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Quantifying the Relationship of Vegetation Cover and Air Pollution: A Spatiotemporal Analysis of PM2.5 and NDVI in Greater Dhaka, Bangladesh

Research Article

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Abstract: This study has quantified the relationship of vegetation cover and air pollution and analyzed the spatiotemporal distribution of Particulate Matter ($PM_{2.5}$) in greater Dhaka, Bangladesh. PM2.5 is widely regarded as the pollutant with the most health impact of all commonly measured air pollutants. It can come from a range of natural as well as man-made sources. Common sources of PM include combustion (from vehicle engines, industry, brick kilns, wood and coal burning), as well as through other pollutants reacting in the atmosphere. Particulate Matter ($PM_{2.5}$) measurements were collected from 11 Continuous Air Monitoring Stations (CAMS) of the Department of Environment, Government of Bangladesh from January 2013toDecember 2018 and AirNow (global air quality data source) located US embassy office in Dhaka from March 2016 to August 2019. Inverse distance weighted (IDW) method was implemented with the help of Geographic Information System (GIS) techniques to explore spatial pattern of $PM_{2.5}$ pollution in greater Dhaka. Google Earth Engine (GEE) cloud computing platform was used to acquire upazila level vegetation cover data through Normalized Difference Vegetation Index (NDVI). The results showed that winter season experienced the highest concentration of $PM_{2.5}$ and the amount is increasing over time. Narayanganj station witnessed the highest increase of $PM_{2.5}$ concentration over the period. The study revealed that vegetation cover and $PM_{2.5}$ concentration have a strong negative correlation (r = -0.75).

Keywords: *Air Pollution • Greater Dhaka • $PM_{2.5}$ • GIS • NDVI*

1. Introduction

Based on $PM_{2.5}$ concentrations, Bangladesh has become the most polluted country in South Asia and Dhaka has been declared as the 2nd most polluted city in the world (IQAir AirVisual, 2018; 2019). Particulate Matter 2.5 or $PM_{2.5}$ is less than 2.5 µm in aerodynamic diameter and is a key pollutant of air which has significant effect on public health (Begum *et al*., 2013). According to World Bank (2006) two-third of the respiratory health problems in Bangladesh are attributed to air pollution and 10% of the disease burden is accredited to urban air pollution. Air pollution in Dhaka endangers its enormous population to potential health complexities. Air pollution is caused by emission of pollutant gases from vehicles or industries in the air (Hasan, *et al*., 2018; Islam, 2014). The contribution of brick manufacturing and transport in particle pollution is also well established (CAI-Asia & ADB, 2006;Alam, 2009; Begum *et al*., 2004; 2011). Rahman et al., (2010) have found a positive correlation with vehicular and brick kiln emission with particulate matter concentrations in the air as well. In a single year, brick kilns near Dhaka City can expel up to 23,000 tons of $PM_{2.5}$ in the air (Hassan *et al*., 2019; Guttikunda *et al*., 2013). It is reported by the Department of Environment, Bangladesh (DoE, 2019) that vehicles contribute 10.4% of fine particles pollution in Dhaka. Air pollution in Dhaka City

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has captured interests of scholars since early 2000s. Limited number of monitoring stations has confined the researchers to stay within the city boundary for an extensive time period. The joint adoption of Clean Air and Sustainable Environment (CASE) project by the Ministry of Environment and Forest (MoEF), Department of Environment (DoE), Dhaka City Corporation (DCC) and Dhaka Transport Co-ordination Board (DTCB), financed by the World Bank has led to the establishment of several continuous air monitoring stations (CAMS) across the country, lifting the confinement to researchers to study air pollution in areas beside Dhaka City. 'Greater Dhaka' which includes Dhaka, Narayanganj, Gazipur, and Narsingdi districts that plays significant role in the economic development of Bangladesh. In recent time, greater Dhaka has been experiencing high $PM_{2.5}$ concentration in the lower atmosphere. In a report of Bangladesh Air Pollution Management (BAPMAN) Project, Department of Environment, MoEF (2019) has listed 1230 brick kilns in or near the study area. Air pollution in the districts within greater Dhaka has increased and is likely to increase in the future. The present study aims to conduct spatiotemporal analysis of $PM_{2.5}$ concentration and quantify the relationship of vegetation cover and air pollution in greater Dhaka, Bangladesh.

Materials and Method

Selection of Study Area: Residing almost in the middle of the country, Dhaka, Narayanganj, Gazipur and Narsingdi districts make important economic cluster as it finds itself with the presence of four city corporations, several industrial zones including the one that earns maximum remittance for the country, the ready-made garment sector. Dhaka is the capital city and comprises two city corporations i.e., South Dhaka City Corporation (the southern or old part of the city) and North Dhaka City Corporation (northern or new part of the city). The other two city corporations are Gazipur City Corporation, gained the status of city corporation in 2013 and Narayanganj City Corporation, achieved its status a couple of years earlier than Gazipur City Corporation, in 2011. Dhaka, Narayanganj and Gazipur districts are considered as air pollution hotspot in the country and Narsingdi shares its boundary with the other two districts and has a large number of industries within itself. There are five (out of eleven) CASE monitoring stations and a US based air quality monitoring station (AirNow, a partner of USEPA, NOAA, CDC, NASA, NPS etc.) located within the boundary of the study area (Figure-1).

