A SPATIOTEMPORAL EVALUATION OF THE RELATIONSHIP BETWEEN AIR QUALITY INDEX (AQI) AND URBAN VEGETATION COVER (NDVI) IN DHAKA CITY

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ABSTRACT

The research measures the spatiotemporal link between vegetation cover and air quality in Dhaka, Bangladesh. The main objective of the study was to establish and examine the relationship between the Normalized Difference Vegetation Index (NDVI) and the Air Quality Index (AQI) in the city of Dhaka in order to determine the required density of uniformly distributed vegetation that will help to maintain Dhaka's safe air quality and contribute to negligible health impacts as per United States Environmental Protection Agency (US EPA) guidelines. The study involved analyzing Dhaka's air quality during the preceding years (2016-2020), monitoring air quality at 11 locations for two periods/seasons of the year, and examining the geographical distribution of NDVI, criteria air pollutant ($PM_{2.5}$, PM_{10}, CO, NO_2, and SO_2) concentrations, and AQI of the study area. The criteria air pollutants are air pollutants namely Particulate Matter of diameter 2.5 and 10 microns ($PM_{2.5}$ and PM_{10}), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Ozone (O_3) and Lead (Pb); for which acceptable levels of exposure can be determined and for which an ambient air quality standard has been set. Such air pollutants if exist in ambient air at higher levels than the standard may cause adverse impacts on human health. HAZSCANNER HIM-6000, a portable air quality monitoring equipment, was used to measure the air quality at the monitoring stations. To create a spatial distribution map of NDVI, satellite photos (LANDSAT 8 OLI/TRS C1 L1) of the research area were collected from the United States Geological Survey (USGS) website. ArcMap, a software utilizing Geographic Information System (GIS), was used to develop spatial distribution maps of the NDVI, criteria pollutant concentrations, and the Air Quality Index (AQI). Graphs were used to display the relationships between the necessary values. From the results, it was determined that Dhaka's air quality is more polluted during the winter (dry) season than it is during the monsoon (wet) season. Comparing the dry and wet periods, the rise in AQI ranged from 42.61% to 332.35%. In both the wet and dry seasons, a significant Spearman correlation of -0.76 and -0.90 was observed between NDVI and AQI. The findings indicate that to maintain the AQI levels within the USEPA's safe range in Dhaka city during the monsoon and winter, uniformly distributed vegetation density of at least 10% and at least 39.7% is required respectively.

Keywords: *AQI, NDVI, USEPA, Criteria Pollutant, Spearman Correlation.*

1. INTRODUCTION

Atmosphere, one of the three major components of the Earth's biosphere is day by day sinking to greater pollution levels mostly due to anthropogenic activities. In recent times Bangladesh has become highly susceptible to air pollution. Bangladesh is the most air-polluted country in the world from 2018 to 2021 as per 'World Air Quality' reports published by IQAir; a worldwide Air Quality Index (AQI) monitoring organization. According to the '2021 World Air Quality Report' by IQAir, Bangladesh has ranked 1st in AQI for $PM_{2.5}$ (Particulate matter of size equal to or lesser than 2.5 microns; considered as a common proxy indicator of air pollution) with an annual average concentration of 76.9 $\mu g/m^3$ which is around 15 times higher than the safe concentration levels (0-5 $\mu g/m^3$) recommended by the World Health Organization (WHO) and 5 times higher than the $PM_{2.5}$ standards (0-15 $\mu g/m^3$) of Bangladesh and United States Environmental Protection Agency (US EPA) (Source: IQAir). To mention further, Dhaka, the capital of Bangladesh, is the second most polluted city in the world in terms of $PM_{2.5}$ concentration as per IQAir report in 2021. (Source: IQAir)

