The Dhaka University Journal of Earth and Environmental Sciences, Vol. 11 (1): 2022

Comparison between Local and Global Methods to Develop AQI in Representing the Spatial Pattern of Air Quality of Dhaka City

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Manuscript received: 19 July 2022; accepted for publication: 01 November 2022

ABSTRACT: An Air Quality Index (AQI) is a means of evaluating air quality in respect to the relation between air quality and the entire environment of an area. The main objective of the study was to compare the development of AQI using global methods and local methods to identify which could represent the more significant pattern from a spatial perspective in Dhaka city (DNCC and DSCC). The pollutants used in this study are CO, NO2, SO2, O3, CH4, CO2, PM2.5 and PM10. For the global AQI, indexing was performed using the guidelines in 'Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index' by USEPA (United States Environmental Protection Agency). This method identified and mapped the most responsible pollutant that represents the pollution pattern of the area. For local AQI, an overlay method was developed where all the relevant pollutants were weighed according to their significance and summed; their weights calculated using a Principal Component Analysis (PCA). Component analysis could find a better-correlated variable to represent the distribution from all the variables, deeming it a good feature-selecting tool. The result from this study suggests that the local AQI better represents the air quality of the study corresponding to certain real scenarios. Mapping the pollution has helped in validating the spatial pattern of the pollutants. Such methods, which include all the variables influencing the atmospheric dynamics, could establish a better pattern for the local environment. The temporal background of the factors could be considered as situations may change over time. For air quality, this could be performed with any variables apart from atmospheric constituents and can be even replicated for any component of the environment, which may help in comprehending the local environmental quality. The study would be useful to devise a proper system to develop AQI considering all the spatial and temporal effects.

Keywords: Air Quality Index; Air Pollutants; Overlay Mapping; $PM^{2.5}$

INTRODUCTION

The industrial revolution was a major success in terms of society, technology and a multiplicity of services in one hand, it also resulted in the production of massive amounts of air pollutants on the other hand (Manisalidis et al., 2020). Without a doubt, air pollution has now reached a level of global hazard. Air pollution from anthropogenic sources is now a public health hazard worldwide. According to a report from the World Health Organization (WHO) in 2022, it is responsible for approximately 4.2 million and 3.8 million deaths that result from exposure to ambient (outdoor) and household air pollution, respectively.

An Air Quality Index (AQI) is a component of the Environmental Quality Index (EQI), which was developed and used in the late 1960s by the National Wildlife Federation of the United States of America (Inhaber, 1976). Its primary goal was to strengthen the link between air quality and human health. The Environmental Protection Agency (EPA) of the United States of America established five pollution criteria in 1999 i.e. particulate matter (PM), carbon monoxide (CO), ozone (O_3), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). According to a report from WHO, there are areas all around the world, where the air quality has exceeded the standard limit yet still abodes approximately 91% of the world's population. In terms of air quality, Dhaka, the capital city of Bangladesh, has been declared as a highly polluted city in the world based on $PM_{2.5}$ measurements and AQI (Sarker et al., 2019; Islam and Chowdhury, 2021). Dhaka scored 193 in the US Air Quality Index (AQI) in April 2021, ranking as one of the cities having the poorest air quality. The situation is very serious, as five of the top ten causes of death in Bangladesh are related to air pollution (Momen et al., 2021). The concentration of airborne particulate matter (PM) has reached 5 times the standard value (DoE, 2018). The average yearly $PM_{2.5}$ level in Dhaka is 97.1 µg/m3, making it the world's 2nd most polluted city. During the dry season (October-April), Dhaka's

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DOI: https://doi.org/10.3329/dujees.v11i1.63716

air quality is at its worst (Momen et al., 2021). The primary sources of particulate matter in Dhaka City's air are motor vehicle emissions and brick kilns located in and around the city (DoE, 2018). Bangladesh has a low environmental performance value (rank: 162/180 countries) according to the Environmental Performance Index (2020), owing primarily to a low air quality index (Islam et al., 2021). The government began developing regulatory framework in 1999 to achieve US-EPA and Bangladesh National Air Quality Standards, particularly for Dhaka city (Pavel et al., 2021).

Chemical compounds, e.g., NO_2 and SO_2 would also be abundant in the atmosphere of Dhaka city, originating from both cars and factories. The brick kilns emit a large amount of smoke and haze, which contains other compounds such as CO and O_3. Seasonal industrial operations emit a significant amount of pollutants into the atmosphere, including SO_2, NO_2, CO, CO_2 and other wastes. A number of small and medium-sized RMG industries expel untreated effluents into water, along with air pollutants such as SO_2, NOx and suspended particulate matter (PM_{10} and $PM_{2.5}$) content in the air (Rabbi et al., 2018). Dhaka's waste is composed primarily of organic waste, which decomposes to produce CH_4. The waste management here produces CO_2 and CH_4, with emissions occurring at almost every stage, from transportation to recycling, recovery, and final disposal (Rahman et al., 2010). Matuail Landfill, Tejgaon Industrial Area, waste dumping grounds in Dhaka's Aminbazar and Narayanganj, the Narayanganj sewage treatment plant and croplands across the country are among the six sources shortlisted by a technical committee formed by the government. CO_2 emissions are directly proportional to traffic congestion caused by high fuel consumption at that time. Dhaka's air contains up to 1,500 parts per million of CO_2, a concentration caused by the city's high population density and severe traffic congestion. During traffic jams, vehicle speeds drop to 4 to 5 km/h, causing vehicles to move slowly while engines continue to run for up to 1 to 2 hours. Both exhaust gas and braking are likely major sources of heat and carbon emissions (Asaduzzaman et al., 2019). Much of the $PM_{2.5}$ pollution found in ambient air is caused by emissions from the combustion of gasoline, oil, diesel fuel, or wood, as well as a significant proportion of PM_{10}. Local natural and anthropogenic sources, such as brick kilns, brickfields, landfills, agricultural fields, and burning fuel smog and home appliances, have been identified as polluting Dhaka's air quality.

The concentration of SO_2, NOx, CO, PM_{10}, $PM_{2.5}$ and O_3 in the country's major cities has significantly increased in recent years (Islam et al., 2021). A comparison of CO_2 concentrations in all Bangladeshi cities indicates that Dhaka has higher CO_2 concentrations than the rest of the country. During the COVID-19 outbreak lockdown in April-May 2020, $PM_{2.5}$, NO_2, SO_2, and CO concentrations had reduced by 26%, 30%, 7%, and 7%, respectively. Based on a 24-hour averaging period, the mean $PM_{2.5}$ concentration in 2020 was 26% lower than the mean $PM_{2.5}$ concentration in 2019, and the rates of decline were 12% and 10%, respectively, in comparison to 2018 and 2017. When compared to the same period in 2019, the mean and maximum NO_2 concentrations in April and May 2020 decreased by about 30% and 22%, respectively. The mean and maximum CO concentrations have dropped by 7% and 5%, respectively, whereas the mean SO_2 concentration in April-May 2020 has reduced by almost 7%, compared to the mean concentration at the same time last year (Islam and Chowdhury, 2021). Because NO_2 is a major component in vehicle emissions, its reduction is more significant during the lockdown period (Islam and Chowdhury, 2021). Since 2016, both PM_{10} and $PM_{2.5}$ concentrations have decreased. Dhaka's annual PM concentration was about 12% lower in 2017 compared to 2013-14 (DoE, 2018). According to a government directive, all Fixed Chimney Kilns (FCK) with high emissions will need to be upgraded to low emission models in order to continue producing bricks. A significant number of the FCKs have been updated to a newer version, known as ‘ZigZag’ technologies, which deals with the pattern of arrangement of the bricks to promote air flow. To determine whether the initiatives are actually being effective to reduce pollution along with identifying the potential causes, it will be necessary to monitor the PM trends in Dhaka over the ensuing years. (DoE, 2018).

AQI is a numerical measure of the condition of air quality in a given area. In Bangladesh, the AQI is calculated using the current concentrations of five criteria pollutants: PM (PM_{10} and $PM_{2.5}$), NO_2, CO, SO_2, and O_3. An AQI measure, which is a numerical value, indicates how clean (lower value) or polluted (higher value) the air is, based on a predefined scale. This mainly quantifies the potential health consequences for the general public. Certain methods can be used to create an Air Quality Index (AQI), with some recommending looking for the most significant pollutant and mapping it to understand its spatial pattern. A method was established to develop AQI from mapping the most responsible pollutant based on some allowed breakpoints for the maximum concentration of the pollutant in order to be discounted as a health hazard, according to the USEPA's 2018 report titled 'Technical Assistance Document for the Reporting of Daily Air Quality - the Air Quality Index.' In this study, the same method was used to identify AQI in global methods, also known as 'global AQI.' However, based on the preceding discussion, all of the pollutants contributing to air pollution recognize the importance of taking into account all of the local pollutants in order to produce a more definite result and identify other responsible pollutants affecting the cities' air quality. Because of the fact that not all pollutants have the same statistical significance, different weights can be assigned based on their statistical significance. This type of AQI, termed 'local AQI' in this study, is unique to the aforementioned phenomena. In this study, a local AQI was also used to compare with the global AQI to identify the better suit to represent the concurrent real spatial scenario. Thus, the primary goal of the study was to compare the method of creation of AQI, using global and local methods variables unique to the study area and season of study. This is to determine whether local AQI can be more suited than global AQI, as well as to understand the complete spatial pattern of air quality. Thus, the main objectives of the present study are: i) to develop a local AQI method for representing the air quality in the concurrent times for the study area and ii) to compare the local AQI to a predefined global AQI in terms of their spatial patterns.