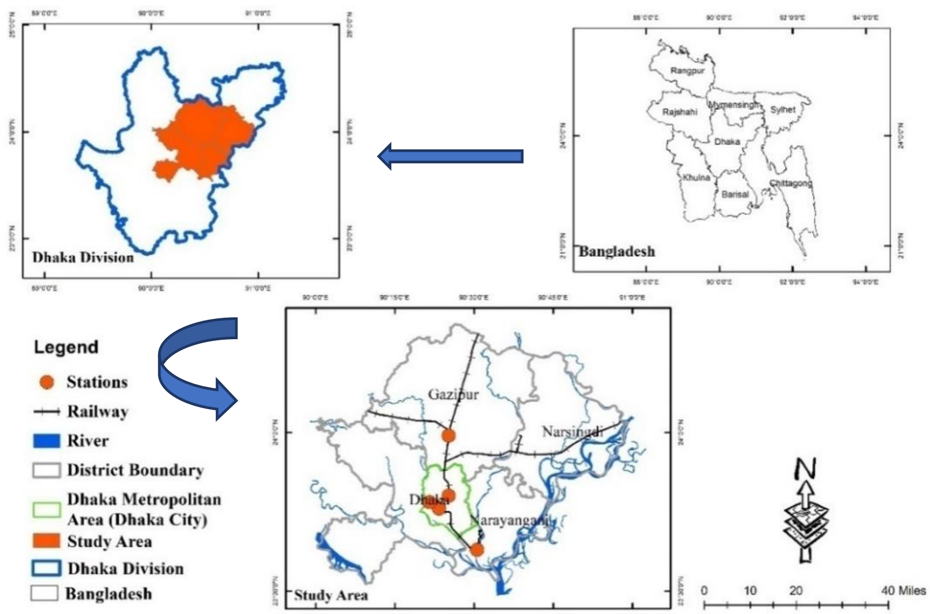


Figure 1. Location of the study area

Data Source and Collection: The Department of Environment, Government of Bangladesh and AirNow of USA and Google Earth Engine were the principal sources of pollution data for the study. The two organizations have six monitoring stations within the boundary of the study area. Google earth cloud computing platform i.e. Google earth engine provided historical MODIS satellite images for vegetation cover.

Air Quality Monitoring Stations: The Department of Environment (DoE) has established 11 monitoring air pollution stations across the country as a part of their Clean Air and Sustainable Environment (CASE) project. US consulate office in Dhaka has another air quality monitoring station making a total of 12 monitoring stations in the country (Table-1).

Table 1: Locations of Continuous Air Pollution Monitoring Stations (CAMS) and AirNow monitoring station in the major cities of Bangladesh

Area	Station	Latitude	Longitude	Area	Station	Latitude	Longitude
Sangshad Bhaban, Dhaka	CAMS-1	23.76^0N	90.39^0E	Agrabad, Chattogram	CAMS-7	22.32^0N	91.81^0E
BARC Office, Dhaka	CAMS-2	23.76^0N	90.39^0E	Baira, Khulna	CAMS-8	22.48^0N	89.53^0E
Darussalam, Dhaka	CAMS-3	23.78^0N	90.36^0E	Sopura, Rajshahi	CAMS-9	24.38^0N	88.61^0E
Gazipur	CAMS-4	23.99^0N	90.42^0E	Red Crescent Campus, Sylhet	CAMS-10	24.89^0N	91.87^0E
Narayanganj	CAMS-5	23.63^0N	90.51^0E	DFO Office Campus, Barisal	CAMS-11	22.71^0N	90.36^0E
TV Station, Khulshi, Khulna	CAMS-6	22.36^0N	91.80^0E	Natun Bazar, Dhaka	US Embassy	23.80^0N	90.42^0E

Source: DoE, 2020

Spatial Distribution of $PM_{2.5}$: Spatial distribution maps of $PM_{2.5}$ concentrations were produced using interpolation technique to create a continuous surface over the study area from measured values of pollution in distinct locations. The average value of each upazila (Thana- in case of Dhaka City) was then acquired using zonal statistics. The average concentration of $PM_{2.5}$ for each upazila was acquired for 72 months since 2013.

