recharging, rainwater harvesting, and drip irrigation methods.

These can control problems related to water scarcity. On the other hand, pretreatment of wastewater before its discharge into water bodies will protect the flowing water from pollution. The further cultural environment could be maintained by renewing and preservation of scenic beauty and developing historical sites, airy and making residential development open and using only eco-friendly land use methods for management of climate-related effects. For finding quick solutions local and national governments should cooperate to manage crop production, price rise, and storage with solutions for weather-related risks mainly making society, administration, and government proactive in disaster response. Making environment safety-based policies, and development planning establishing control-warning centers can reduce vulnerability to disasters caused due to climate change.

11. Conclusions

To reverse climatic conditions as normal a 50% cut down must be required in gaseous emissions. Further, to reduce major prevailing major changes in the elevation of global temperature CO_2 emission must be stopped completely up to zero by 2050. It will solve the problem of accidental torrent rains; floods, droughts, and vector population. For control of communicable diseases integrated surveillance, investigation, long term funding is required. It will assist in to study of epidemiological reasons and the identification of pathogen-host-vector interaction at the molecular level. Further, to reduce the burden of infectious diseases as the development of rapid, accurate, low-cost diagnostics; novel therapeutics, and vaccines; innovative vector control and surveillance tools are also required for quick action. An early warning system is required to integrate clinical research, health, and climate operations. More speedy data and knowledge-sharing platforms, outreach and education, response activities, community education, and social mobilization via social media are essentially required. The global health community has many actors that pursue this common agenda, including multilateral organizations; funders, including governments and foundations; non-governmental organizations; researchers; and practitioners. Besides following a long route to combat communicable diseases, it will be much better to aware people of their self-protection, vector control, sanitation, and recycling of waste, and approach them to learn health and hygiene principles. Parasites show high antigenic variation and acquired both eco-climatic adaptations and drug resistance against conventional drug spectrum, therefore, new highly effective drug regimens, antibodies, antiserum, and vaccines are required to fight against newly emerging climate-induced microbial diseases. This is highly important to know the ecology, genetics, and molecular mechanisms of disease transmission, host-parasitic interaction and developing drug resistance in microbial pathogens.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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ARTICLE

Indoor Air Pollution and Its Determinants in Household Settings in Jaipur, India

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ABSTRACT

Individuals spend 90% of their time indoors, primarily at home or at work. Indoor environmental factors have a significant impact on human well-being. It was a longitudinal study that assessed the major factors that reduce indoor air quality, namely particulate matter, and bio-aerosols, using low-cost sensors and the settle plate method, respectively also to determine the effect of atmospheric parameters and land use patterns in households of commercial, industrial, residential, slum, and rural areas of the city. PM2.5 concentration levels were similar in most parts of the day across all sites. PM10.0 concentration levels increased indoors in a commercial area. PM2.5 concentration showed a negative correlation with temperature and a positive correlation with relative humidity in some areas. Very high values of PM2.5 concentration and PM10.0 concentration have been observed in this study, inside households of selected rural and urban areas. Pathogenic gram-positive cocci, gram-positive rods, Aspergillus, and Mucor species were the most common bacterial and fungal species respectively found inside households. This study examined particulate matter concentration along with bio-aerosols, as very less studies have been conducted in Jaipur the capital of Rajasthan, a state in the western part of India which assessed both of these factors together to determine the indoor air quality. Rural households surrounding the periphery of the city were found to have similar pollution levels as urban households. So, this study may form the basis for reducing pollution inside households and also for taking suitable measures for the reduction of pollution in the indoor environment.

Keywords: Indoor air pollution; Particulate matter; Bio-aerosols

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1. Introduction

There is regional heterogeneity in India, where places with various atmospheric conditions result in different indoor air quality. North Indian states, for example, have higher PM2.5 g/m^3 levels (557-601 g/m^3) than southern states (183-214 g/m^3) [1]. Because of their low incomes, those who utilize solid biomass for domestic purposes are exposed to poor-quality, toxic air within their homes. It is noteworthy that three billion people use the aforementioned energy source to prepare their everyday needs for cooking and heating [2]. Long-term exposure to indoor environments with insufficient air exchange and poor air quality and harmful bio-aerosols may cause sick-building syndrome (SBS), allergic reactions, respiratory tract infections, chronic obstructive pulmonary disease(COPD), and asthma [3]. Since most individuals spend 90% of their time indoors, primarily at home or at work, indoor environmental factors have a significant impact on human well-being [4]. Indoor air pollution can be produced by occupant activities such as cooking, smoking, using electronic equipment, using consumer products, or emissions from building materials inside homes or structures. Dangerous pollutants can be found inside buildings, including biological contaminants, particulate matter (PM), aerosols, volatile organic compounds (VOCs), carbon monoxide (CO), and others [5]. Biological aerosols (bio-aerosols) are a subgroup of atmospheric PMs made up of cellular components, microorganisms (bacteria and archaea), and dispersal units (fungal spores and plant pollen) [6]. Indoor air pollution levels can be impacted by concentrations of outdoor air pollution associated with anthropogenic and natural sources, including road traffic, wildfire smoke, and dust re-suspension. Additionally, factors including the kind, location, and distance of the pollutant sources; the size, shape, orientation, and arrangement of the buildings; as well as geography and weather patterns, all have an impact on how the pollutants around the structure disperse [7]. Indoor exposure is greatly influenced by household characteristics and occupant behaviours, particularly cigarette smoking for PM2.5, gas appliances for NO_2, and household items for volatile organic compounds (VOCs) and polyaromatic hydrocarbons (PAHs). High interior air pollution is caused by a home's proximity to busy highways, redecorating, and tiny housing size [8]. People in metropolitan areas spend more than 90% of their waking hours indoors, according to research on this group. A considerable majority of people's time is spent outside of residential indoor spaces, in workplaces, schools, and other commercial and industrial structures. Adults in North America spend 87% of their time indoors, with the remaining 17% spent in automobiles and 7% outdoors, according to specific studies [9]. Studies have indicated that breathing "clean" indoor air helps with both respiratory and non-respiratory symptoms like headaches and eye pain [10]. A common but avoidable risk factor for respiratory illnesses is household air pollution. The most efficient intervention to lower the burden of household air pollution (HAP)-related diseases is probably the substitution of solid cooking fuels with clean fuels like liquid petroleum gas (LPG), as demonstrated by India's "Ujjwala" initiative [11]. In India, the national burden of disease is accounted for by environmental and occupational risk factors, with indoor and outdoor air pollution ranked as one of the major risk factors [12].