METHODS

Study Area

The study area extends between latitudes from 24° 40’ N to 23° 54’ N and longitudes from 90° 19’ E to 90° 30’ E. The total area is 277 sq km. The study area had been divided into 20 zones, with 10 zones in each City Corporations, DNCC (Dhaka North City Corporation) and DSCC (Dhaka South City Corporation). This division has been done according to the official websites from DNCC and DSCC. There are a few areas that fall in neither of the 2 parts and thus are deducted from the study, e.g., Dhaka Cantonment. The spatial reference of this data has been set to the Geographic Coordinate System, GCS_WGS_84.

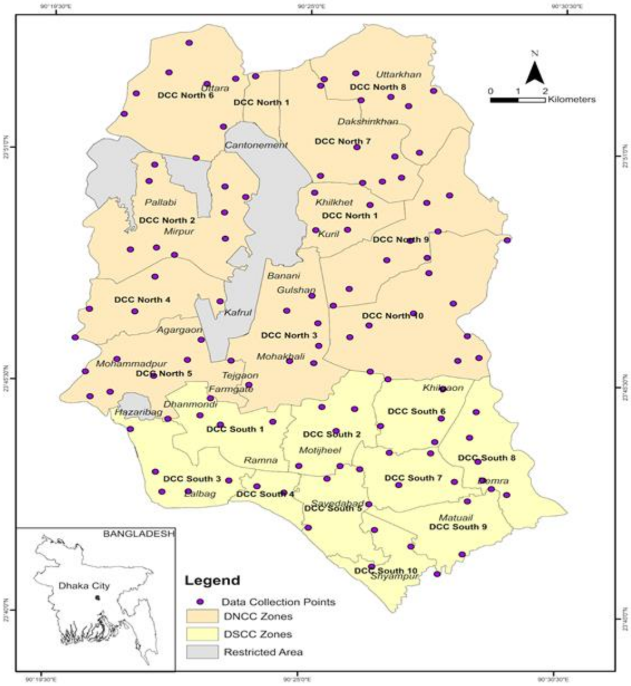

Figure 1: The Selected Region (20 Zones in DNCC and DSCC) and Data Collection Sites (in points) for the Study

Data Overview

The pollutants used in this study are CO, NO_2, SO_2, O_3, CH_4, CO_2, $PM_{2.5}$ and PM_{10}. Concentration data for CO, NO_2, SO_2, O_3 and CH_4 were acquired from Sentinel-5 Precursor mission sensors (TROPOMI) using remote sensing methods in Google Earth Engine for March 2022 to April 2022. Winter (dry) season was best for collecting data for atmospheric constituents as they have the highest dispersal rate along with continued emission from the sources (Momen et al., 2021). Concentration data for CO_2, $PM_{2.5}$ and PM_{10} were collected from the field as they were not available in secondary sources (Figure 1). Before field data collection, a total number of 116 points were generated across the study area by digitising over the study area shapefile. Hence, it was georeferenced with the geographic coordinates from the shapefile. The number of points depended on the distance between each point, which was taken to be a minimum 900 m, which, by means of test interpolations from known rasters, was found to be the maximum distance that could render smooth raster surfaces. These 116-point data were 116 sites for collecting pollutant concentration data using an air sampler. We used the ‘Series 500’ portable air quality monitor from *Aeroqual* which had to be calibrated before registering the concentrations (ppm). The concentration is registered in real-time with a 3 minutes calibration window. The data had been compiled in a written spreadsheet with the coordinates of latitudes and longitudes. Later this data was georeferenced as point data and then rasterized to the separate kinds of pollutants.

Table 1: Sources of Data Used in the Study and Their Acquisition Information

Data	**Source**	**Information**
Mean CO, NO_2, SO_2, and O_3 (mol/m^2) concentrations (vertically integrated column density)	TROPOMI on the Sentinel 5 Precursor (S5P) acquired using Google Earth Engine	Spatial resolution: 30 m. Data collected from March 2022 to April 2022
Mean CH_4 Concentration (column averaged dry air mixing ratio of methane (ppbV))	TROPOMI on the Sentinel 5 Precursor (S5P) acquired using Google Earth Engine	Spatial resolution: 30 m. Data collected from March 2022 to April 2022
Mean CO_2, $PM_{2.5}$ and PM_{10} concentrations (ppm)	Data collected from designated areas.	A total of 116 Point Data (spread across the study area at a distance of 900 m from each other). Data collected from March 2022 to April 2022

Data Analysis for Global AQI

For the global AQI, indexing was performed using the guidelines in 'Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI)' by USEPA (United States Environmental Protection Agency) in 2016. According to this report, a single pollutant had to be sought out using table 2.

Table 2: Breakpoints of the value ranges used for global AQI.

O_3 (ppm) 8-hour	**$PM_{2.5}$** (µg/m^3) 24-hour	**PM_{10}** (µg/m^3) 24-hour	**CO** (ppm) 8-hour	**SO_2** (ppb) 1-hour	**NO_2** (ppb) 1-hour	AQI	Remarks
0.000 - 0.054	0.0 – 12.0	0 - 54	0.0 - 4.4	0 - 35	0 - 53	0 - 50	Good
0.055 - 0.070	12.1 – 35.4	55 - 154	4.5 - 9.4	36 - 75	54 - 100	51 - 100	Moderate
0.071 - 0.085	35.5 – 55.4	155 - 254	9.5 - 12.4	76 - 185	101 - 360	101 - 150	Unhealthy for Sensitive Groups
0.086 - 0.105	55.5 - 150.4	255 - 354	12.5 - 15.4	186 - 304	361 - 649	151 - 200	Unhealthy
0.106 - 0.200	150.5 - 250.	355 - 424	15.5 - 30.4	305 - 604	650 - 1249	201 - 300	Very unhealthy
-	250.5 - 350.4	425 - 504	30.5 - 40.4	605 - 804	1250 - 1649	301 - 400	Hazardous
-	350.5 - 500.4	505 - 604	40.5 - 50.4	805 - 1004	1650 - 2049	401 - 500	Hazardous

AQI is basically the highest value for each pollutant calculated using the formula as follows:

$$I_p = \frac{I_{hi}-I_{lo}}{B_{hi}-B_{lo}} \times (C_p - B_{lo}) + I_{lo} \text{ ------------------(1)}$$

Where,

I_p= the index for pollutant p

C_p= the truncated concentration of pollutant p

B_{hi}= the concentration breakpoint that is greater than or equal to C_p

B_{lo}= the concentration breakpoint that is less than or equal to C_p

I_{hi}= the AQI value corresponding to B_{hi}

I_{lo}= the AQI value corresponding to B_{lo}

The study sorted out the average values of each of the pollutants needed, i.e., $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, O_3, to input as the concentration of pollutant (C_p) in the formula (1) and converted the units as per table 2. Then the calculation of the index (I_p) for each pollutant. The study found that, $PM_{2.5}$ had the highest index value (176), deeming it the responsible pollutant for air quality in the study area. A brief of the process is stated below.

The mean of $PM_{2.5}$ was found to be 104 (µg/m^3). Now with the readings according to formula (1) and table 2, the study compiled the following expression for $PM_{2.5}$.

$$I_{PM2.5} = \frac{I_{hi}-I_{lo}}{B_{hi}-B_{lo}} \times (104 - B_{lo}) + I_{lo} = \frac{200-151}{150.4-55.5} \times (104 - 55.5) + 151 = 176$$

The same had been repeated for each pollutant, among which the index for $PM_{2.5}$ was the highest. Thus, the study created the map in figure 5, for $PM_{2.5}$ as the map for AQI for the study area. The map could be classified according to the 'Remarks' (Table 2). The $PM_{2.5}$ raster was first reclassed to 0-500 to match the indices in the table and later was classified accordingly. At 176, $PM_{2.5}$ had an index of 'Unhealthy' (Table 2). For the rest, the indices were (in descending order) NO_2 : 119; PM_{10} : 105; SO_2 : 81; CO : 46; O_3 : 37.