Inverse distance weighted (IDW) interpolation method was chosen because it prioritizes local influence in case of predicting an unknown value of a particular place. IDW uses the measured values of known locations to predict the value of an unknown location (Tarmizi *et al*., 2014, Jha *et al*., 2011, Wong *et al*., 2004).

$$Z_p = \frac{\sum_{i=0}^{n}\left(\frac{Z_i}{d_i^p}\right)}{\sum_{i=1}^{n}\left(\frac{1}{d_i^p}\right)}$$

Here,

Z_P = value to be estimated, Zi= known value

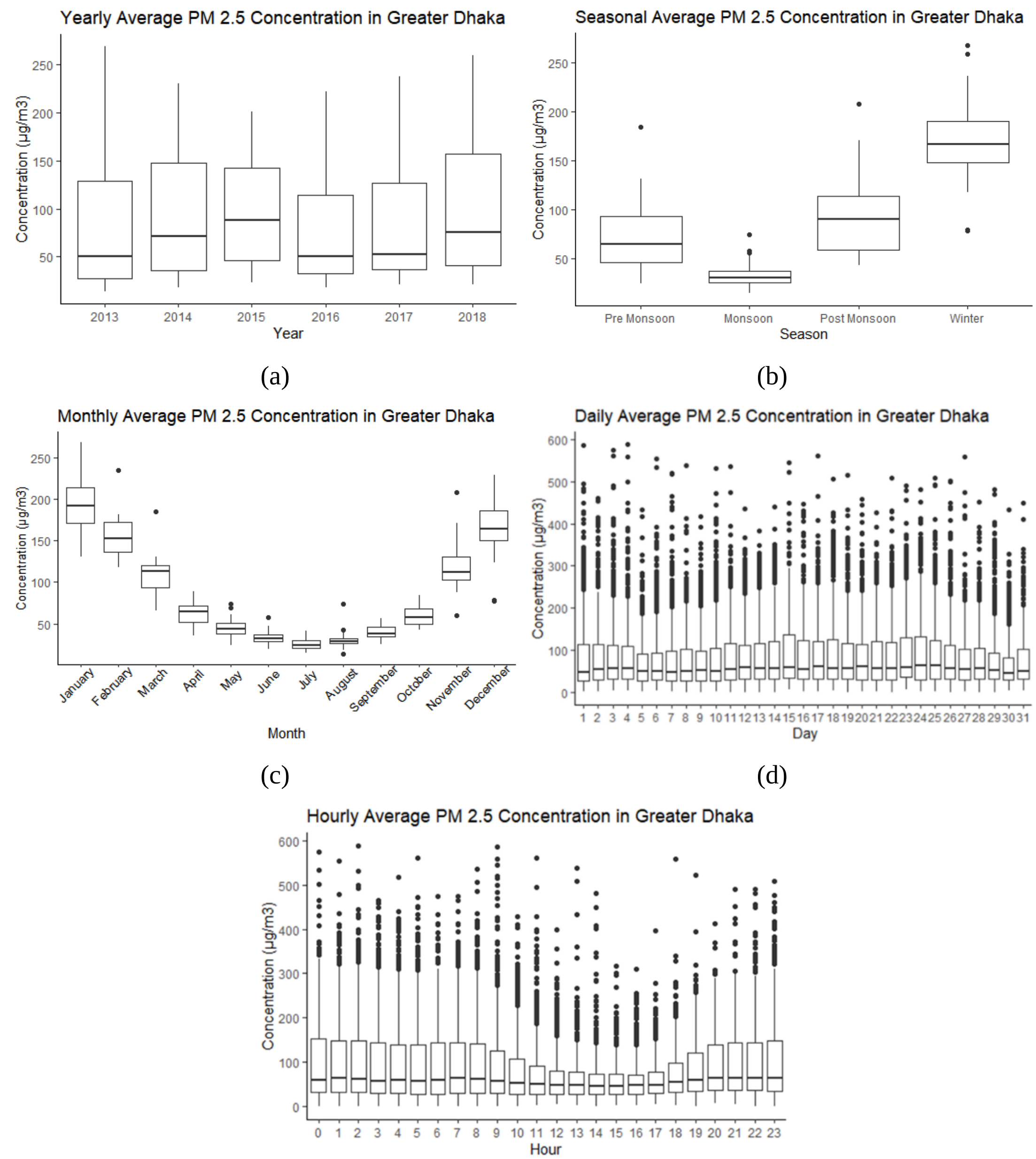
d_i^p = distance to known point, n = user selected exponent

Normalized Difference Vegetation Index: Cloud computing platform, Google earth engine was used to acquire monthly average data for each upazila (Thana in case of Dhaka City) with highest quality cloud free from MOD13Q1 version 006 Terra Vegetation Indices 16-Day Global 250m for study area from January 2013 to December 2018.

Quantifying Relationship of NDVI and $PM_{2.5}$: The dynamic nature of both concentration of $PM_{2.5}$ and NDVI makes it difficult to explore their relationship. The small-scale upazila level monthly data provides a large sample size to determine the relationship of the two variables. The $PM_{2.5}$ concentration of each upazila (Thana- in case of Dhaka City) was divided by its area (in square kilometer), those values represent the average $PM_{2.5}$ concentration of per square kilometer of the upazila. The $PM_{2.5}$ concentration per sq.km. was then tested against the average NDVI of each upazila by conducting the Spearman correlation test was conducted to test and quantify the strength or weakness the monotonic relationship between NDVI and $PM_{2.5}$. In Spearman's rank correlation the coefficients between 0.10 and 0.29 represent a small association, coefficients between 0.30 and 0.49 represent a medium association, and coefficients of 0.50 and above represent a large association or relationship.