Very little data are available on indoor air pollution in Jaipur. Therefore, the study was carried out with the objectives of studying indoor air pollution in different household settings in Jaipur and determining the effect of atmospheric parameters and land use patterns.

2. Materials and methods

Study location: The study was conducted in Jaipur, the capital of Rajasthan, a state in the western part of India. The Thar Desert is a part of the state. It is located at latitude-N 26.922070 and longitude-E 75.778885. It has a population of 3,073,350 (2011 Census) and is spread over 11,143 km^2. The city has mixed land use, with residential, commercial, and industrial areas coexisting and dotted with slum clusters in between. At its periphery, the city is surrounded by rural areas where the primary occupation is farming.

Study Design: Longitudinal Study Design.

Study location: For data collection, one household was chosen from each of the following areas: residential, commercial, industrial, slum, and rural (**Figure 1**).

Data collection: Data on pollution parameters were collected in selected households through real-time continuous monitoring of particulate matter using laser base sensors and outdoor data were obtained from Rajasthan State Pollution Control Board (RSPCB). Assessment of bio-aerosols in the households to identify pathogenic microorganisms present inside households was done using the passive settle plate method.

Indoor air quality was monitored using sensor-based low-cost air quality monitors, the Purple Air PA-II (Manufactured by Purple Air Inc., USA). One unit was installed in each of the selected households. Data were collected for a period of three months from 07 March 2022 to 30 June 2022. The device captured PM2.5 levels at a 60-second interval along with PM10, PM1.0, temperature, and relative humidity.

On the day of sampling, the Petri plates were examined for contamination prior to use for the bio-aerosol assessment. The labeling of information and media pouring was done in a laminar air flow hood in a sterile environment. The plates were covered with a sterile lid and were assembled in a sterile transport bag or container according to the schedule of sampling. At the sampling site, the passive settle plate method was used, which meant that the Petri dish was placed 1 m above ground level, 1 m from any obstacle, and exposed for one hour. The exposed Petri dishes for bacteria were incubated at 37 degrees Celsius, for 48 hours of growth and CFU/plate was counted. Petri dishes for fungi were incubated at 28 degrees Celsius, for 72 hours of growth and CFU/plate was counted. Bacterial colonies grown on blood agar were subjected further to gram staining for identification of gram-positive and gram-negative bacteria. Fungal colonies were subjected to staining with cotton blue dye for identification of the type of fungi species.

Data analysis: The PM2.5 $\mu g/m^3$ levels obtained from the monitors were transferred to an MS Excel sheet and converted into six hourly average values.

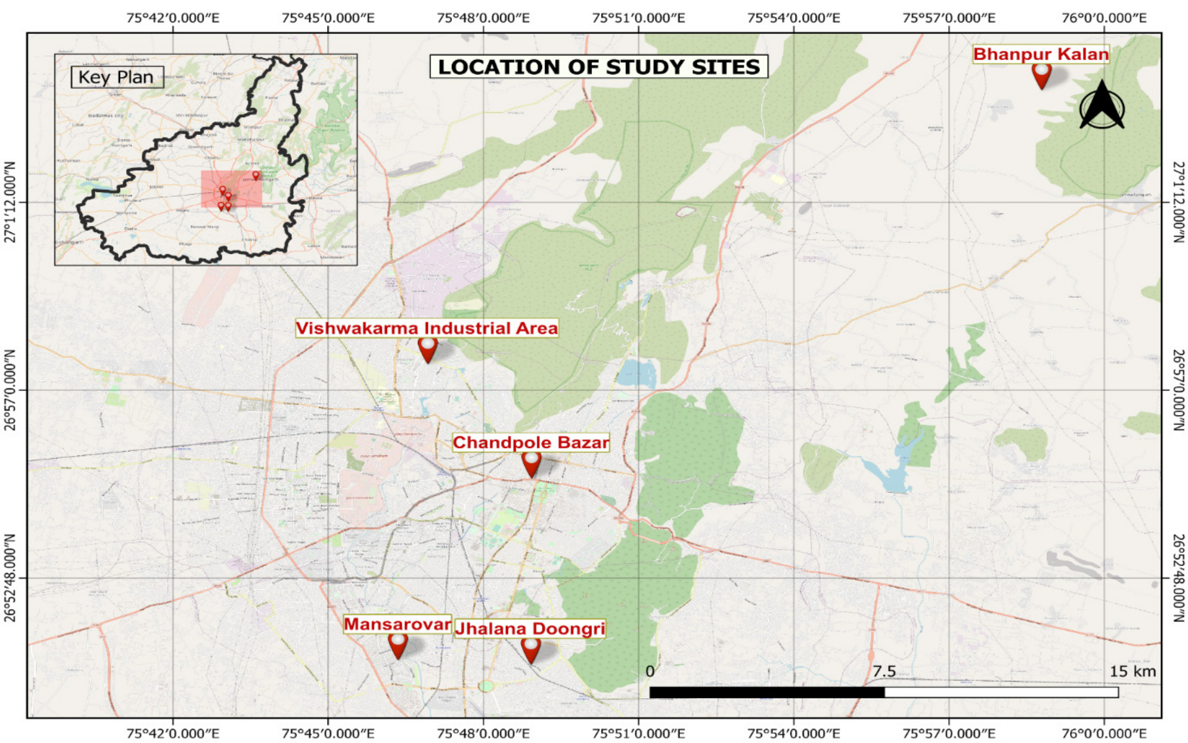

Figure 1. Sampling sites map of Jaipur, Rajasthan, India.

The quarters were divided as 6.00 a.m. to 11.59 a.m., 12.00 noon to 5.59 p.m., 6.00 p.m. to 11.59 p.m., and 0.00 hours to 5.59 a.m. Similarly, the temperature and relative humidity data were also converted to six-hourly averages.

3. Results

The quarterly average values of PM2.5 μg/m^3 of all sites for three months are shown in graphs (**Figures 2 to 5**). It was found that in the morning hours, PM2.5 μg/m^3 values in all places were highest in March than in April; this might be due to low ambient temperature and high humidity observed during this time, as shown in **Figure 2**. In the afternoon slot, as shown in **Figure 3**, all the places have shown different rise and drop patterns, indicating other factors like domestic pollutant emission sources and external outdoor sources affect PM2.5 μg/m^3 concentration and values. The evening and night slot values of PM2.5 μg/m^3 also varied spatially. Very high concentrations of particulate matter are found inside households as the moderate range for PM2.5 is from 0 to 35 and for PM10.0 it is 51-154 according to air quality index: a guide to air quality and your health. EPA, August 2019 AQI air quality index "a" People with heart or lung disease, children, or older adults (EPA-456/F-19-002), as in most areas the values are reaching 250 to 300 which is above the normal range.