A map was generated with all the pollutant data by weighting them according to their significance, these weights had been derived from the indexing method mentioned in formula (1) and WHO Fact Sheet 2021. The steps for this collective mapping have been elaborated in this section. ArcMap 10.3 software was used for the analysis in this study. The pollutant data collected remotely were raster images (.tif) masked to the outer boundary of the study area. The point pollutant data collected from the field were first interpolated using the 'Kriging' tool and then masked and resampled to fit the rest of the datasets. Interpolation is important here as we would need to derive values using geostatistical precision on the raster surface between the designated points where data were not collected. According to the software documentation, Kriging helps interpolate the unknown raster values using spatial arrangement and the proximity to the known input values. For the data for PM_{10}, imputation had to be performed as there were some gaps in the data. We used the MICE (Multiple Imputation by Chained Equations) method for interpretation and calculated an accuracy to 3 decimal places.

The data collected thus far is processed for overlay analysis. Before running the overlay, the first task was to ensure the feasibility of the data by formatting the numeric values for the analysis. The data type had to be changed to 32 bit unsigned integer (formerly floating point) and the attribute table had to be built. This had to be done for reclassifying the data as continuous data with floating points cannot be divided to classes discreetly. Moreover, without reclassifying the different kinds of measurements of the pollutants can not be standardised. All the pollutant rasters were then reclassified the same scale (1-127). Here, as the pollutants collected from the field were limited to the 116 different point locations, they had the least variability in values. Thus, the numbers of unique values were kept only at 127 to avoid data redundancy, which can distort patterns. Subsequently, the data were used as input rasters for the overlay analysis. A common Geographic Coordinate System (GCS_WGS_84) and 30 m cell size were used along the study for maintaining consistency in the analysis.

Data Analysis for Local AQI

For local AQI, 'Weighted Overlay' was chosen as it can extract the weights for each pollutant while overlaying in layers and also users can set influence factors based on real scenarios as prior to the analysis. The general formula for this analysis can be as follows where, *'w'* denotes weights for each parameter or more commonly known as Influence Factors, *'c'* is the cell value for that parameter and *'n'* is the number of parameters.

Output for Weighted Overlay:

$$=\sum_{i=1}^{n} w_i c_i \text{------------------(2)}$$

$=\{(0.29)\times(PM_{2.5})\} + \{(0.13)\times(CO)\} + \{(0.13)\times(NO_2)\} + \{(0.12)\times(CH_4)\} + \{(0.11)\times(SO_2)\} + \{(0.11)\}\times(PM_{10})\} + \{(0.10)\times(O_3)\} + \{(0.01)\times(CO_2)\}$

According to the ArcGIS documentation, the overlay analysis overlays each raster over the other and adds the values of pixels overlaid on top of the other by their assigned weights. The weights to each pollutant was calculated using Principal Component Analysis (PCA) from *DimensionityReduction* tool of QGIS 3.22.7 version software, where the percentage of the component loading scores were calculated and used as the weights. A pollutant with a higher loading score would get a higher weight. The loading scores qualify the correlation of that specific pollutant to the others (Siswadi et al., 2012). Component analysis was chosen for this study as it could find a better-correlated variable to represent the distribution from all the variables, deeming it a good feature-selecting tool (Mao, 2005). It can be easily seen how the ranks for each pollutant was calculated based on the loading scores (Table 3). The column PC1 was calculated in percentage, which was used as the weights for respective pollutants in formula (2). The PC1 was chosen among all the components as it had the highest eigenvalue to depict the highest explained variance (Siswadi et al., 2012).

Table 3: Loading Scores (Descending Order) for All Pollutants ('λ' Refers to Eigenvalues)

Pollutant	PC1 (λ = 316.283)	PC2 (λ = 226.873)	PC3 (λ = 171.4)
$PM_{2.5}$	**0.011**	0.007	-0.024
CO	**0.005**	-0.009	-0.004
CH_4	**0.005**	-0.010	0.000
NO_2	**0.005**	-0.011	0.007
SO_2	**0.004**	0.009	0.016
PM_{10}	**0.004**	0.007	-0.003
O_3	**0.003**	0.011	0.007
CO_2	**0.000**	0.000	-0.005

This resultant value would be a single cell value and it would repeat for each cell in the rasters. For this, it is very important that all the rasters have been masked to the same dimension (same number of cells across the length and the same for the width). Otherwise, the inputs would be uneven with either cropped out or overhanging parts. The output is mapped in Figure 6.

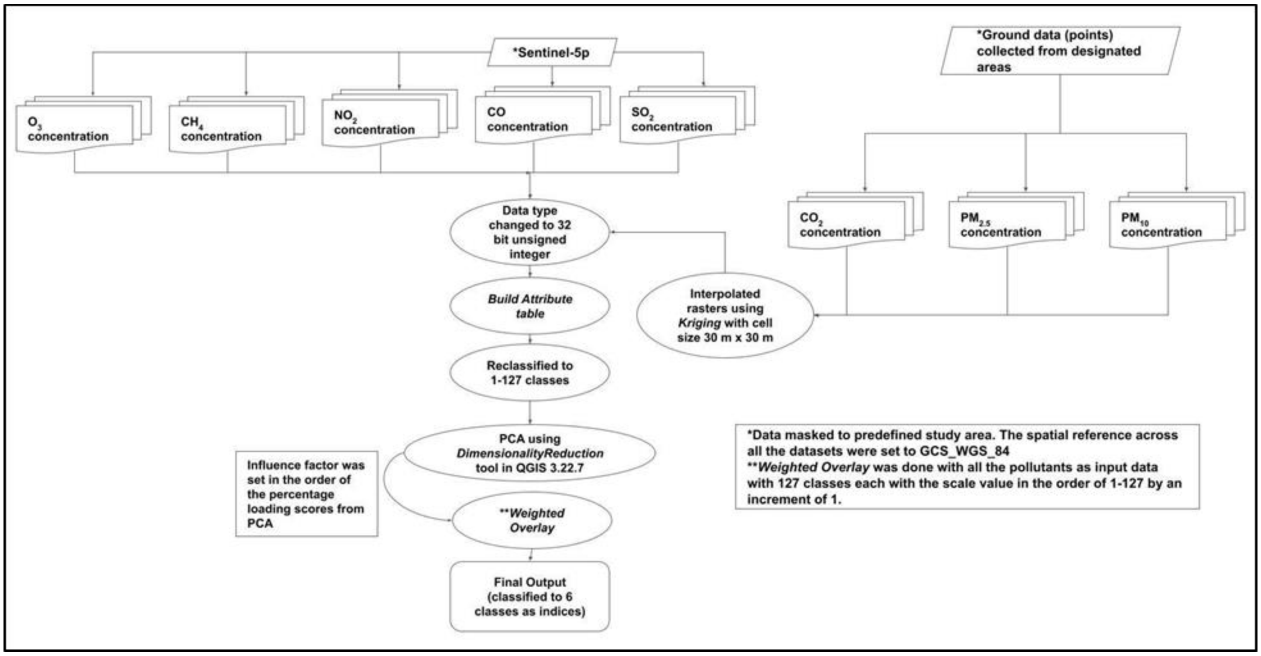

Figure 2: Flowchart of the Methods Used for Overlay Analysis

Result

The pollutant data have been processed in map layout and masked to the study area for simpler comprehension of the spatial pattern (Figure 3). Here, among the concentrations of CH_4, CO, NO_2 and O_3, CH_4 is the column averaged mixing ratio to dry air and CO is column density. The CH_4 data is offline thus, has a coarser resolution. However, CO concentration is quite spread out (except in Northeastern parts) whereas CH_4 is concentrated in the Southern regions. Both of the NO_2 and O_3 pollutants are depicted by their column density (concentration). It is visible how they both are reciprocal to each other when it comes to spatial distribution; O_3 concentrations rise moving North and for NO_2 it gradually falls, although overall NO_2 has a higher concentration.