Results and Discussion

Trend of $PM_{2.5}$ in Greater Dhaka: Based on the six monitoring stations situated within the boundary of greater Dhaka in the years 2013-2018, the average concentration of $PM_{2.5}$ is 89.78 µg/m3. The national ambient air quality standard (NAAQS) for Bangladesh $PM_{2.5}$ concentration is 15 µg/m3 (DoE, 2018) which means greater Dhaka has been experiencing 6-7 times higher concentration since 2013. The average concentrations of $PM_{2.5}$ for 2013 to 2018 are 83.42, 90.01, 96.27, 79.57, 80.24 and 98.94 µg/m3 respectively. This indicates that particulate pollution is increasing. The concentration of $PM_{2.5}$ is highest in winter season (December-February) in greater Dhaka.



(a) (b) (c) (d) (e)

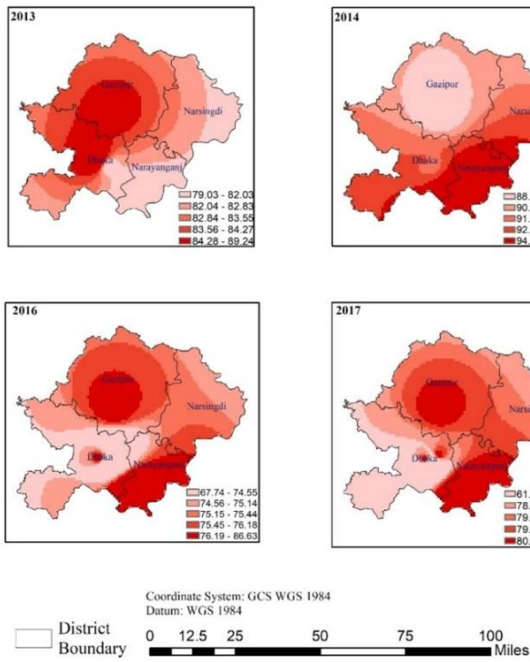
Source: Based on DoE and AirNow data, 2020

Figure 2. Trend of $PM_{2.5}$in Dhaka since 2013(a) yearly (b) seasonal (c) monthly and (d) daily (US Embassy) and (e) hourly (US Embassy)

The average $PM_{2.5}$ concentration for monsoon (June-September), pre-monsoon (March-May), post-monsoon (October – November) and winter are 31.59, 71.53, 91.85 and 171.06 µg/m3 respectively. The highest concentration is observed in the month of January with an average of 192.66 µg/m3 and the lowest is observed in July with an average of 25.31 µg/m3 (Figure-2 a, b, c). For US Embassy located in Dhaka, the highest recorded $PM_{2.5}$ concentration was 561µg/m3 recorded on 17/01/2017 at 6 a.m. The hourly $PM_{2.5}$ concentration is high at night and starts to decrease around the 9th hour of the day or 10 a.m. It starts to increase again after 6 p.m. (Figure-2 d, e).

Annual Average of $PM_{2.5}$ Concentration

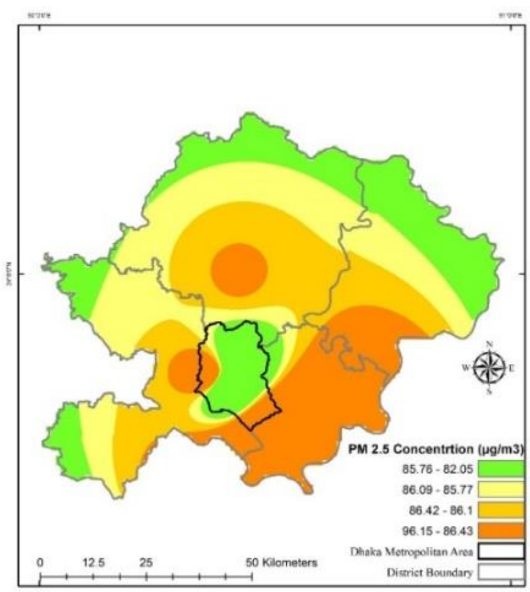
The study area experienced a rise in the level of $PM_{2.5}$concentration. However, some places encountered a more increase than other places within the study area. The highest increase is seen around the Dhaka city, Narayanganj and Savar (Figure-3). In 2013, $PM_{2.5}$ concentration in air of the study area ranged from 79.03 – 89.2 µg/m3. The range broadened between 77.84-102.05 µg/m3 in 2018. During 2013, the lowest annual average concentration was seen in areas of Narayanganj, Dhaka South City Corporation and parts of Narsingdi. Though, the lowest was almost 6 times higher than the NAAQ standard. Since 2013, on an average, Gazipur and Narsingdi experienced 10 μg/m3 increase and the southern part of the study area experienced more than 20 μg/m3 increase in the $PM_{2.5}$ concentration. This has portrait the severity of air pollution in the study area. It has also seen an unusual concentration of $PM_{2.5}$going up to an average of 119 μg/m3 in southern parts (Narayanganj, South Dhaka City Corporation) of the study area in the year 2015 (Figure3).