Air pollution and its health impacts are, therefore, a major problem to Dhaka city's population and environmental condition. Immediate responses to this key issue are a must. Substantial reduction and improvement of air quality are ensured through both artificial and natural control methods and strategies. However, natural forestation and vegetation have proven to be the primary reducers of air pollution and improving AQI. In a study for 0.01-0.1 µm size particles and wind speed 0.3-1.5 m/s, Cypress (Cupressus leylandii) and Pine (Pinus sylvestris L.) hedges were found to substantially decrease deposition velocity for sub-micrometer particles (Deshmukh et al., 2019). Higher vegetation density along with higher Leaf Area Index (LAI) or Leaf Area Density (LAD) has shown increased deposition of pollutants near the surface (Baldauf, 2017). Additionally, trees absorb gaseous pollutants through stomatal uptake to eliminate them (Zheng et al., 2021). One of the most current studies is based on species-specific features and suggests species selection guidelines for better urban air quality, especially in open-road areas (Barwise & Kumar, 2020). Better tree cover helps to lower overall air temperature which can overally reduce Biogenic Volatile Organic Compounds (BVOCs) and O_3 levels in urban areas. Lower Land Surface Temperatures (LST) were observed in areas covered with urban trees than in built-up areas all over Europe (Schwaab et al., 2021). These literature provide an overall idea of the impact of forestation on various natural pollution-controlling mechanisms.

Certain studies reveal the biogenic volatile organic compound emission from vegetation, which can alternatively have an adverse impact on the environment. Natural or biogenic emissions of volatile organic compounds (BVOCs) from vegetation are the dominant global source of reactive carbon in the atmosphere. Ozone, a significant criterion pollutant, is created when BVOCs are oxidized in the atmosphere in the presence of nitrogen oxides. Studies indicate that multiple factors like certain physiological conditions, stress severity, and extensive heat winds causing the urban heat island (UHI) effect; can contribute to the production of BVOCs by trees (Fitzky et al., 2019). Certain trees during periods of extensive heat and weak winds can emit isoprene which is an agent for ozone production (Simon et al., 2019). Recent researches imply that specific species of trees used for urban greening; especially broad-leaved trees released the most isoprene, while needle-leaved trees released the most monoterpenes during the summer season. (Duan et al., 2023). Research conclusions in Bangladesh only depict that lesser $PM_{2.5}$ concentration is eminent in afforested areas with vegetation cover in greater Dhaka (Kulsum & Moniruzzaman, 2021). Summarizing literature reviews worldwide, although trees improve air quality, the effect is highly variable on spatiotemporal distribution, species, density, and pollutant criteria.

Upon extensive literature review, it was quite evident that although there is quite a remarkable amount of work regarding the impact of trees on air improvement, the amount of research in the context of Bangladesh is scarce and very limited. Furthermore, no work is present related to the quantitative analysis of the relation between the vegetation density of randomized local species and the subsequent air quality. For this, the research aims to estimate the amount of uniformly distributed vegetation density required to keep the Air quality of Dhaka safe. The research aims to measure several air pollutants at different locations, calculate the AQI of those locations, and analyze the relationship between the air quality and the corresponding density of the surrounding area. A best-fit regression is used to determine the relationship and identify whether the relationship is significant for consideration. The objective behind the work is to identify whether urban vegetation and greening methods used in Dhaka are enough to tackle its current air pollution and if not, how much vegetation density theoretically would suffice to reduce the pollution to safe levels. The secondary goal of the research would be to assist in providing integrated solutions for Air Quality Management Plans (AQMP), green urban planning, and forestation.

2. METHODOLOGY

2.1 Area of the Study

The research focuses on the Dhaka City Corporation area. Dhaka, the capital of Bangladesh, is located at the coordinates 23° 48' 39.8016" North and 90° 24' 27.3888" East. Dhaka city has an area of 305.47 square kilometers. Figure 1 and Figure 2 show the map of Dhaka city i.e.; the area of study.