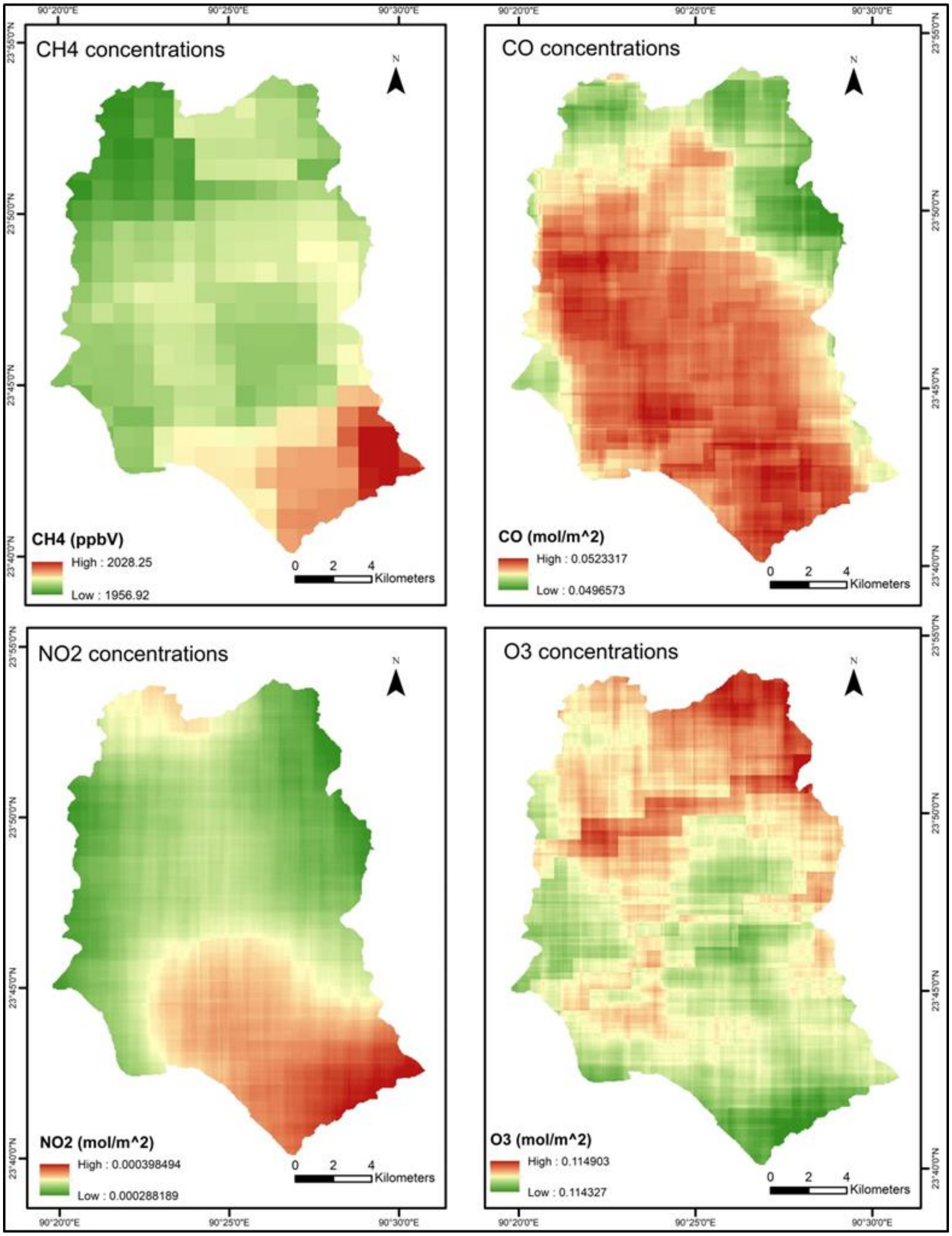

Figure 3: Spatial Distribution of CH_4, CO, NO_2, and O_3 in the Study Area

For the concentration of SO_2, CO_2, $PM_{2.5}$, and, PM_{10} the study identified that SO_2 is concentrated in the Northwestern and Southwestern parts of the area (Figure 4). A strip of atmosphere in the middle of the study area seems to have less SO_2 concentration. The concentration of CO_2 follows a trail from one side of the study area to the other. It is heavily concentrated in the parts with higher numbers of industries in the Southwest and is the lowest in the Central East of the study area. This study used 2 types of particulate matter data, i.e, $PM_{2.5}$ and PM_{10}. The $PM_{2.5}$ has a very small diameter (2.5 µm), allowing it to traverse a greater distance, creating such interesting patterns as seen in the figure (Figure 4) whereas, PM_{10} is highly concentrated in the Northern east and Southern part of the study area.

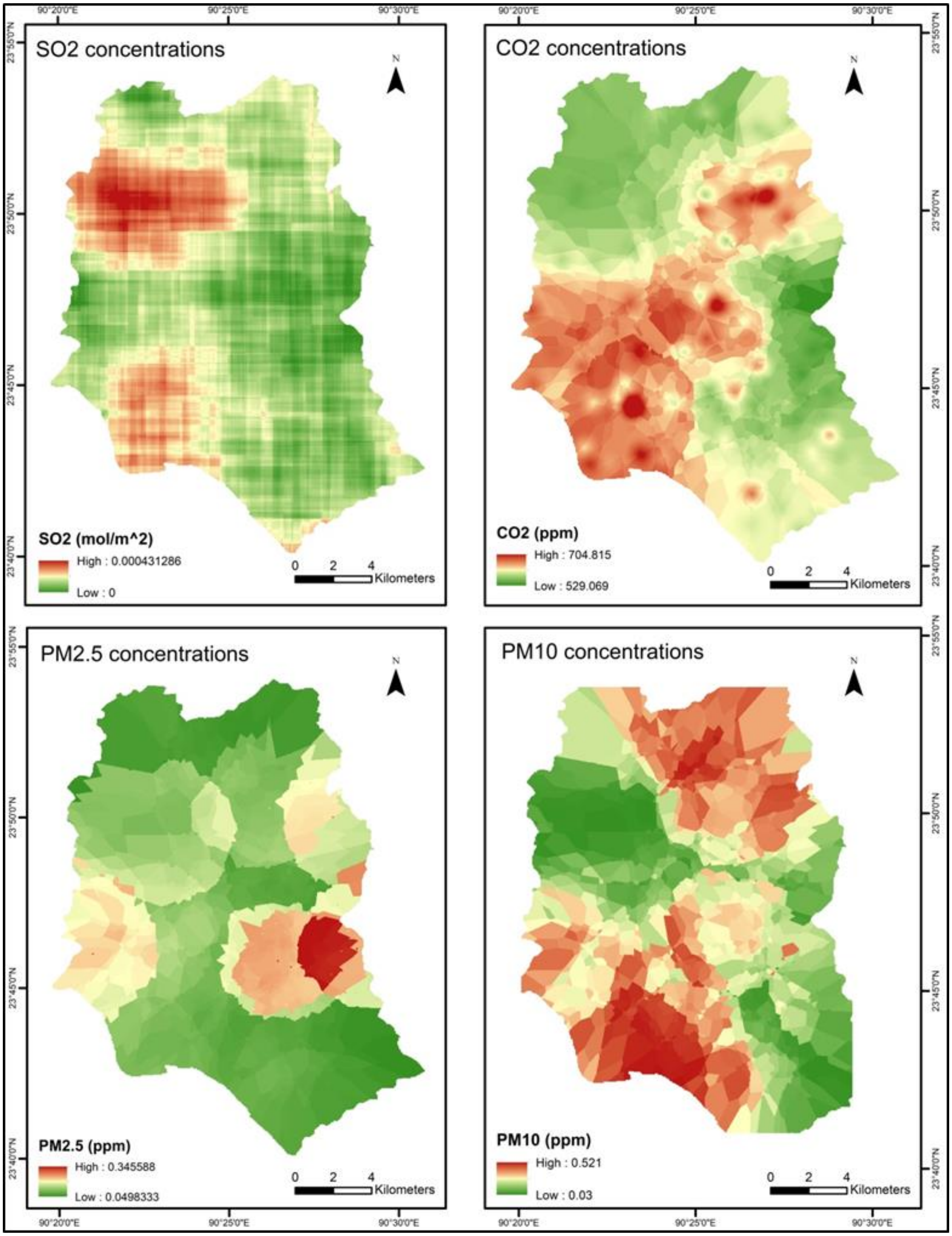

Figure 4: Spatial Distribution of $SO_{2,}$ CO_2, $PM_{2.5,}$ and, PM_{10} in the Study Area

In the present study, $PM_{2.5}$ is mapped, being identified as the most responsible pollutant by the method developed by USEPA (Figure 5). The indices have been classified into 6 classes namely 'Good', 'Moderate', 'Caution', 'Unhealthy', 'Very Unhealthy' and 'Extremely Unhealthy'. Both DNCC and DSCC have air quality varying from zone to zone as depicted from the map. Several zones of DNCC and DSCC lying on the Northernmost and Southernmost parts, are with 'Good' and 'Moderate' air quality, which indicates less $PM_{2.5}$ concentration. Central North zones of DNCC show to have 'Caution' which means the air quality would most likely be polluted if no measures are initiated. The mid-section or central part of the study area has a variation of $PM_{2.5}$ concentration, showing 'Unhealthy' 'Very Unhealthy' and 'Extremely Unhealthy' quality. Overall, the Southern part of the study area comprising Ramna, Motijheel, Sayedabad, Matuail have been indexed from 'Caution' to 'Good' air quality whereas, Mohammadpur, Hazaribag, Tejgaon Industrial area, Farmgate in the Southwest have been identified as 'Extremely Unhealthy' air quality. However, central part of the study area that includes Mirpur, Pallabi, Kafrul, Gulshan, Banani, Mohakhali, has 'Caution' and 'Good' air quality as depicted in the map. The DNCC Zone 4, 5, 9, 10 and DSCC Zone 6 partly sharing with Zone 2, have the highest pollution.