Source: Analysis based on DoE and AirNow data, 2020

Figure 3. Spatiotemporal distribution of annual average $PM_{2.5}$ in the study area

Spatial Distribution of $PM_{2.5}$: Based on the inverse distance weighted interpolation method which considers that the neighboring values have most influence, the spatial distribution of $PM_{2.5}$ in greater Dhaka (Figure- 4) shows that highest concentration of $PM_{2.5}$ in the period of 2013-2018 is seen in Narayanganj Upazila (southern part of the study area), western part of Dhaka City and Gazipur Sadar Upazila (86.43-96.15 μg/m3). The lowest concentration of $PM_{2.5}$ has seen in the outer parts of the study area and in the central part of Dhaka (82.05 – 85.76 μg/m3).

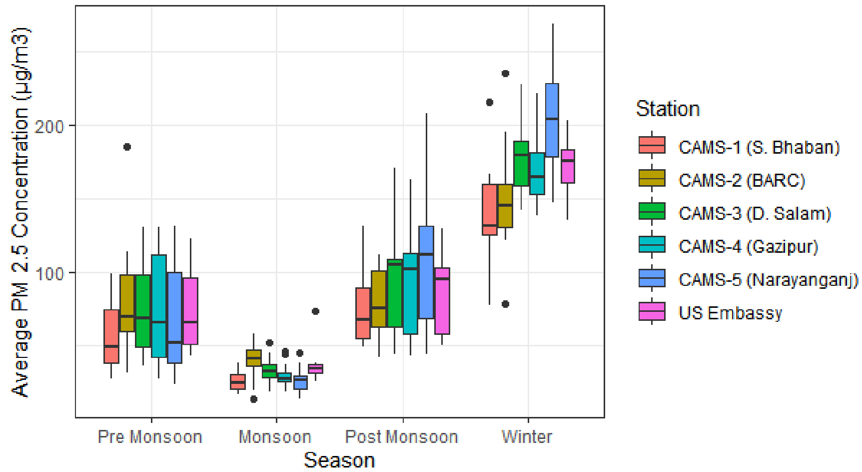


Source: Analysis based on DoE and AirNow data, 2020

Figure 4. Spatial distribution of $PM_{2.5}$ concentration over the study area.

Seasonal Variation of $PM_{2.5}$

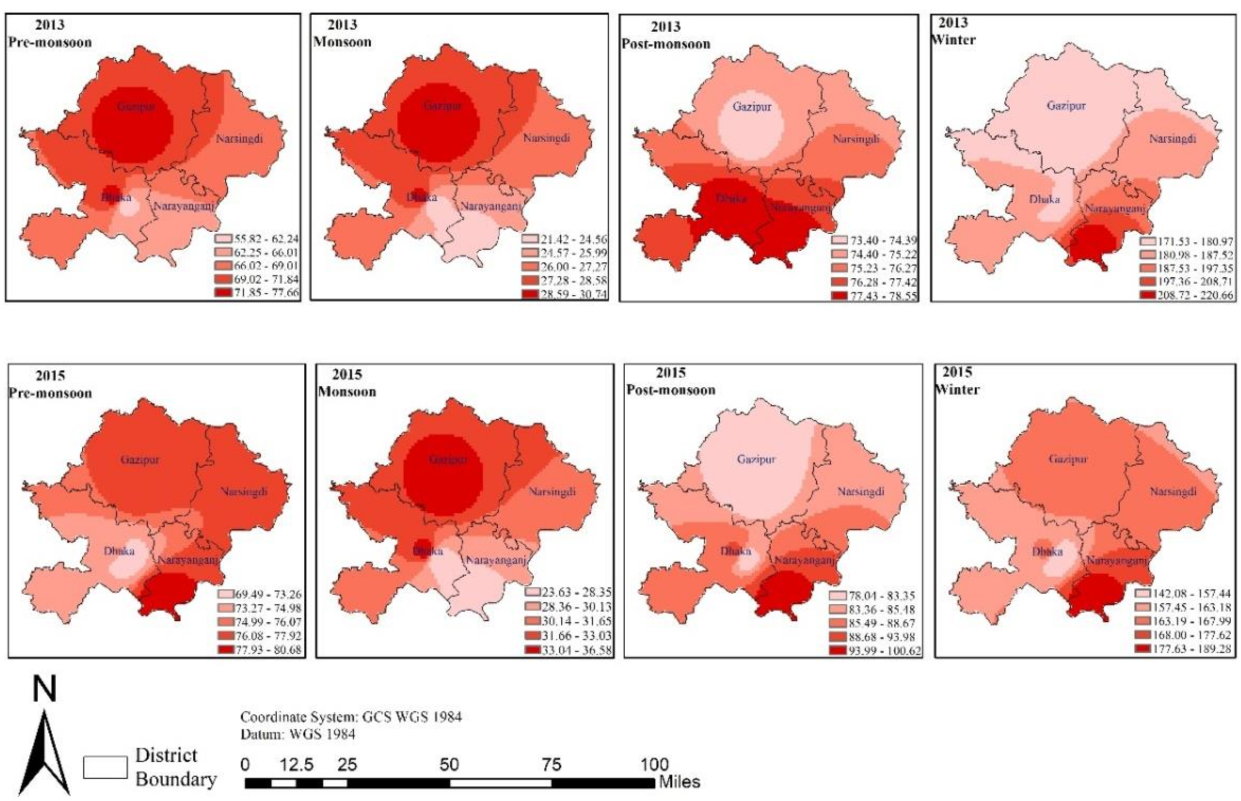
Spatiotemporal Distribution: The concentration of $PM_{2.5}$ (Figure 5) starts declining in the pre-monsoon season (March-May) and remains lowest in monsoon season (June-September). During post-monsoon (October – November) the concentration of $PM_{2.5}$ starts to increase and reaches peak in winter (December – February). CAMS-5 (Narayanganj) experiences the highest concentration of $PM_{2.5}$ in winter and post- monsoon while CAMS-4 (Gazipur) observes the highest and widest range of $PM_{2.5}$ concentration in pre-monsoon. CAMS-2 (BARC) observes the highest concentration during monsoon and CAMS-1 (Sangshad Bhaban) observes the lowest concentration in every season.