3.1 Indoor and outdoor PM10.0 μg/m^3 levels

A comparison of PM10.0 μg/m^3 twenty-four hourly average data obtained from Purple Air PA-II (Manufactured by Purple Air Inc., USA) with outdoor PM10.0 μg/m^3 twenty-four hourly average data obtained from Rajasthan State Pollution Control Board (RSPCB) from March 2022 to May 2022 is given in **Figures 6 to 9**. On March 22nd, we observed that the value of PM10.0 μg/m^3 increased indoors (101 μg/m^3) as compared to outdoors (74 μg/m^3) in the commercial area due to heavy dust presence by the construction work taking place in the street during this time period which also affected the households nearby. Again, on April 8th, 2022, the value of PM10.0 μg/m^3 increased in the commercial area.

3.2 Correlation of PM2.5 μg/m^3 and temperature

PM2.5 μg/m^3 and temperature were found to have a negative correlation at the 0.01 (2-tailed) level in industrial (–0.445), rural (–0.447), slum (0.358), residential (–0.315) areas and not in a commercial area.

3.3 Correlation of PM2.5 μg/m^3 and relative humidity

A positive correlation between PM2.5 μg/m^3 and humidity was found to be significant at the 0.01 level (2-tailed) in commercial areas (0.161), rural areas (0.557), slum areas (0.257) and not in an industrial and residential area as there were no proper ventilation sources present in commercial, rural and slum area so, due to humid environment particulate matter showed a positive correlation with humidity whereas residential area has proper ventilation sources and industrial area have more of the dusty environment due to continuous industrial activities, factories work and on road traffic presence so a negative correlation was observed.

3.4 The effect of land on bacterial and fungal counts

In the rural area, the bacterial microbial counts were highest inside the bedroom, bathroom, kitchen, and living room as compared to other areas as shown in **Table 1**, due to the presence of more dust, pet presence, improper cleaning of households, access to pet waste, no ventilation sources like exhaust fans or air purifiers, biomass fuel used for cooking which produced more waste and improper waste disposal as compared to urban and slum area where these reasons were less observed. Also, the fungal microbial counts in the bathroom, bedroom, kitchen, and living room were more due to similar reasons as compared to other areas as shown in **Table 2**. Pathogenic gram-positive cocci and gram-positive rods were the dominant bacterial species found in all the areas. Aspergillus and Mucor species were identified as the dominant fungal species in all the sampled households in the city which can cause a group of infections.

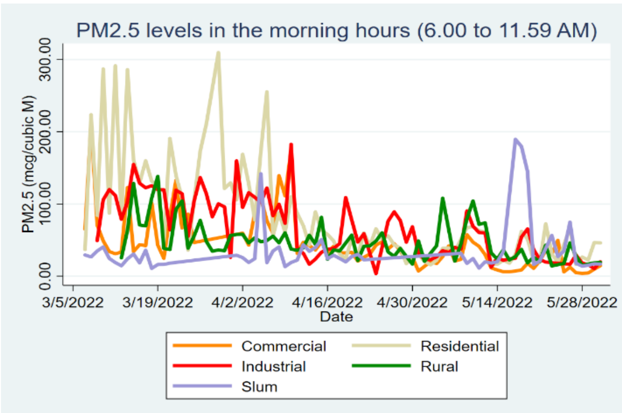

Figure 2. All five zones' quarter 1 PM2.5 μg/m³ values.

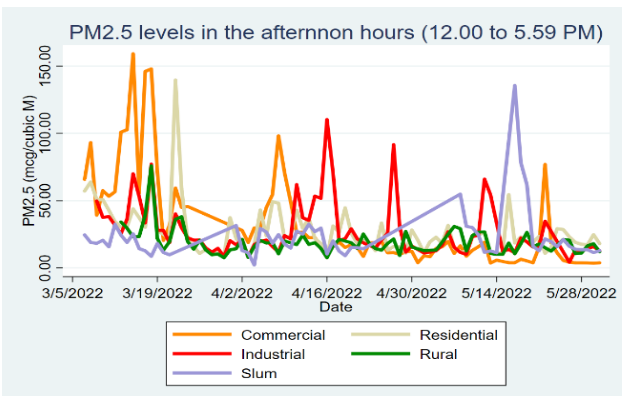

Figure 3. All five zones' quarter 2 PM2.5 μg/m³ values.

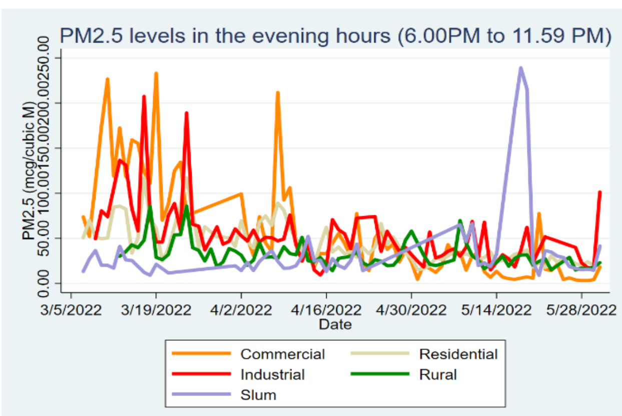

Figure 4. All five zones' quarter 3 PM2.5 μg/m³ values.

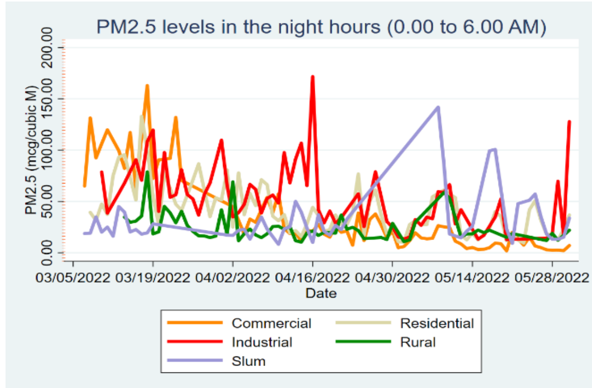

Figure 5. All five zones' quarter 4 PM2.5 μg/m³ values.