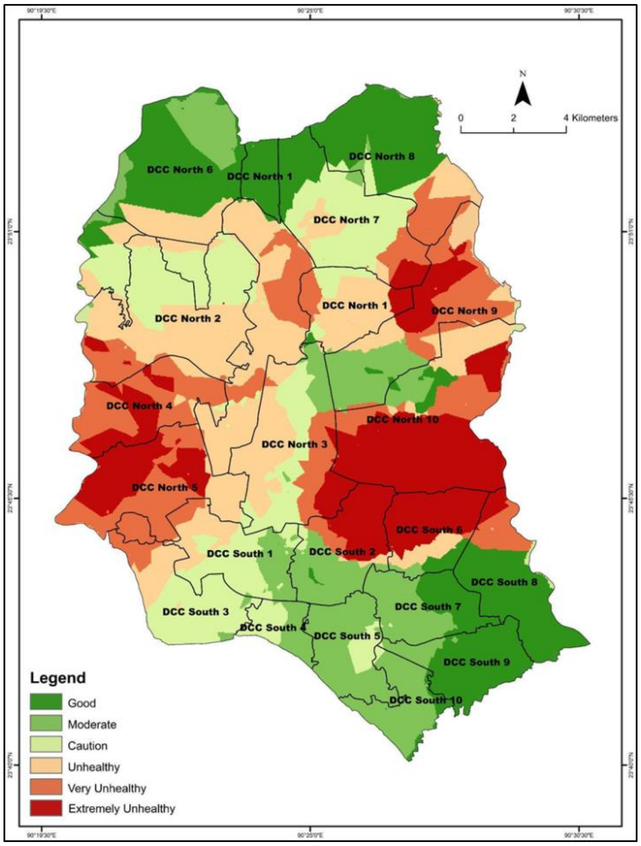

Figure 5: Air Quality Index ($PM_{2.5}$) of Dhaka City (DNCC and DSCC)

In case of Weighted Overlay or Overlay mapping, the raster has been classified into 6 distinct classes (Figure 6), namely, 'Least Polluted', 'Less Polluted', and 'Fairly Polluted', 'Polluted', 'Most Polluted' and "Extremely Polluted' using all pollutants. A total number of 6 classes were used in visualising the maps with the same range, they are as follows in order, 19-41, 42-52, 53-57, 58-62, 63-73, 74-95. They are formed in geometric progression. Although they are classified in the same way, they have different labels. The labels for $PM_{2.5}$ (Figure 5) were copied from Table 2, but the labels for Overlay mapping (Figure 6) were created from a less public health perspective and solely focusing on pollution. It shows severe deterioration of air quality in the Southwest part of Dhaka city. In DSCC, Zone 1, 2, 3, 4 and 5 are the 'Extremely Polluted'. Some parts in the Southeast have less pollution and are categorised as 'Least Polluted' and 'Less Polluted' consisting of DSCC Zone 8 and 9 are under this class. The other part of the study area, DNCC, has comparatively less zones with heavy pollution. Because DNCC Zone 2, 4 and 5 are counterparts to Zone 1 of DSCC, they are found to be 'Extremely Polluted'. Similar conditions were noticed in the case of Zone 10 in the DNCC and a very small part in the Central North part of the study area. Few zones with 'Fairly Polluted' can be seen in dispersed patterns in the Central North, while DNCC 6, 8 and 9 share 'Less polluted' air.

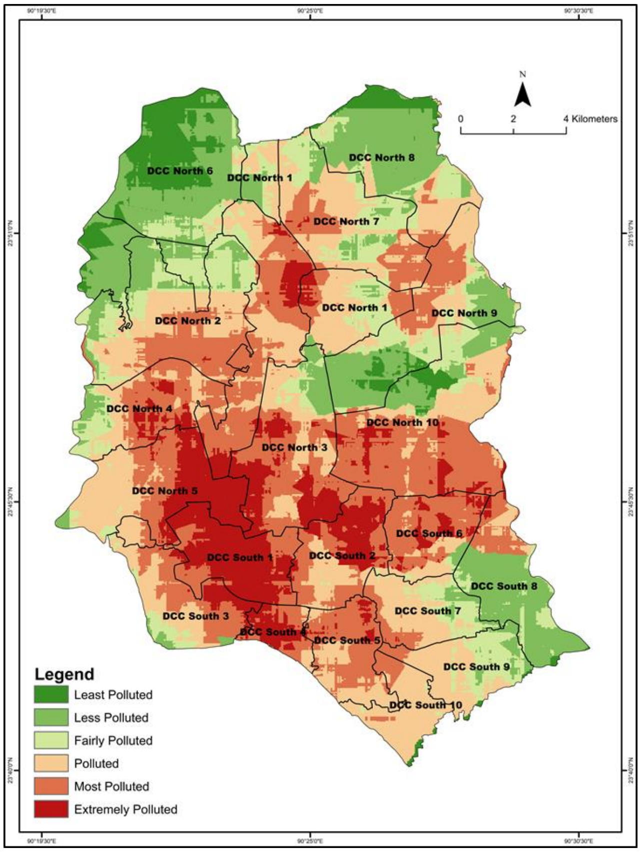

Figure 6: Output from Weighted Overlay Using all the Pollutants

DISCUSSION

Pollutant Data

The statistical information of the pollutant data is compiled in Table 4. The measurements of the pollutant concentration is not same for every pollutant, e.g. CH_4 concentration is basically in ratio of masses whereas CO or CO_2 is general concentration, albeit different units. Therefore, simple conversion will not work and correspondence among them can only be done passively. Having said that, one can deduce from the standard deviation (SD) information about the dynamism of the pollutants, e.g., CO having the lowest SD, would mean most of the values in the study area fall in and around the mean (0.0513 mol/m^2) whereas, for CO_2 with the highest SD, would mean higher spreading of data. The spatial arrangement of the individual pollutants is represented in the maps (Figure 3 and 4).

Table 4: Statistics of the Pollutant Data Used in the Study

Pollutants	Statistics			
	Maximum	Minimum	Mean	Standard Deviation
CH_4 (ppbV)	1995.25	1945.92	1974.47	9.866
CO (mol/m^2)	0.053233	0.049567	0.0513	0.0005
CO_2 (ppm)	704.815	528.473	583.106	25.51
NO_2 (mol/m^2)	0.000345	0.000202	0.000280	3.31
O_3 (mol/m^2)	0.114903	0.114327	0.11461	8.49
$PM_{2.5}$ (ppm)	0.34558	0.049833	0.104176	0.0408
PM_{10} (ppm)	0.521	0.04615	0.164	0.106
SO_2 (mol/m^2)	0.000542	0	0.00027	6.918

The concentrations of CH_4 and CO vary from place to place in the study area (Figure 3). The spatial distribution and concentration of CH_4 is relatively higher in the Southeastern part which includes Matuail landfill and Demra areas. These places have been mainly waste dumping grounds and unusable wetlands. However, Savar, Tejgaon industrial area in the Western and Central-western part of the city seems to have a moderate level of concentration. The Northern and Northeastern parts, being under development and expansion, have less concentration of CH_4. The CO concentration in the air of Dhaka city is fairly high almost all over the place, only with the exception in the Northeastern part. Biomass and fuel-burning, roads and soil dust, and vehicular emissions are the main factors to increase CO (Pavel et al 2021). The NO_2 concentration is regular in most parts of the city, as having a close link to vehicular emission. Yet, from the central part of the city that has junctions such as Tejagaon, Farmgate, Motijheel, Ramna, Khilgaon to the Southeast part shows a gradual increase of NO_2. In the case of O_3, this city has a moderately low concentration and is lowest in the south of the city. The Northern-east part of the city shows highest concentration of O_3. Furthermore, step ladder patterns in the North and central part including Mirpur, Cantonment area, partly Khilkhet and Dakhshinkhan and Hazaribag, Dhanmondi and Khilgaon shows higher concentration of O_3.

The concentration of SO_2 is comparatively higher in the Northwestern part including Mirpur and adjacent areas and the Southwestern part including Tejgaon industrial area, Farmgate, Dhanmondi areas (Figure 4). The concentration of CO_2 is significant and higher than in any other city in Bangladesh (Figure 4). The Southwestern part of the city gradually trails up to the Northeastern part. Some areas such as Mohammadpur, Dhanmondi, Farmgate, Tejgaon, Agargaon, Mirpur, Kuril, and Uttara contain the main roads of the city consisting of traffic congestion. However, the number of vehicles is increasing, and so do fuel combustion, heat production, and carbon emission. The particulate matter (PM) map visualises the spatial distribution and concentration of the study area (Figure 4). In the first map, the concentration of $PM_{2.5}$ is quite high in most of the functional areas such as Uttara, Pallabi, Tejgaon, Agargaon, Farmgate, Dhanmondi, Ramna, Motijheel and adjacent areas. Dust from the roads, construction sites, and emissions from vehicles are the major source of $PM_{2.5}$. Along with sporadic construction sites, ongoing mega projects such as Metrorail and Elevated Expressway construction contribute to raising the concentration of $PM_{2.5}$ in the air, degrading air quality. Although it is heavily concentrated with zones falling under both DNCC in and DSCC (e.g. Hazaribag, Dhanmondi, Lalbag, Sayedabad, Motijheel and its adjacent areas in the Southwest and Uttara, Uttarkhan and Dakshinkhan and the peripheral areas in the Northeast), the spatial distribution and concentration of PM_{10} in air is relatively very low compared to that of $PM_{2.5.}$ Moving to the Central Northeast, (Badda, Rampura, Beraid), PM_{10} is moderately concentrated and lowering to the Northwest part, Mirpur, Pallabi, Kafrul, Cantonment, Gulshan, Banani, Kuril and Southeast part, Matuail, Demra, Shyampur have less concentration.