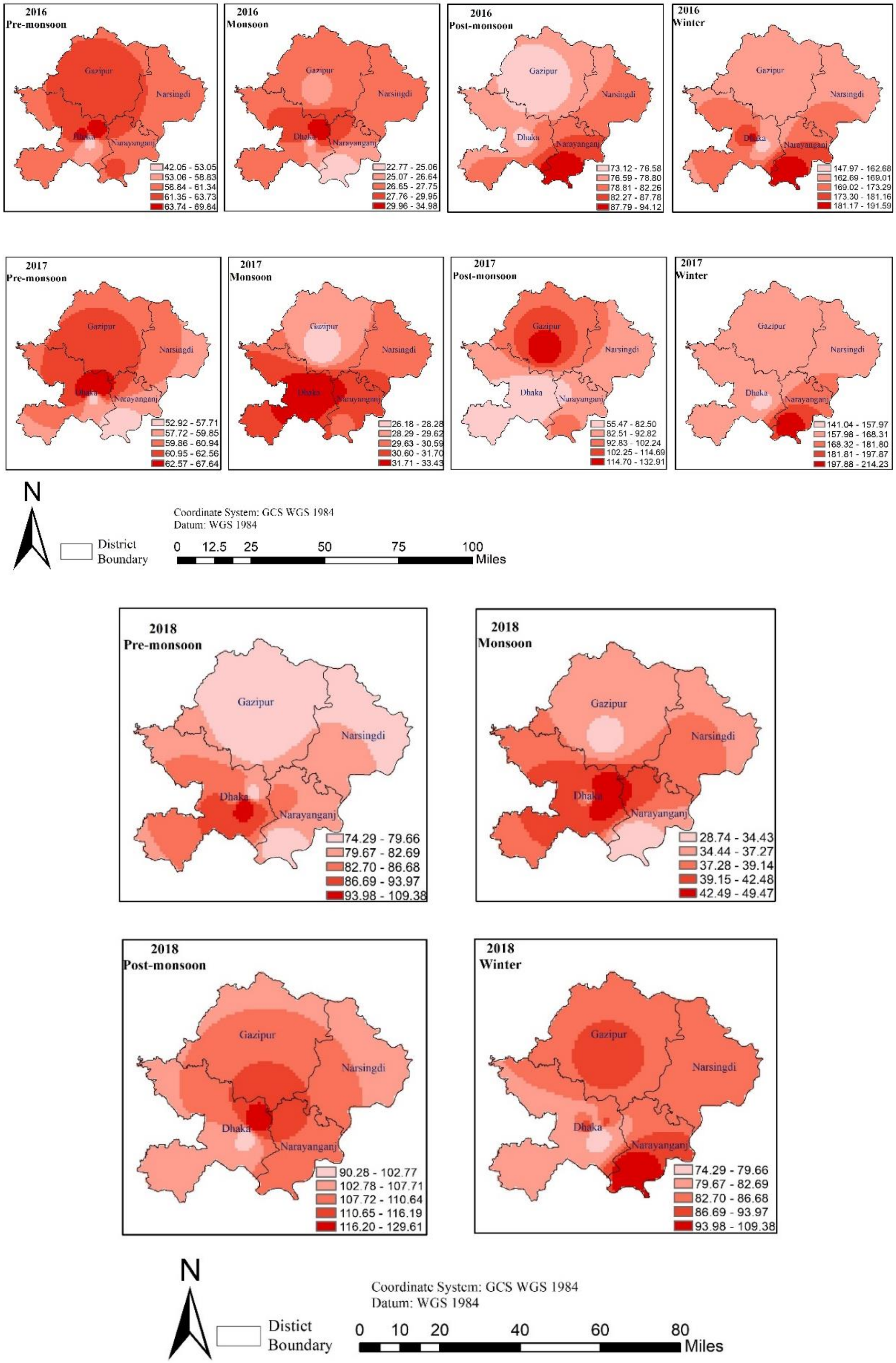


Source: Analysis based on DoE and AirNow data, 2020

Figure 5. Box plot of seasonal variation of $PM_{2.5}$ concentration among six stations in greater Dhaka