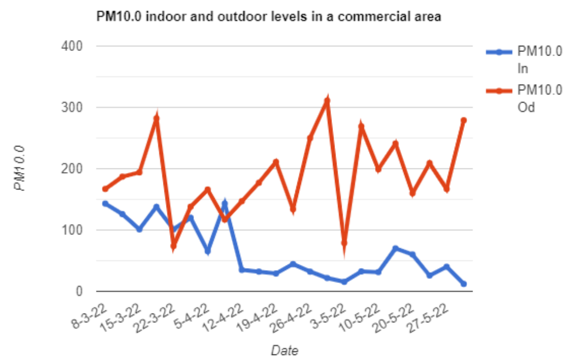

Figure 6. PM10.0 μg/m³ indoor and outdoor levels in a commercial area.

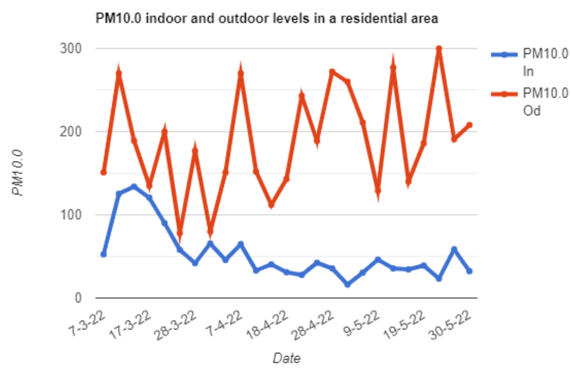

Figure 7. PM10.0 μg/m³ indoor and outdoor levels in a residential area.

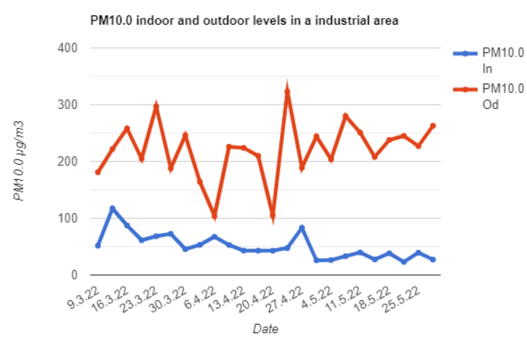

Figure 8. PM10.0 μg/m³ indoor and outdoor levels in an industrial area.

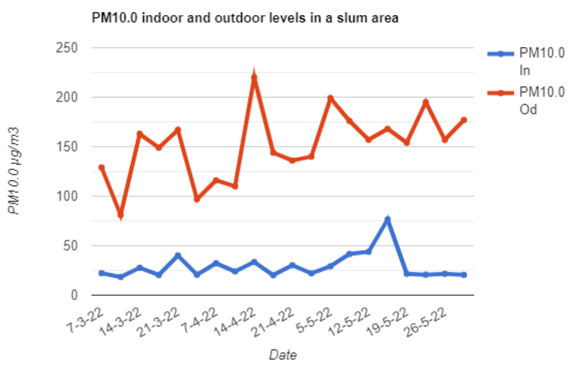

Figure 9. PM10.0 µg/m^3 indoor and outdoor levels in a slum area.

4. Discussion

The patterns of PM2.5 µg/m^3 levels were similar for three-quarters of the day across all sites. PM2.5 µg/m^3 showed a statistically significant negative correlation with temperature and a positive correlation with relative humidity in some areas of the city. Very high values of PM2.5 µg/m^3 and PM10.0 µg/m^3 have been observed in the study inside households including rural areas. The effect land used on microbial counts (bacterial and fungal) is shown. Inclusion of all the environmental (presence of different PM levels, presence of different bio-aerosols with their amounts), geographical (all the different land patterns taken for the study), and atmospheric parameters (temperature and relative humidity) in Jaipur city and based on the observed results, it can be safely inferred that indoor air pollution is as high as outdoor air pollution, contrary to the belief about indoors being less polluted. In the case of extreme pollution, residents are advised to stay indoors. It was also an important observation, that rural households were as polluted indoors as urban households.

5. Conclusions

This study examined particulate matter concentration and bio-aerosols in households in Jaipur. Rural households have similar pollution levels as urban areas. Many policies have been introduced to reduce the level of outdoor air pollution but very less policies have been introduced which are working on indoor air pollution and their implementation remains a challenge. Issues with air quality starts at home,

Table 1. The influence of land used on bacterial microbial counts (CFU/Plate).

Place -	Commercial area	Industrial area	Slum area	Residential area	Rural area
Bedroom	25	45	18	20	95
Kitchen	22	16	19	9	33
Barth room	50	23	12	8	88
Living room	25	24	21	14	39
Balcony	50	47	30	40	30

Table 2. The influence of land used on fungal microbial counts (CFU/Plate).

Place-	Commercial area	Industrial Area	Slum area	Residential area	Rural area
Bedroom	4	5	1	2	6
Kitchen	8	2	3	3	6
Barth room	1	2	4	2	7
Living room	6	7	6	3	7
Balcony	4	6	3	5	9

switching to renewable energy sources, providing sufficient ventilation in dwellings, and cross ventilation in homes can also assist, using exhaust fans in homes with inadequate ventilation helps re-mediate the air quality issues. Rural areas should switch to LPG for cooking purposes, as biomass fuel usage along with regular smoking is affecting health at a crucial level, maintenance of hygiene in the house by cleaning animal droppings regularly should come into practice. This study may form the basis for reducing pollution in households.

Ethical Approval

The proposal was approved by the Institutional Ethics Committee of ICMR-NIIRNCD, Biomedical and Health Research ICMR-NIIRNCD Jodhpur.

Author Contributions

1) Corresponding Author - Anukrati Dhabhai, (Project technical officer) ICMR – NIIRNCD, single handedly collected data from all locations in Jaipur city, performed all the laboratory tests and identifications of bioaerosolsand prepared proposal, manuscript, and did the data analysis.

2) Co-author - Dr. Arun Kumar Sharma, Director, (Scientist "G") ICMR – NIIRNCD, Jodhpur helped in conceptualizing the proposal, data analysis and manuscript preparation.

3) Co-author - Dr Gaurav Dalela, Head of Department (Microbiology) RUHS, College of Medical Sciences helped in bio-aerosols estimation and identification.

4) Co-author - Dr S.S Mohanty, (Scientist "E") ICMR-NIIRNCD helped in bio-aerosols estimation with fungal identification.