Table 5: Variability of Atmospheric Constituents in Terms of Spatial and Temporal Scales (Adapted from Seinfeld and Pandis, 2016)

	Spatial Scale								
Temporal Scale	1 m - 10 m	10 m - 100 m	100 m - 1 km	1 km - 10 km	10 km - 100 km	100 km - 1000 km	1000 km - 10,000 km	> 10,000 km	Remark
1 sec-100 sec	OH								*Short-lived Species*
	NO_3								
	H_2O								
100 sec-1 hour		CH_3O_2							
1 hour-1 day		C_5H_8	C_3H_6						*Moderately Long Lived Species*
			DMS						
1 day-1 year			NOx	H_2O_2	Aerosols				
				SO_2	CO				
				O_3					
1 year-10 years						CH_3Br			*Long-lived Species*
						CH_3CCl_3			
10 years-100 years							CH_4	CFCs	
							N_2O		
Atmospheric Scale	*Microscale*		*Urban scale*		*Mesoscale*		*Global scale*		

All the pollutants do not have the same spatial and temporal dynamics and are further influenced by the initial and local factors (Table 5). For example, according to a document by USEPA, CH_4 is 25 times as potent as CO_2 (not included in Table 5) at trapping heat in the atmosphere, but it is much more short-lived than CO_2. If the air quality is measured by just the prompt effects of air pollutants, in the previous case, CH_4 would deem a much worse threat than CO_2 but the gap would shrink overtime. Also, 'Trapping-heat' is just as harmful as any other health effects as it can cause heat strokes etc. Similarly, given enough time, some pollutants can travel much further than the others, thus mapping for one a specific period of time could overlook some pollutants, with their spatial and temporal effects altogether (Table 5). Air quality needs to be evaluated as a collaborative approach of all the possible constituents at hand and should be reviewed at a feasible interval of time. To avoid any cumbersome approach, research should be done to devise a reasonable system to develop AQI considering the aforementioned issues.

The classified images collected via remote sensing were assessed for accuracy. The study used Overall Accuracy and Kappa Coefficient for the classifications. As mentioned, the data for CO_2, $PM_{2.5}$ and PM_{10} were collected from the field, as they weren't available in secondary sources. The air sampler could determine a few other pollutants except the 3 aforementioned, among them CH_4, NO_2 and SO_2 had usable information. The study calculated the accuracies for each pollutant (Figure 7) in which, remotely sensed CH_4, NO_2 and SO_2 data were used to compare with the respective data collected from the sampler. Pollutant concentration data were collected and processed in the same way as the other field data mentioned. For the purpose of accuracy assessment, field and satellite data were classified in the same way (into 18 classes). This way the study created an error matrix and calculated the accuracies. It is understandable that the accuracies were satisfactory on average, with the Overall Accuracy of SO_2 being the highest at approximately 81%., followed by CH_4 (80%) and NO_2 (76%).

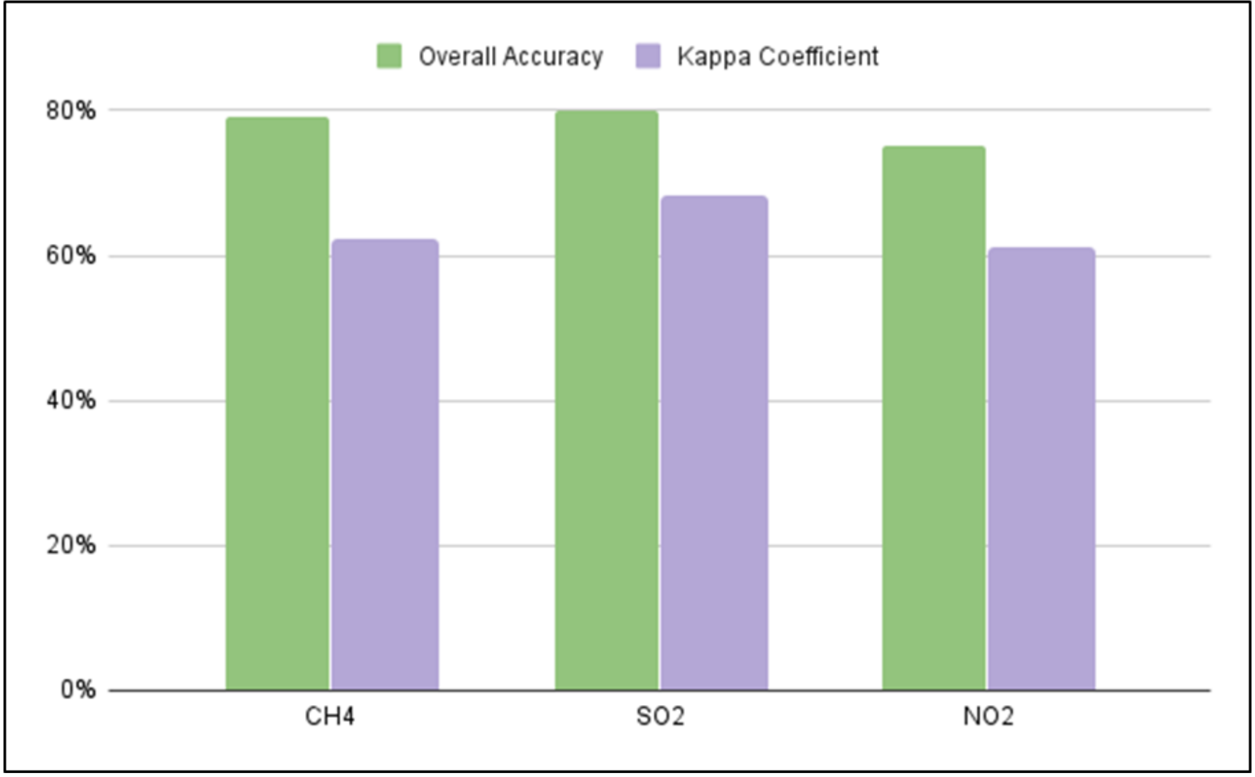

Figure 7: Accuracy Assessment Performed for the Study

Air Quality Index of DNCC and DSCC

For $PM_{2.5}$ mapping, in the North part, Uttara and its adjacent areas to peripheries have 'Good' air quality according to AQI (Figure 5). The DNCC Zone 4, 5, 9 with 10 and DSCC Zone 2 with 6 have severe degradation of air followed by 'Unhealthy' and 'Extremely Unhealthy' in terms of air quality. This can be inferred, zones with 'Unhealthy' are moderate in concentration, 'Very Unhealthy' are high in concentration and, 'Extremely Unhealthy' are heavily concentrated by $PM_{2.5}$. In DSCC, specifically DSCC Zone 1, has zones with severe deterioration of air quality (Figure 6). This may be due to the clustering of major industries in and around those areas in Keraniganj (Hassan et al., 2019). Comparing Figure 6 to the study area map in Figure 1, the study identified that almost the whole of western and central-western DSCC is the 'Most Polluted'. The DSCC Zone 1, 2 and 4 are the 'Most Polluted' because of dense population, transportation and vehicles, traffic congestion, industrial zones, urban households, and unplanned constructions. The DNCC has zones with the 'Least Polluted' and 'Less Polluted' zones although, Zone 3 and 5 share the 'Most Polluted' air, according to the index due to the existence of tanneries, industrial areas, and development activities. The DNCC Zone 1, 2, 4, and partially, 7 are 'Polluted' and these are too adjacent to the 'Most Polluted' zones. The DNCC has the 'Least Polluted' and 'Less Polluted' zones in the periphery, i.e. DNCC Zone 6, due to the existence of water bodies, agricultural land, and DNCC 9 and 10 for barren land and since bureaucratic and several governmental headquarters and Cantonment areas being located around these parts.

The USEPA AQI is basically focused on the health effects one might experience within a few hours at minimum. It is a single numerical value on a range of 0 to 500 calculated using the pollutant concentrations measured, in an area. Higher AQI corresponds to more severe air pollution and consequently greater health concern. The $PM_{2.5}$ had the highest index value of 176 and this ranges between 151-200 and categorised as ‘Unhealthy’ in referring to AQI standards, as this study found. The map shows the spatial distribution of $PM_{2.5}$ and the variation in the air quality of the study area (Figure 5). Southwest and Southeast of DNCC with several zones are heavily concentrated with $PM_{2.5}$ and fall under ‘Unhealthy’, ‘Very Unhealthy’ and ‘Extremely Unhealthy’ classes ranging 151-200, 201-300 and 301-500 respectively. The Overlay mapping, on the other hand, illustrates pollution level using all the pollutants, their distribution and an overall air quality of study area covering both DNCC and DSCC zones (Figure 6). In both Southwest and Southeast and partially the Northeast part, the pollution level indicates to be ‘Polluted’, ‘Heavily Polluted’, and ‘Most Polluted’ and DSCC is seemingly more polluted than DNCC. Even in the Overlay mapping, $PM_{2.5}$ is the most responsible pollutant to indicate the unhealthy air quality along with having the most polluted zones in Dhaka city, as found in this study.