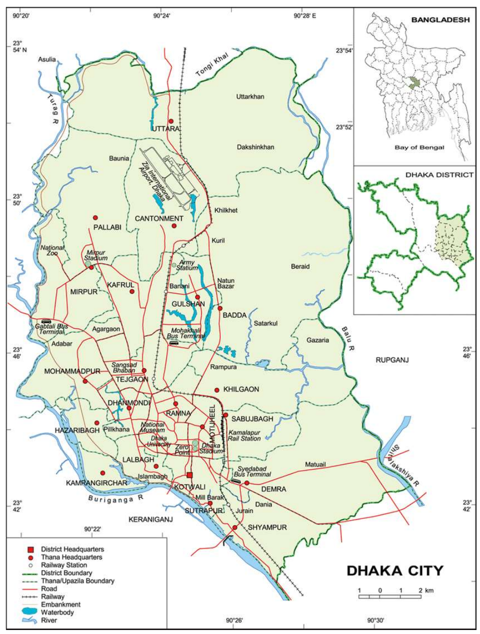

Figure 1: Administrative map of the study area

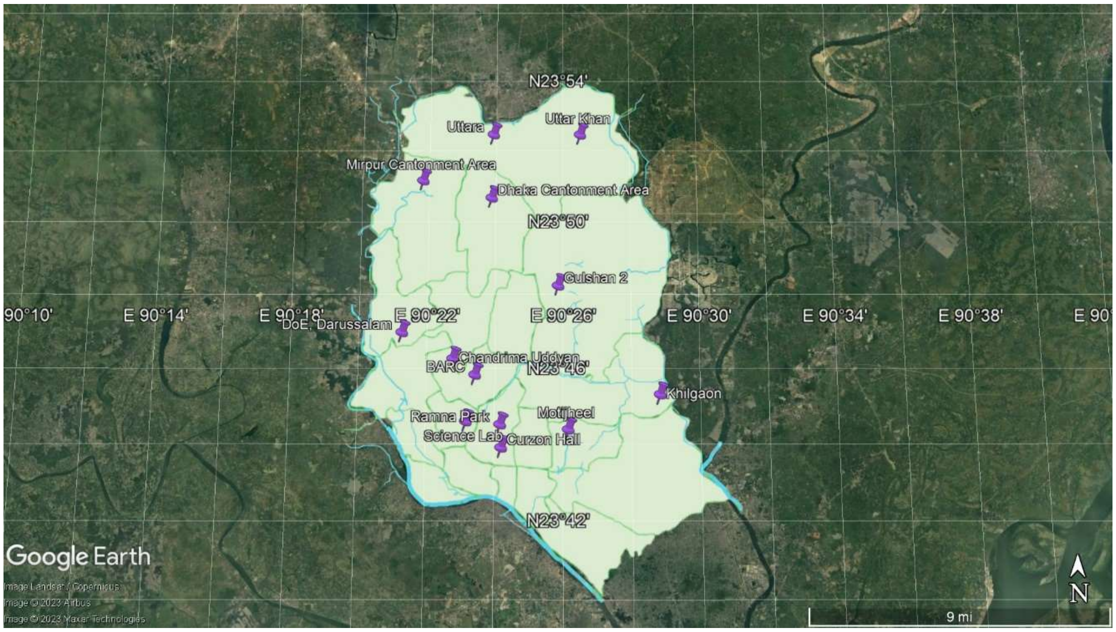

Figure 2: Satellite Image of the area of the study

2.2 Data Collection

The study was initialized by collecting and assessing the air quality of different geographical locations of Dhaka city for the previous five years from 2016 to 2020.

2.2.1 Primary Data Collection

The primary data of ambient air pollutant concentrations were collected at 11 locations. The monitoring locations were selected based on varying vegetation density (NDVI values) and high traffic activity to achieve an efficient interpolation which is required for geographical mapping of varying air pollutant concentrations all over Dhaka city. The data consisted of PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2 concentrations. Table 1 shows the stations of the monitoring for primary data collection.

Table 1: Monitoring locations for primary data collection

Serial No.	Area/Monitoring Location	Latitude	Longitude
1	Curzon Hall	23°43'38.95" North	90°24'6.66" East
2	Chandrima Uddyan	23°46'0.07" North	90°22'41.30" East
3	Ramna Park	23°44'15.32" North	90°24'4.64" East
4	Uttara (Sector 12)	23°52'11.90" North	90°23'49.70" East
5	Mirpur Cantonment Area	23°50'53.53" North	90°21'43.68" East
6	Uttar Khan	23°52'11.57" North	90°26'25.57" East
7	Dhaka Cantonment Area	23°50'24.58" North	90°23'47.02" East
8	Khilgaon	23°45'2.91" North	90°28'44.31" East
9	Science Lab	23°44'20.21" North	90°23'4.95" East
10	Gulshan 2 (Gulshan Lake Park)	23°47'58.57" North	90°25'46.00" East
11	Science Lab	23°44'7.47" North	90°26'3.73" East