5) Co-author - Dr Ramesh Kumar Huda, (Scientist "C") ICMR-NIIRNCD provided help and support in execution of laboratory work for bioaerosols estimation.

6) Co-author - Dr Rajnish Gupta (Technical Assistant) ICMR-NIIRNCD helped in all ways possible to carry out bio-aerosols part of the study along with fungal identification.

Conflict of Interest

The authors share no conflict of interest.

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ARTICLE

Ionospheric Currents in the Equatorial and Low Latitudes of Africa

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ABSTRACT

The magnetometer data obtained for 2008 from geomagnetic stations installed across Africa by magnetic data acquisition set (MAGDAS) have been used to study the ionospheric Sq current system in the equatorial and low-latitudes of Africa. The aim of this work is to separate the quiet-day field variations obtained in the equatorial and low latitude regions of Africa into their external and internal field contributions and then to use the paired external and internal coefficients of the SHA to determine the source current and induced currents. The method used involved a spherical harmonic analysis (SHA). This was applied in the separation of the internal and external field/current contribution to the Sq variations. The result shows that the variation in the currents is seen to be a dawn-to-dusk phenomenon with the variation in the external currents different from that of the internal currents both in amplitude and in phase. Furthermore, the seasonal variation in the external current maximizes during the March equinox and minimizes during the December solstice. The maximum current observed in AAB and ILR is due to the Equatorial Electrojet Current present in the AAB and ILR stations. Seasonal variation was observed in the geomagnetic component variations as well as in the currents. This is attributed to the position of the sun with respect to the earth at different months of the year. The equinoctial maximum is observed in external current intensity which occurred mostly during the March Equinox.

Keywords: Equatorial; Low latitudes; Africa; Ionospheric Sq; Currents

1. Introduction

The magnetic field can be divided into three distinct parts as seen on the earth's surface: The observed magnetic field is made up of three compo-

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nents: The Main Field, the External Magnetic Field, and the Crustal Field. The Main Field is the largest component of the magnetic field and is thought to be produced by electrical currents in the fluid outer core of the Earth. The External Magnetic Field is thought to be produced by interactions between the Earth's ionosphere and the solar wind. Electric currents are comparable to those fluctuating in the atmosphere of the Earth flow in the conducting Earth below the source current. The characteristics of the source currents and the distribution of electrically conducting materials in the Earth affect the size, direction, and depth of penetration of the induced currents. Magnetometers detect the composite of external (source) and interior (induced) field components from the currents at observatories on the surface of the Earth. The amplitudes and phase connections were demonstrated to be helpful in calculating the conductivity of the deep earth when these currents were divided into their component portions using Spherical Harmonic Analysis (SHA) or other integral techniques [1]. The period of fluctuation of the source current and the distribution of electrically conducting materials in the area of the earth beginning to be explored determine the depth of penetration of the induced current into the deep earth [2].

Campbell and Schiffmacher [3] established equivalent ionospheric source currents representing the quiet-day geomagnetic variations for a half-sector of the Earth that induced Australia. They used a spherical harmonic separation of the external and internal fields for the extremely quiet condition existing in 1965. According to their result, the month-by-month behavior of the current system indicated a clockwise vortex source with a maximum of 12.8×10^4 A in January and a minimum of 4.4×10^4 A in June.

Takeda [4] noted that the intensity of the Sq currents in high solar activity was about twice as large as it is in low solar activity. By comparing the amplitude of the Sq for the same value of conductivity, Takeda [5] pointed out that solar activity depends on the Sq amplitude. He noted that the seasonal variation is seemingly due to differences in neutral winds or due to the magnetic effect of the field-aligned current (FAC) flowing between the two Hemispheres generated by the asymmetry in the dynamo action.

The aim of this work is to separate the quiet-day field variations obtained in the equatorial and low-latitude regions of Africa into their external and internal field contributions and then to use the paired external and internal coefficients of the SHA to determine the source current and induced currents.

2. Data source

The average hourly geomagnetic data used in this study were obtained from geomagnetic stations established in parts of the region (Ilorin (8.5°N, 4.68°E), Lagos (6.4°N, 3.27°E), Addis Ababa (9.04°N, 38.77°E) and Hermanus (34.34°S, 19.24°E)) by magnetic data acquisition set (MAGDAS), Japan for the year 2008 as presented in **Figure 1**.

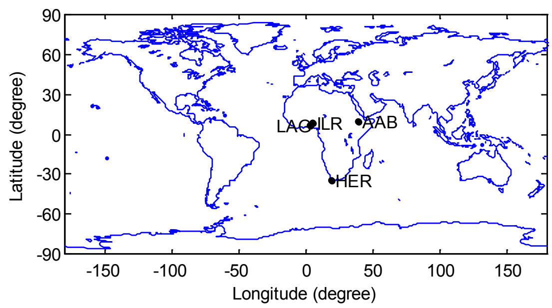

Figure 1. Geographical map showing the study area.

3. Method of analysis

The method employed in this work involves the Spherical Harmonic Analsysis (SHA) devised by Guass (1838) in solving the magnetic potential function *V*. It was Guass [6] who showed that the potential has two parts: the external (source) and internal (induced) parts of the potential function. He expressed the magnetic potential of the Sq field, *V* measured from the daily mean values at the universal time, *T* comprises of both the internal (induced) current and the external source current as a sum of spherical harmonics as:

$$V_n^m = C + a\sum_{n=1}^{\alpha}\sum_{m=0}^{n}\left\{\left(a_n^{me}\left(\frac{r}{a}\right)^n + a_n^{mi}\left(\frac{a}{r}\right)^{n+1}\right)\cos(m\phi) + \left(b_n^{me}\left(\frac{r}{a}\right)^n + b_n^{mi}\left(\frac{a}{r}\right)^{n+1}\right)\sin(m\phi)\right\}p_n^m(\theta) \quad (1)$$

where *C*, *θ*, *a*, r *and ϕ* denote a constant of integration, the geomagnetic colatitude, the earth's radius and the local time of the observatory respectively. a_n^{me}, a_n^{mi}, b_n^{me} and b_n^{mi} are Legendre polynomial coefficients, *e* and i represent the external and internal values, respectively. P_n^m are Legendre polynomials and are functions of colatitude *θ* only. The integers, *n* and *m* are called degree and order respectively. Following Campbell [7] the equivalent current function, J(φ) in Amperes for an hour of the day, φ/15 (the longitude divided by 15°) is obtained from:

$$J = \sum_{m=1}^{4}\sum_{n=m}^{12}[U_n^m\cos(m\phi) + V_n^m\sin(m\phi)]\,P_n^m \quad (2)$$