Figure 6 shows the distribution of seasonal $PM_{2.5}$ concentration has observed changes in spatial patterns during the period of 2013-2018 except 2014. Compared to other parts of the study area Dhaka observes the highest concentration of $PM_{2.5}$ in pre-monsoon and monsoon season (Figure 6). An exception of this attribute was seen in 2015's pre-monsoon season when Dhaka experienced lowest concentration (69-73µg/m3) than other surrounding parts. However, Dhaka did not experience a low concentration of $PM_{2.5}$ than usual, rather the other parts i. e. Gazipur, Narsingdi and Narayanganj experienced higher concentration of particulate pollution than usual. In 2013, Dhaka experienced the highest concentration of $PM_{2.5}$ (94-100.6 µg/m3) but later the concentration started to decline until 2018. Gazipur, Narayanganj and Narsingdi seem to have more pollutant in their air than Dhaka city during winter season. Narayanganj has experienced he highest concentration of $PM_{2.5}$ since 2013 during the winter season.

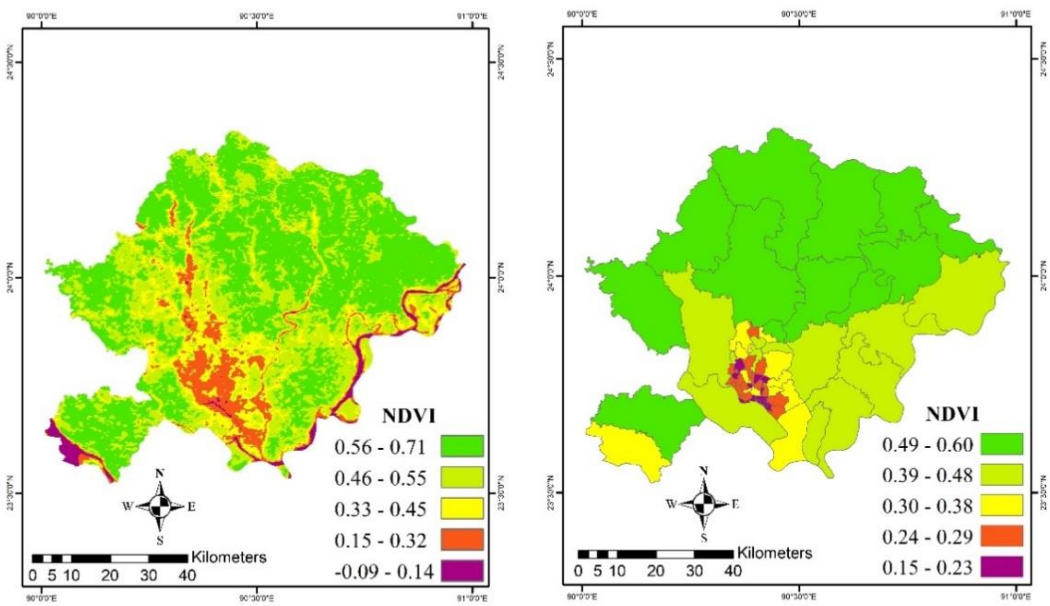




Source: Analysis based on DoE and AirNow data, 2020

Figure 6. Spatial distribution of seasonal $PM_{2.5}$ in greater Dhaka for different years

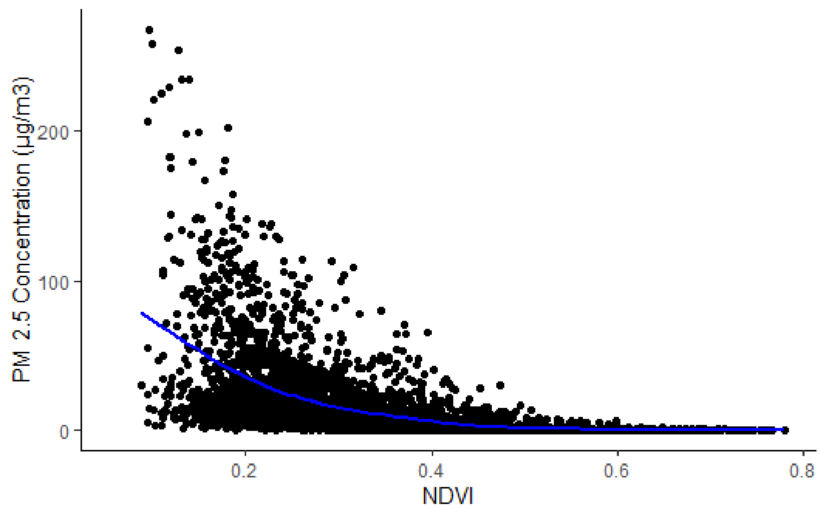
Normalized Difference Vegetation Index: The average normalized difference vegetation index (NDVI) retrieved from MOD13Q1 V6 (MODIS Terra Vegetation Indices 16-Day Global 250m) for the study area during 2013-2018 period, portrays that the central and south-central part of the study area has low vegetation cover (Figure 7). The highest average NDVI is seen in the northern part of the study area with a range of 0.49-0.60 because of the presence of deciduous forest. Narayanganj district and Savar area have NDVI value that ranges between 0.39-0.48 which indicates the presence of croplands and homestead forests. Parts of western Dhaka and Narayanganj City Corporation have an average NDVI that ranges from 0.30 - 0.39 which indicates presence of low to moderate vegetation cover.