The ambient air quality or air pollutant concentrations were measured using the Haz-Scanner Model HIM-6000 air quality monitoring station. The Haz-Scanner is a portable air quality monitoring equipment that can directly measure and record the concentrations of Particulate Matter ($PM_{2.5}$ and PM_{10}), Carbon Monoxide (CO), Nitrogen Oxides (NO_x, NO_2), Sulphur Oxides (SO_x, SO_2), Ozone (O_3) and Total Suspended Particle (TSP).

2.2.2 Secondary Data Collection

As a part of the air quality management plan of the government of Bangladesh, the Department of Environment (DoE) has established 11 Continuous Air Monitoring Stations (CAMS) all over the 8 major cities of Bangladesh for their Clean Air and Sustainable Environment (CASE) project. Air pollutant concentrations of the ambient air for the years from 2016 to 2020 were collected from three of these stations located in Dhaka for secondary data. Furthermore, air pollutant concentrations measured at three of all the stations located at Dhaka were also collected during the dates of air quality measurements at the primary data monitoring locations. Table 2 shows the three monitoring locations of secondary data located in Dhaka.

Table 2: Monitoring locations of secondary data collection

ID	Location	Latitude	Longitude
CAMS-1	Sangshad Bhaban, Sher-e-Bangla Nagar	23.76° North	90.39° East
CAMS-2	Farmgate	23.76° North	90.39° East
CAMS-3	DoE, Darussalam	23.78° North	90.39° East
Note: CAMS-1 and Chandrima Uddyan (Sl no.) of Table 1 are based on the same location. Only one of the two data collected is used for analysis.			

2.2.3 Satellite Image Collection

To develop the Normalized Difference Vegetation Index (NDVI) map of the study area, a satellite image (LANDSAT 8 OLI/TRS C1 L1 for 2021) of the study area was collected from the United States Geological Survey (USGS) website in the format of Tag Image File Format (TIFF). The Spectral bands used for the development of the NDVI map were Band 5- Near Infrared (NIR) and Band 4- Red.
The coordinates of the monitoring locations were exported in KMZ file format from the Google Earth Pro application to be used for GIS map development. Layer files of the administrative map of Bangladesh were collected from https://geodash.gov.bd/ .

2.3 Development of Spatial Distribution Map of NDVI of Dhaka

The NDVI map of Dhaka city was developed using ArcMap, a geospatial processing program of ArcGIS that utilizes the Geographic Information System (GIS) to create, manage, analyze, and map all types of geographically referenced information or data. Normalized Difference Vegetation Index (NDVI) map of Dhaka was developed using Band images from the collected LANDSAT Image. Using the Raster Calculation feature under Map Algebra of Spatial Analyst Tools from ArcMap, the LANDSAT data were processed to form the spatial distribution map of NDVI of Dhaka.

2.4 Analysis of Previous Air Quality Trends (2016-2020)

The secondary data obtained from the CAMS-1, CAMS-2, and CAMS-3 were analyzed for the years 2016-2020 to develop average monthly pollutant concentrations and air quality index (AQI). Upon reviewing the NDVI map of Dhaka city and the average monthly variations in air pollutant concentrations of Dhaka for the previous five years the 11 monitoring locations mentioned in Section 2.2.1 were designated for primary data collection.