With 4 for the maximum value of *m*, and 12 for the maximum value of *n*. For the external current representation, we have:

$$U_n^m = -\left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n+1}\right)a_n^{me}\left(\frac{a}{R}\right)^n \quad (3)$$

$$V_n^m = -\left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n+1}\right)b_n^{me}\left(\frac{a}{R}\right)^n \quad (4)$$

And the internal current representation, we have:

$$U_n^m = \left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n}\right)a_n^{mi}\left(\frac{R}{a}\right)^{n+1} \quad (5)$$

$$V_n^m = \left(\frac{5R}{2\pi}\right)\left(\frac{2n+1}{n}\right)b_n^{mi}\left(\frac{R}{a}\right)^{n+1} \quad (6)$$

where, *R* is the radius of the Earth in kilometers.

The value of a is the radius of a sphere whose surface is located where a current could flow to give the fields described at the Earth's surface by the SHA, hence the name "Equivalent Current". It is believed that the dynamo current sources are in the ionospheric E-region (near 100 km altitude). Because there is other evidence that the dynamo current source is in the E-region ionosphere, near 100 km altitude, the value of a ≈ R and the ratio $\left[\frac{a}{R} - 1\right]$ may be omitted from the current computations [8].

However, the equivalent external current intensity I of latitudinal component Θ and longitudinal component ø can be determined (in amperes) from J by:

$$I_\theta = \frac{1}{r\sin\theta}\frac{\partial J}{\partial \emptyset} \quad (7)$$

$$I_\emptyset = -\frac{1}{r}\frac{\partial J}{\partial \theta} \quad (8)$$

Therefore, the total current intensity (internal and external) can be given by:

$$I = I_\theta + I_\emptyset \quad (9)$$

4. Results and discussion

Figure 2 shows the external currents for the four African stations: ILR, LAG, AAB and HER while **Figure 3** shows the contour map for the external current in Africa. The variation in the external currents occurred in all hours of the day from dawn to dusk. The external current curves for all the stations are seen to increase gradually from midnight values to a maximum intensity around 10:00 for AAB, 11:00 for LAG, 11:00 for Lagos and 13:00 for HER and a gradual decrease to midnight values. This effect is also observed in the contour maps for the external current shown in **Figure 3**. The contour lines of the contour map are seen to be increasing inwards which indicates a positive variation pattern.

It is observed that the nighttime values are minimal. This is due to the disappearance of the sun which is the main source of ionization in the ionosphere. Takeda [4] noted that the intensity of the Sq currents in high solar activity was about twice as large as it is in low solar activity. Moldwin [9] also noted that the ionospheric ionization at any given position depends on the position of the sun in the sky and on its absolute output.

At night, the amount of sunlight goes to zero and production due to photoionization ceases. However, the currents are not observed to be zero. This therefore suggests that the observed nighttime currents are from sources different from the ionospheric sources. Moldwin [9] noted that these currents are from other sources like the magnetospheric and ring currents. Obiekezie [10] pointed out that these currents filter into the ionosphere at night even during magnetic quiet periods. This non-zero current at night is reported by other researchers such as Campbell [11], Okeke and Rabiu [12], Rabiu [13], and Obiekezie, et al. [14].

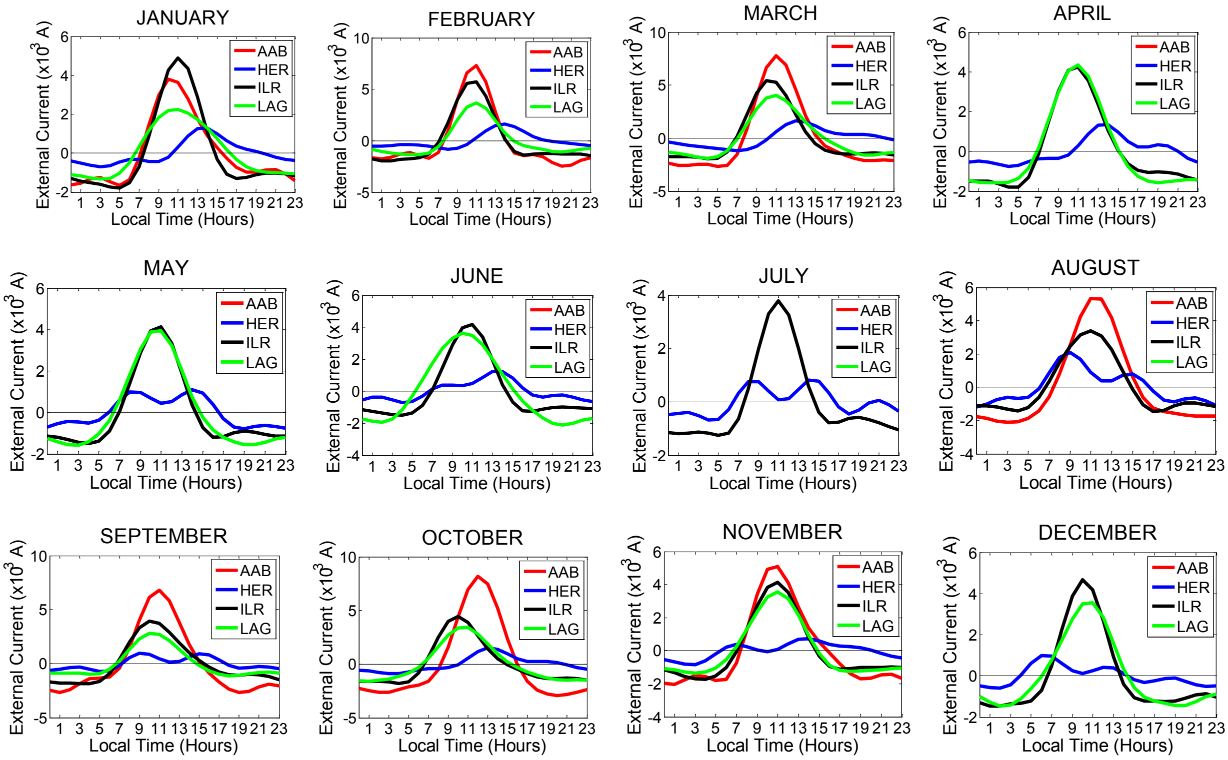

Figure 2. External Sq current across Africa (ILR, LAG, AAB, HER).