Source: Based on MOD13Q1 V6, 2020

Figure 7. Average normalized difference vegetation index (NDVI) in greater Dhaka

Relationship of Vegetation Cover and $PM_{2.5}$: The spatial relationship of vegetation cover and $PM_{2.5}$ concentration was analyzed at upazila level in greater Dhaka using monthly data from 2013 to 2018. There are 62 upazilas (Thana-in case of Dhaka City) in greater Dhaka and 72 months through 2013 to 2018. A total of 4392 entries of data were used in correlation study.



Source: Authors, 2020

Figure 8. Spatial relationship of vegetation cover and $PM_{2.5}$ concentration in greater Dhaka

The Spearman rank correlation with SPSS software version 22.0 was used in the study. Spearman's correlation is a nonparametric measure of degree of association between two variables, where the correlation coefficients of 0.50 and above represent a large association or relationship. The correlation coefficient of NDVI and $PM_{2.5}$ is -0.75 which means, there exists a strong downhill correlation between vegetation cover and $PM_{2.5}$ concentration. This means that places with high vegetation covers experiences low $PM_{2.5}$ concentration. The graph (Figure 8) shows that highest concentration of $PM_{2.5}$ is seen within the value of 0-0.2 of NDVI. This value represents urban areas or impervious surfaces. So, according to Figure 8, built-up and less vegetation clusters experience the highest concentration of $PM_{2.5}$.

The increasing concentration of particulate matter ($PM_{2.5}$) in air has been a concern of the environmentalists in Bangladesh for a long time especially for Dhaka City. The unavailability of proper data has made it more difficult to assess the situation. However, this study suggests that (i) winter is the season with highest concentration of $PM_{2.5}$in the air and monsoon have the lowest concentration, (ii) surrounding zones of Dhaka City have been experiencing high concentration of $PM_{2.5}$especially Narayanganj, (iii) vegetation cover and concentration of $PM_{2.5}$ is negatively correlated ($r = -0.75$).

Conclusion

This study aimed to conduct spatiotemporal analysis of $PM_{2.5}$ concentration and quantify the relationship of vegetation cover and air pollution in greater Dhaka, Bangladesh. It is evident that over the years the concentration of $PM_{2.5}$ has increased. Since 2013, greater Dhaka has witnessed rise in the $PM_{2.5}$ concentration in its lower atmosphere. According to national ambient air quality standard (NAAQS), the permissible amount of $PM_{2.5}$ concentration in the air is 15 µg/m^3 but greater Dhaka experienced 83.41 µg/m^3 in 2013 and 98.94 µg/m^3 in 2018 respectively. The southern part of greater Dhaka which includes, Dhaka South City Corporation, Narayanganj district and Nawabganj upazila experienced the highest $PM_{2.5}$ concentration in 2018. Among the southern part highest change can be distinguished in Narayanganj.

In the north, Gazipur and Narsingdi districts have also experienced rise in the average annual $PM_{2.5}$ concentration by 10 µg/m^3. Though, more vegetation cover means less concentration of particulate matter in the air, the Gazipur district having a national forest (deciduous) within its boundary, has played little role to restrict the rising concentration of $PM_{2.5}$. This provides a general perception about the intensity of polluting anthropogenic activities that is taking place within the districts. The increase in Narayanganj's $PM_{2.5}$ also refer to severe intensification of anthropogenic activities mostly deforestation and industrialization of the place. Narayanganj is known for its ship breaking industry and the breaking, dismantling and building ships contribute to the pollution of the place.

Savar Upazila, which has also seen an increase in $PM_{2.5}$ concentration, is known as the growing industrial zone with numerous ready-made garment factories and recently transferred leather industry. Narsingdi and Gazipur districts are also experiencing a growing number of ready-made garment factories and are nationally famous for cloth manufacturing industry. These facts suggest that particulate pollution is increasing at a great rate in areas surrounding Dhaka rather than Dhaka itself. The city of Dhaka experiences a steady growth in the concentration of $PM_{2.5}$ in the air. The places with great deal of deforestation and anthropogenic activities within the study area are experiencing excessive increase in the $PM_{2.5}$ concentration.

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