2.5 Primary Data Processing

The ambient air quality was monitored for one hour at each location for the concentrations of PM_{10}, $PM_{2.5}$, CO, NO_2, and SO_2 for two periods of the year: 1. Monsoonal (Wet) Period, 2. Dry (Winter) Period

2.5.1 Conversion to Standard Averaging Period

The obtained 1hour concentrations of the pollutant were converted to the standard averaging time (24 hours for PM_{10} and $PM_{2.5}$, 8 hours for CO, and 1 hour for NO_2 and SO_2) using equation (1) (Cha et al., 1992; Office of the Federal Register, 2023).

$$C_{long} = C_{short}(\frac{T_{Short}}{T_{long}})^p \tag{1}$$

where

C_{long} = Concentration for the longer averaging time, T_{long}

C_{short} = Concentration for the shorter averaging time, T_{short}

T_{long} = Longer averaging time (hours)

T_{short} = Shorter averaging time (hours)

P = Power law exponent=0.28 used for ambient air assessment

2.5.2 Calculation of Air Quality Index (AQI)

According to 'Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI)' published by US EPA, AQI is the highest value of Ip (Index of the pollutant) calculated for each pollutant (Office of the Federal Register, 2023). The formula used is as follows:

$$I_p = \frac{I_{HI} - I_{Lo}}{BP_{Hi} - BP_{Lo}}\left(C_p - BP_{Lo}\right) + I_{Lo} \tag{2}$$

where

I_p = the index for pollutant p

C_p = the truncated concentration of pollutant p

BP_{Hi} = the concentration breakpoint that is greater than or equal to C_p

BP_{Lo} = the concentration breakpoint that is less than or equal to C_p

I_{Hi} = the AQI value corresponding to BP_{Hi}

I_{Lo} = the AQI value corresponding to BP_{Lo}

The corresponding breakpoints of the criteria pollutants are presented in the same technical document.

2.5.3 Development of Spatial Distribution Map of Air Quality

Air pollutant concentration in standard averaging time and AQI obtained from the primary data collection and monitoring were geographically mapped for the city of Dhaka and values were interpolated for the whole geographical area.

Inverse Distance Weighting (IDW) interpolation was used for obtaining values of air quality for the whole study area. Inverse distance weighting (IDW) is a form of deterministic method for multivariate interpolation where the value of a set of scattered points is known. A weighted average of the values present at the known points is used to determine the values allocated to the unknown points. It was decided to adopt the inverse distance weighted (IDW) interpolation approach because it gives local impact priority when estimating an unknown value for a specific location.

2.6 Development of Correlation Between AQI and NDVI:

A best-fit regressive relation between AQI and NDVI was developed for both seasons, where the Y-axis values represented the AQI of the locations and the X-axis values represented the NDVI values of the corresponding AQI. The significance or strength of the relationship for both seasons was evaluated using the R-squared regression value and Spearman's Correlation Rank test.

The R-squared regression value is used as a statistical measure in this relationship that determines the proportion of variance in the dependent variable (AQI) that can be explained by the independent

variable (NDVI). The R-squared value ranges from 0 to 1 where 1 is considered as best possible fit for the relationship. However, values as low as 0.5 can be considered strong in cases of high variance.
The Spearman rank correlation test evaluates how effectively a monotonic function can capture the relationship between two variables. It tests the significance between the two variables using the following equation (3):

$$r = 1 - \frac{6\sum d^2}{n^3 - n} \tag{3}$$

where,
r = Spearman's Rank
d = Difference between corresponding Y-axis and X-axis values
n = Number of samples
Spearman's rank for sample size (12 or 13 in this study) will have a significant relationship between NDVI and AQI if the r value is greater than +0.6 or less than -0.6, where the positive values indicate an increasing correlation and the negative values indicate a decreasing relation.

3. RESULTS AND DISCUSSION

3.1 Average Monthly Variation of Air Quality from 2016 to 2020:

The air pollutant concentration data of ambient air obtained from the CAMS-1 (Shangshad Bhaban), CAMS-2 (BARC), and CAMS-3 (DoE, Darussalam) from the year 2016 to 2020 were analyzed for their average monthly variation of Air Quality Index (AQI).

The Air Quality Index (AQI) was quite high compared to the EPA Standard in the city of Dhaka. Figure 3 shows the monthly AQI for the years 2016-2020 monitored at the stations located at Shangshad Bhaban, BARC, and DoE, Darussalam. From the graphical representation of the data, it is evident the AQI values of all the stations were well above EPA Standard (100) almost all around the year. AQI values were unhealthy (150-200) during November and December of the winter season. The air quality reached very unhealthy (AQI value:201-300) conditions during January and February of the winter and during the onset of summer during March. AQI values ranged from unhealthy for sensitive groups (Children, elderly persons, heart and lung disease patients) to unhealthy levels of concern during the months of April, May, September, and October. It was advisable for the sensitive group of people to reduce prolonged physical exertion. AQI values within or almost within EPA standards i.e., at a safe level during a part of the monsoon starting from June to August. The highest AQI value of 224 was observed at CAMS-3 (DoE, Darussalam) during February and the lowest value of 77 was observed at CAMS-1 (Shangshad Bhaban) during July.