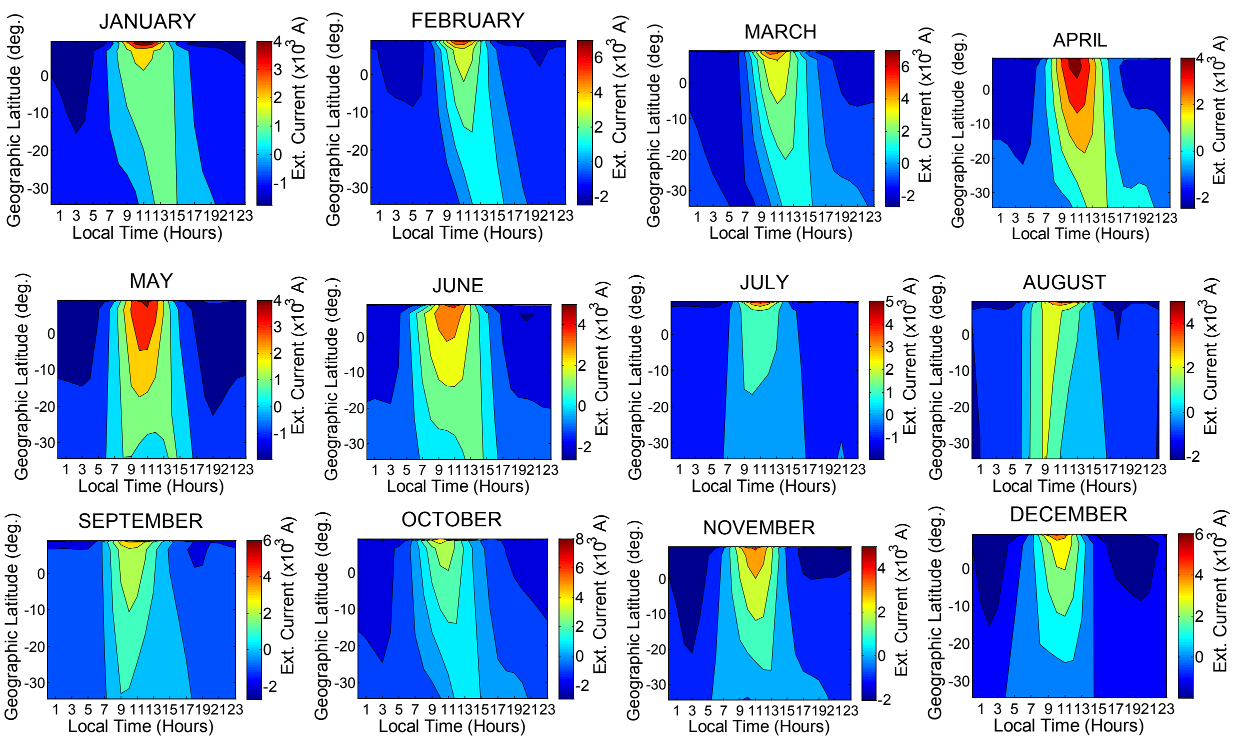

Figure 3. Contour map of external current for equatorial, low and mid latitudes of Africa.

The maximum current was observed in ILR in January and in AAB in almost all the months. AAB and ILR are equatorial electrojet stations located at latitude 0.18° of the dip equator. The equatorial electrojet is a narrow belt of intense electric current in the ionosphere confined to about ±3° of the dip equator. This result is in agreement with the work of Rastogi [15] who observed a maximum diurnal and semi-diurnal variation in X over the dip equator indicative of EEJ. Obiekezie et al. [14] also observed a maximum Sq (H) variation at the AAB station indicative of the EEJ.

The external current pattern in HER station which is in the Southern hemisphere shows a crest-like pattern just like the other three stations in Africa in the Northern hemisphere. This is not in line with the suggested pattern of the ionospheric current system. The ionospheric currents typically form two global horizontal current vortices at the sunlit side of the Earth, one flowing clockwise in the Southern hemisphere and the other flowing counterclockwise in the Northern hemisphere. The HER is expected to have a current pattern opposite that of ILR, LAG and AAB because of the hemispherical differences between them, however, it was observed that HER was having a crest also. This behavior could be attributed to the position of the station with respect to the Sq focus in the southern hemisphere. Hence, it is suggested that within the equatorial and low latitudes, the ionospheric current pattern is the same in both hemispheres.

Maximum external currents were obtained in March equinox for all the stations: ILR, LAG, AAB and HER with a value of approximately 4.8×10^3 A for ILR, 4.2×10^3 A for LAG, 8×10^3 A for AAB and 1.5×10^3 A for HER. This equinoctial maximum in the external currents is in agreement with Obiekezie and Okeke [2]. The minimum external current was observed in June Solstice in ILR, and HER with a value of 3.8×10^3 A, 5×10^3 A and 8×10^3 A respectively. At LAG and AAB, minimum variation was observed during the December Solstice and September equinox with a value of 2.85×10^3 A and 2.5×10^3 A respectively.

As can be seen in **Figure 4**, the variation in the internal currents occurred in all hours of the day