Table 6: Comparison between Most Polluted Areas from Overlay Mapping and $PM_{2.5}$ Mapping

Zone	Most polluted Area in sq km by Overlay mapping (Standard Deviation=3.5)	Most polluted Area in sq km by $PM_{2.5}$ mapping (Standard Deviation=3.75)
DCC North 1	1.5548	0.7065
DCC North 2	1.4073	0.4185
DCC North 3	9.1751	1.7307
DCC North 4	3.5040	3.5667
DCC North 5	8.1239	6.5898
DCC North 6	0.0851	0
DCC North 7	1.7015	1.0188
DCC North 8	0.4175	0
DCC North 9	1.0597	3.2337
DCC North 10	7.7767	**15.3711**
DCC South 1	**10.0035**	0
DCC South 2	6.9436	4.4829
DCC South 3	3.8862	0
DCC South 4	3.0668	0
DCC South 5	2.9647	0
DCC South 6	5.3803	5.9733
DCC South 7	0.8398	0
DCC South 8	1.6984	0.7191
DCC South 9	0.5422	0
DCC South 10	0.9489	0

The study identified from Overlay mapping that the area with highest pollution is in DSCC Zone 1 measuring at 10 sq km (Table 6). But for $PM_{2.5}$ mapping, it is identified that the zone with highest pollution is in DNCC Zone10 measuring at 15 sq km. From satellite data in Figure 8, it is seen that, DNCC 10 is adjacent to water with open vast fields in the east whereas, DSCC 1 is engulfed in industrial and urban housing, wide roads and even train tracks. With so many nil (0) values with the higher standard deviation in the column for $PM_{2.5}$ mapping in Table 6, it is understandable that $PM_{2.5}$ alone could not explain the pollution pattern rather is impeding the pollution trend.

Figure 8: Yellow Pins Showing the Centroid of the Zones i) DCC North 10 and ii) DCC South 1

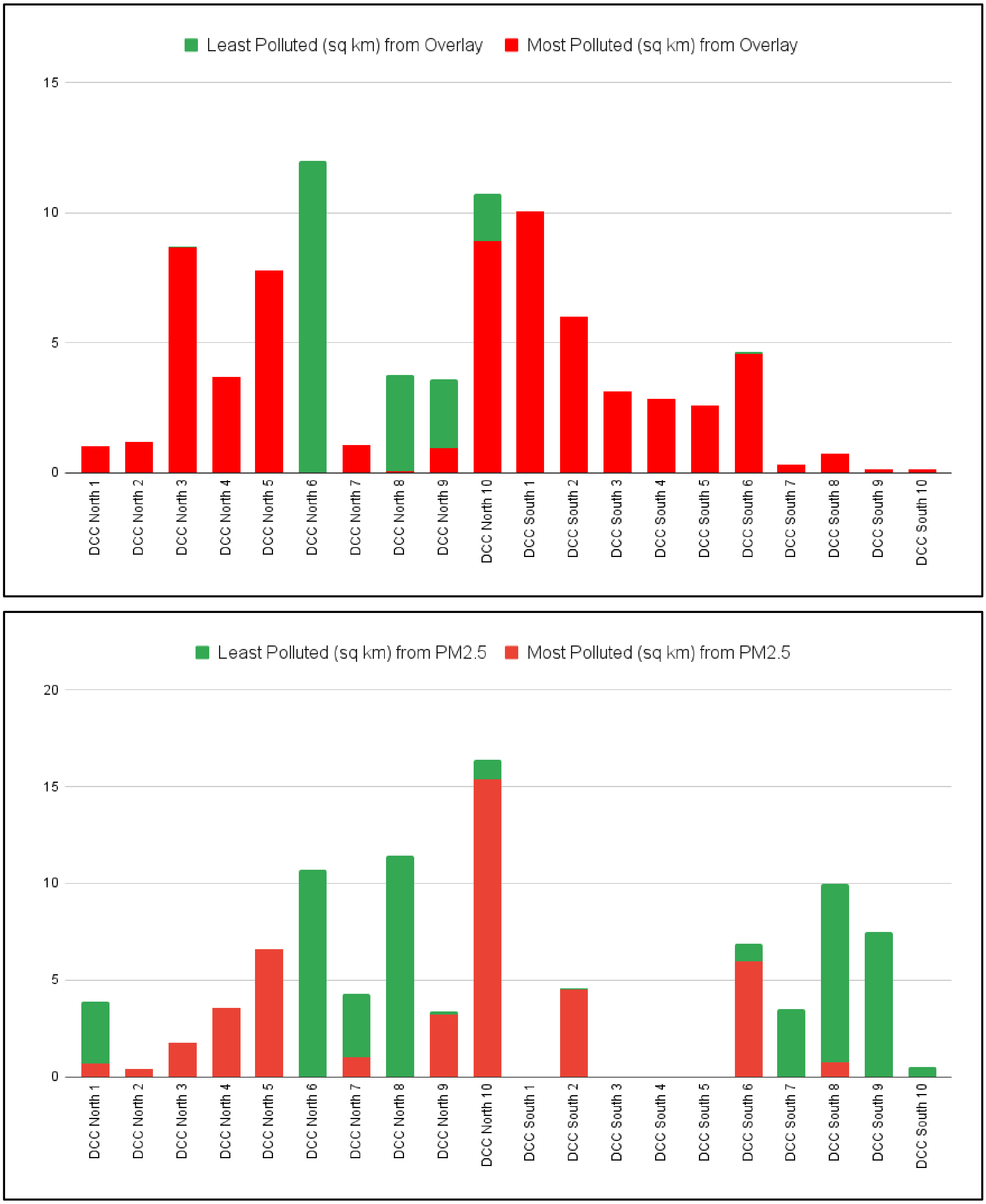

Figure 9: Polluted Area Classification into 'Most' and 'Least' Polluted Areas from i) Overlay Mapping and ii) $PM_{2.5}$ Mapping

There is a discernible difference between area coverage being classified as 'Most Polluted' with 'Least Polluted' from Overlay mapping and $PM_{2.5}$ mapping (Figure 9). Overlay mapping has more of a real distribution with a low standard deviation with almost all the zones having some sort of pollution albeit less in some zones than others. But the mere fact that Dhaka having a high pollution index (Islam and Chowdhury, 2021) has so many zones with less pollution in a dry season (time of data collection in Table 1) impedes the feasibility of using the pattern $PM_{2.5}$ alone for understanding the air quality of any area.

The study identified that the polluted areas from Overlay mapping correlate spatially with the road networks in the city (Figure 10). The road maps were collected from OpenStreetMap (June, 2022), they represent the Tertiary, Secondary and a few Primary roads. The Tertiary roads could not be updated properly for the recent construction projects in the city. Almost 80% of the roads are updated in the file.

Similar correlation is found for waterbodies and less polluted areas from Overlay mapping (Figure 11). The free waterbodies help to absorb excess pollutants and thus there is a negative correlation between pollutants and the presence of waterbodies (Zhu and Zhou, 2019). This is evident in the case of the North and Southeastern parts of the city (Figure 11). There is a large area of water on the east-central part of the map (Figure 11). This is the Hatirjheel area with criss-crossing roads, which aggravate pollution and is not much influenced by the nearby waterbodies, unlike the rest.