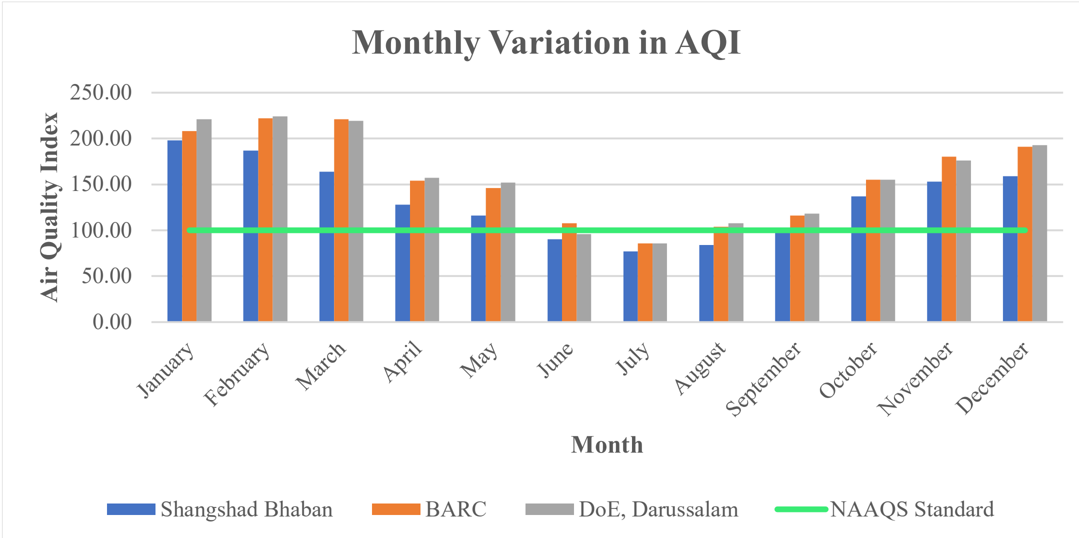

Figure 3: Average monthly AQI value from 2016 to 2020 at CAMS-1,2,3

From the observed average monthly variations in air quality, it is quite clear that the pollution levels are higher during dry period of the year compared to wet seasons. Based on this conclusion the primary data collection of air quality was conducted both in the winter season (December 2022 and January 2023) and monsoon season (September and October 2022).

3.2 Normalized Difference Vegetation Index (NDVI) of Dhaka:

The Normalized Difference Vegetation Index (NDVI) map of the study area is presented in Figure 4.