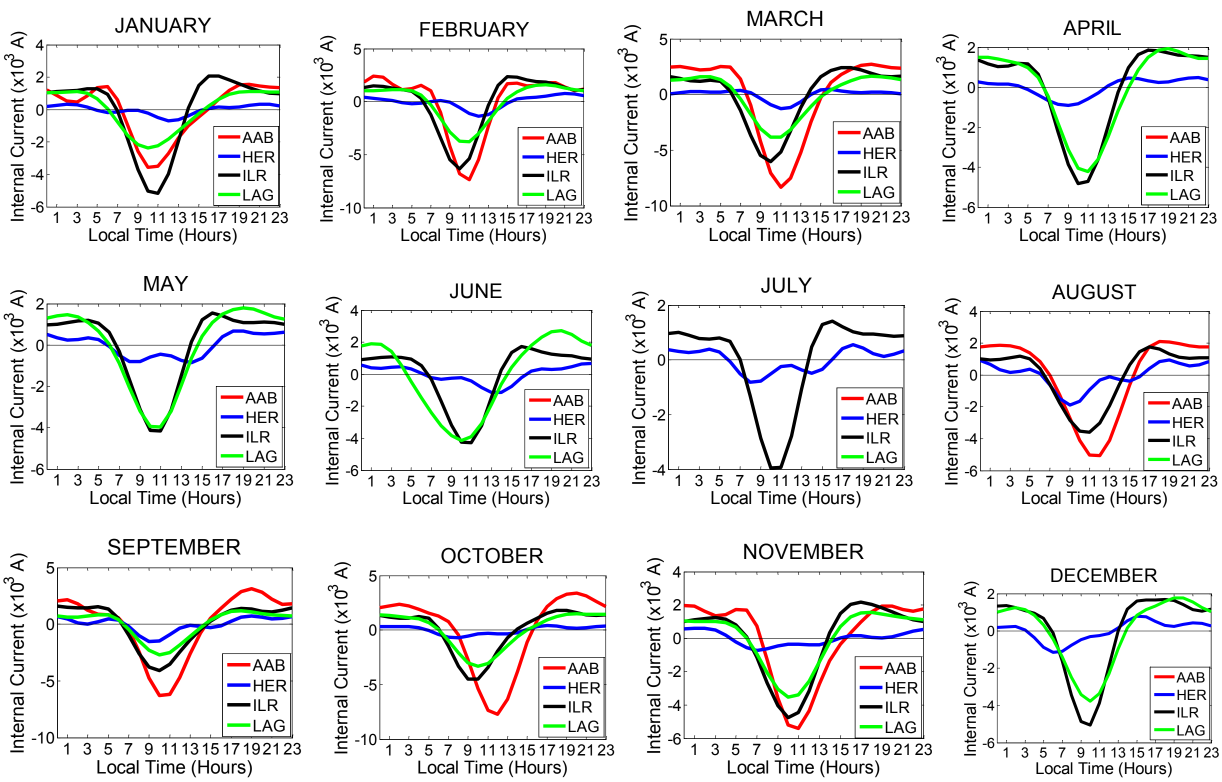

Figure 4. Internal Sq current across Africa (ILR, LAG, AAB, HER).

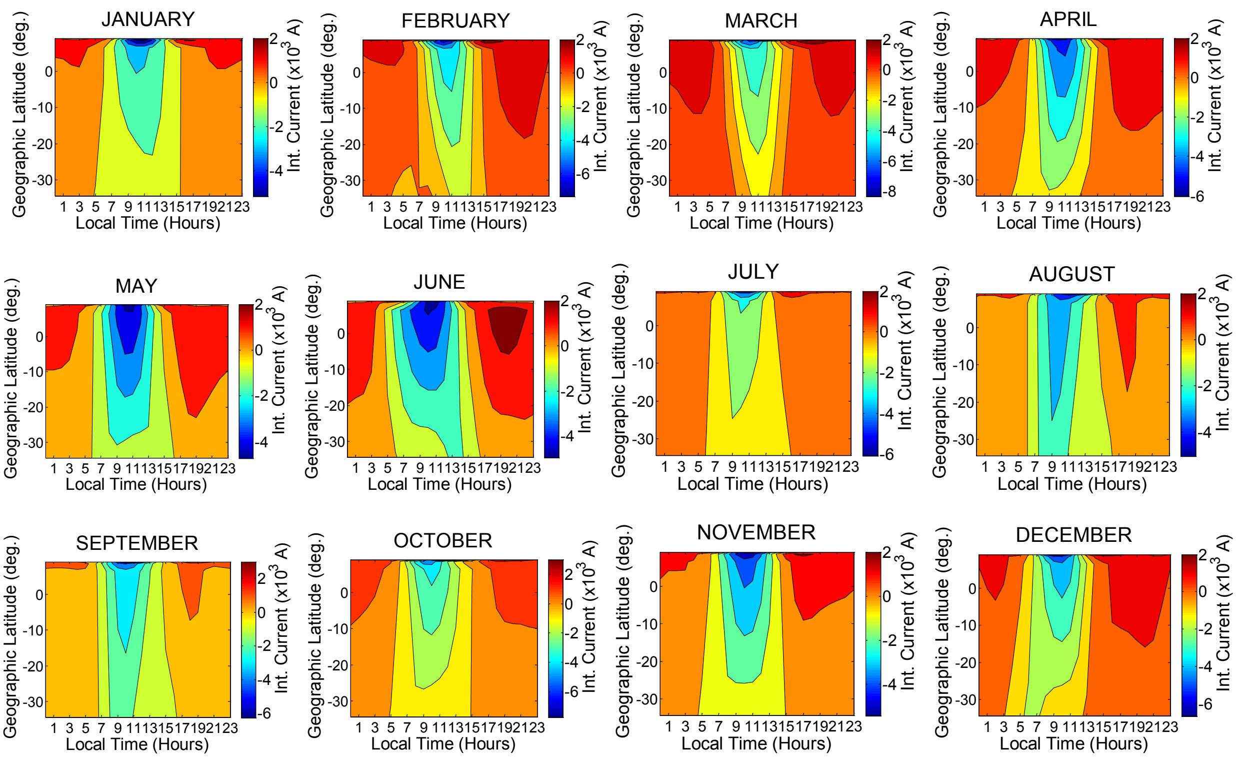

Figure 5. Contour map of internal current for equatorial, low and mid latitudes of Africa.

from dawn to dusk. The observed variation in internal currents is seen to be different from the external currents both in amplitude and phase. These differences observed in the phase and amplitude are a function of the Earth's conductivity. This is also reflected in the contour maps of the internal currents as shown in **Figure 5**. The calculated internal and external currents are seen to be lower than those of Campbell, et al. [16], and Obiekezie and Okeke [2]. Campbell et al. [16] observed external and internal currents in the order of 10^4 A while Obiekezie and Okeke [2] observed external and internal currents in the order of 10^6 A.

5. Conclusions

The application of the solar quiet day ionosphere current has enabled us to study the ionospheric Sq current system in the equatorial and low latitudes of Africa. The following deductions can be made from the results:

1) The maximum current observed in AAB and ILR is due to the Equatorial Electrojet Current present in the AAB and ILR stations.

2) Within the equatorial and low latitudes regions, the ionospheric current pattern is the same in both hemispheres.

3) The position of the station with respect to the Sq focus affects the external current pattern.

4) The source currents varied from the induced currents both in amplitude and phase.

5) Seasonal variation was observed in the geomagnetic component variations as well as in the currents. This is attributed to the position of the sun with respect to the earth at different months of the year.

6) The equinoctial maximum is observed in external current intensity which occurred mostly during the March Equinox.

Conflict of Interest

There is no conflict of interest.

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