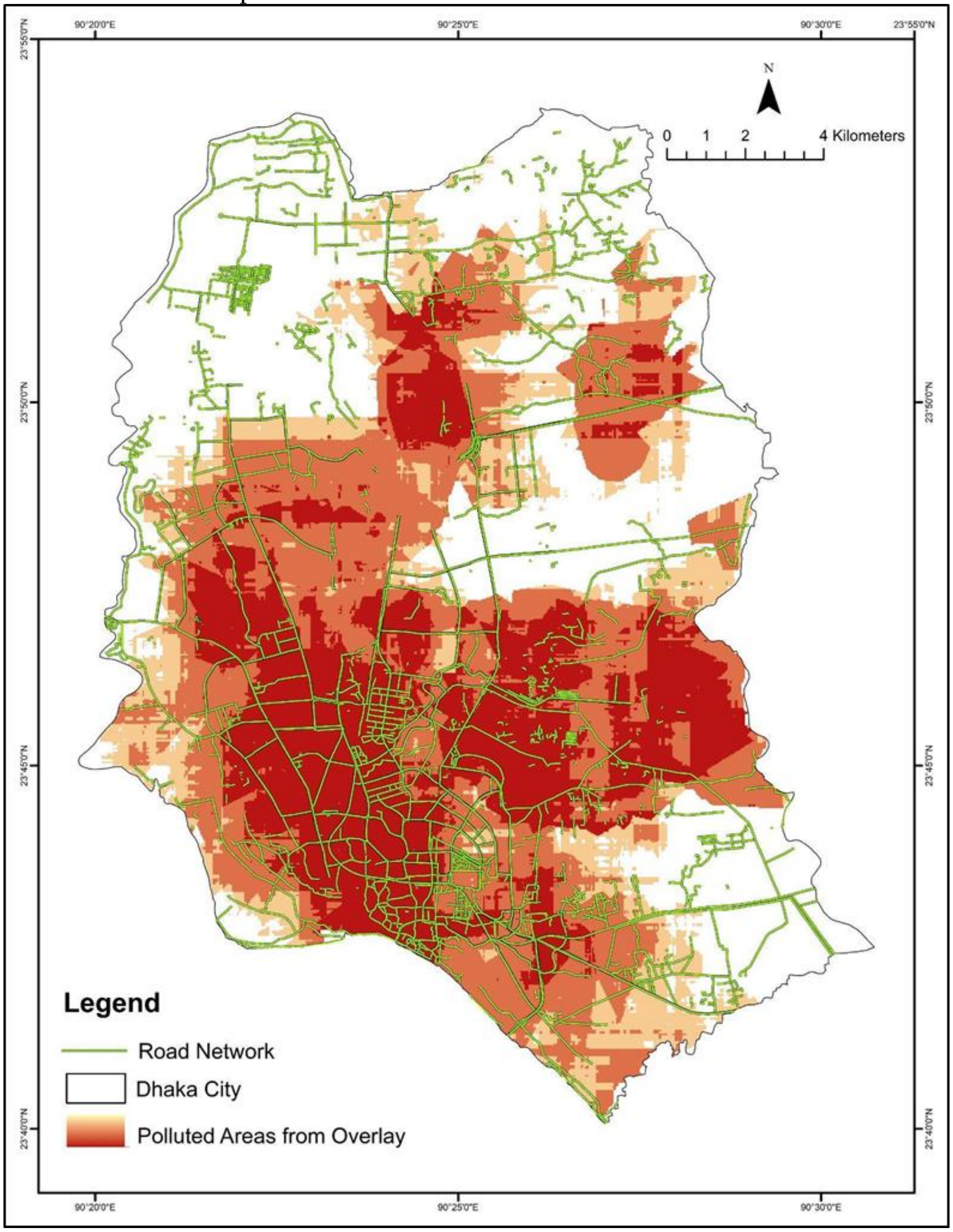

Figure 10: Polluted Areas from Overlay Mapping Against the Road Network in Dhaka City

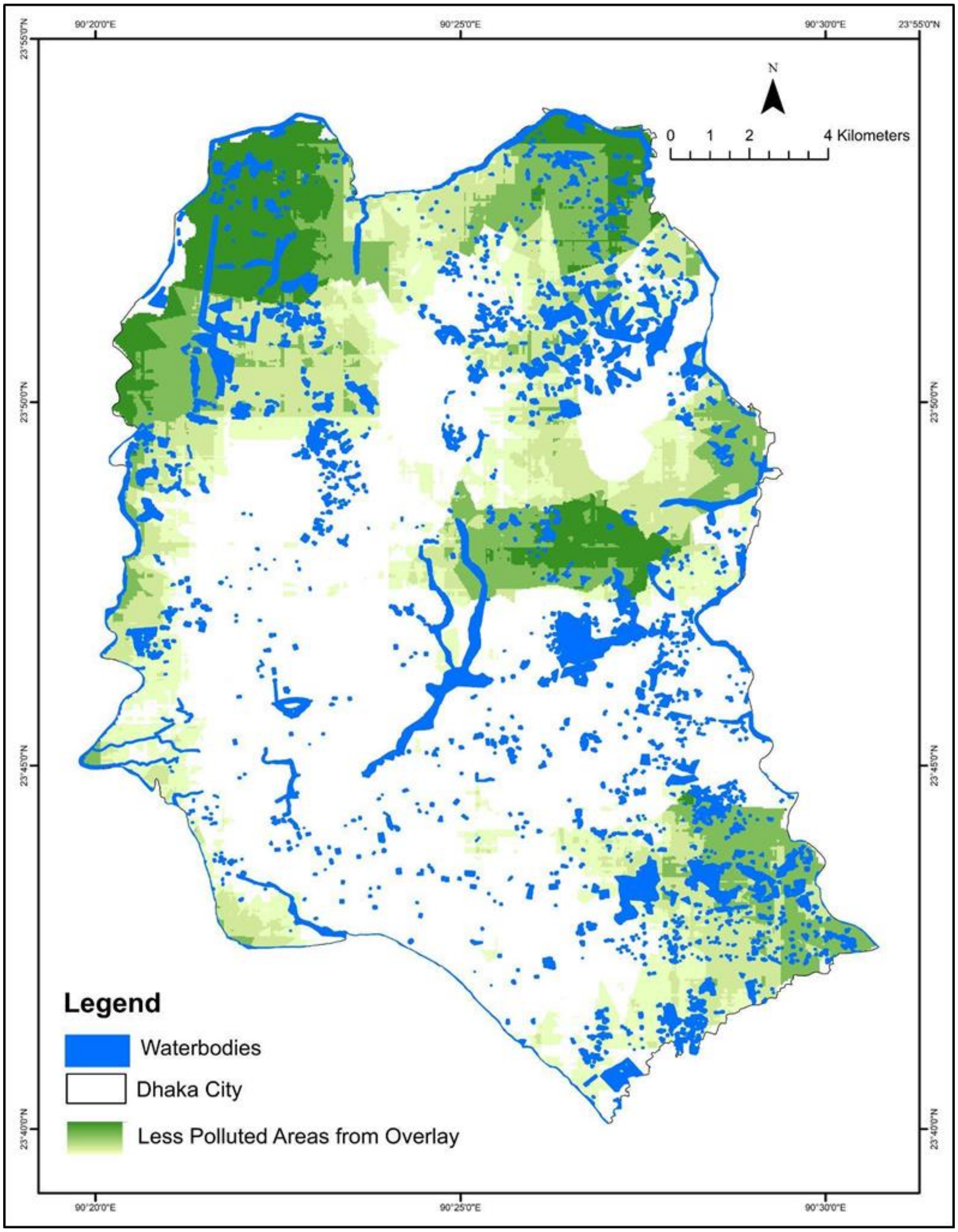

Figure 11: Less Polluted Areas from Overlay Mapping Against the Waterbodies in Dhaka City

CONCLUSIONS

The aimed to compare the development of AQI using global methods and local methods to identify which could represent the more significant pattern from a spatial perspective. The method developed by USEPA was used for developing the global AQI, where a single responsible pollutant was identified. An overlay analysis method was used for the local AQI, where the pollutants are summed with respective weights. The weights were calculated using a component analysis. The study shows that using the local AQI, a more definite spatial pattern could be produced which better corresponds to the concurrent real scenario. An AQI is meant to depict a generic pattern of the area to understand which parts of it have better air quality or less air pollution. For the study area of Dhaka City (DNCC and DSCC), the study identified that although the global AQI suggests DNCC Zone 1 as the highest pollution zone, it is depicted that the areas around that do not correspond to that finding. Rather DSCC Zone 1 has been depicted as the highest pollution zone in local AQI, which is far more coherent to the surrounding areas, i.e, industrial areas in Tejgaon, convergent road networks and rail tracks. Moreover, from the local AQI, the study identified that the waterbodies reciprocating high air pollution, thus they spatially correlate with the least polluted areas. Again, if we note the overall distribution of local and global AQI, the global AQI has a less variance with samples, that is the zones, having nil (0) values. In contrast, the local AQI has a more complete distribution and statistically, a more normal distribution. The illustrated maps corroborate the discussion providing a spatial pattern for the air quality in the study area. It can be therefore recommended that air quality is better studied locally with variables exclusive to the environment. The pollutants can be weighed rather than be completely left out, the more responsible pollutants can be identified using different analysis and can be assigned with higher weights and so on. Such studies are conducive to every environment given a thorough background study, thus is not difficult. As local AQI is exclusive to the study area, AQI concerning a certain climate, topography, demography etc. can be studied and thus more relations can be sought out. Mapping the pollution has helped validate the spatial pattern of the pollutants. The temporal background of the factors should also be considered as situations may change overtime. Considering more variables from the aforementioned aspects such as temperature, air pressure, humidity, elevation, population density etc. along with the atmospheric constituents for AQI, can further consolidate the result. More research should be done in this area to devise a proper system to develop AQI considering all the spatial and temporal effects.

ACKNOWLEDGEMENT

The present study is a part of the project funded by the University of Dhaka under Centennial Research Grant. The authors are thankful to the University for the mentioned financial support to the study.

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