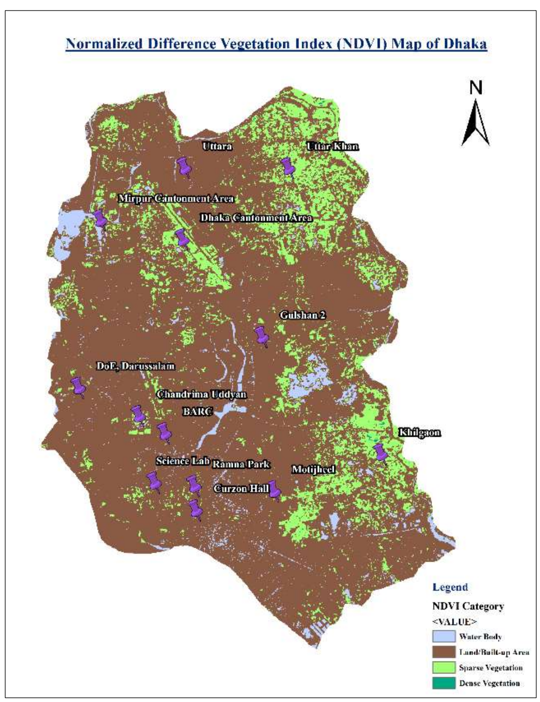

Figure 4: Spatial Distribution of NDVI in Dhaka city

The map shows that the city of Dhaka was mostly comprised of barren and built-up land areas. No major river was observed in the area other than a few water bodies which were present in a scattered manner in the city. Although densely vegetated areas (vegetation cover greater than 50% and NDVI value higher than 0.5) were very rare in the city, the North-Eastern and South-Eastern parts of the study area had prominent sparse vegetation of tree density ranging from 10% to 31.71%. The monitoring locations in Khilgaon and Uttar Khan are mainly present in such parts of the city. Prominent sparse vegetation was also observed in areas located near/around Dhaka Cantonment, Mirpur Cantonment, and Gulshan 2.

3.3 Air Quality Monitored in Dhaka City

3.3.1 Wet Season

The air quality of Dhaka varied between all levels of concern during the monsoon. From Figure 5 it is evident that most of the monitoring locations had AQI less than 100 i.e. within safe levels of US EPA Standards. However, the air quality was in the unhealthy categories for BARC, DoE, and Science Lab. Hazardous conditions have been observed in the Science Lab area as per Figure 6. Surrounding areas including DoE, Darussalam had very unhealthy air quality. Good and moderate air quality were more prevalent in the North and South-Eastern parts of the study area where monitoring locations had relatively higher NDVI values.

3.3.2 Dry Season

The air quality in the dry season was unhealthy all over Dhaka city as seen in the spatial distribution map in Figure 7. The AQI values ranged from 104 (Unhealthy for sensitive groups) to 252 (Very healthy). For a NDVI value of 0.35 at Khilgaon, the air quality reached an index of 104 which was still unhealthy for sensitive groups.

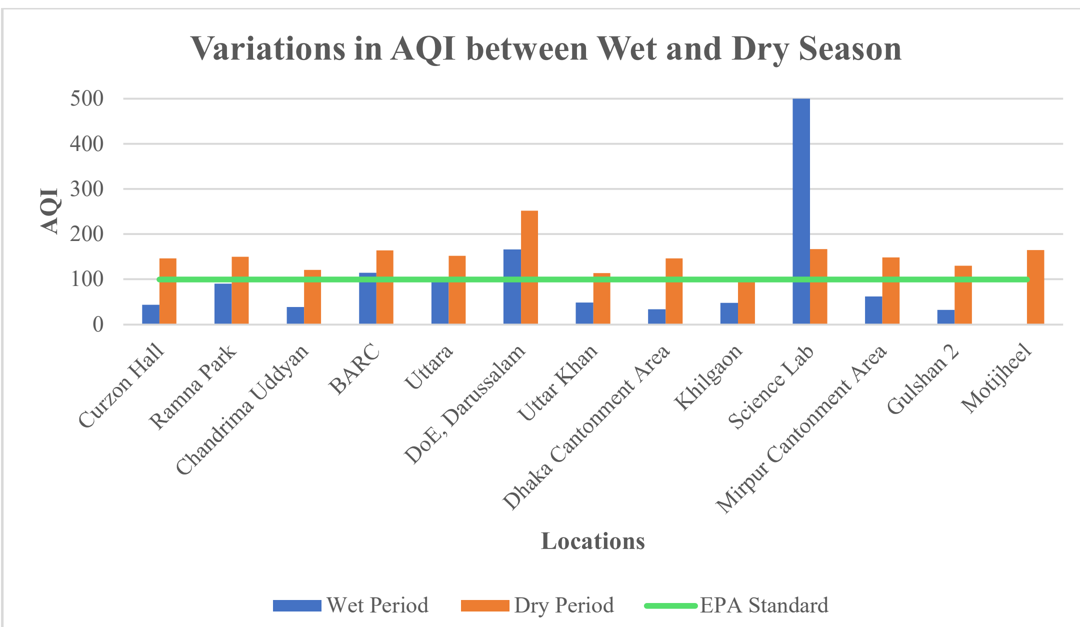

Figure 5: Variations in AQI between Wet and Dry Season

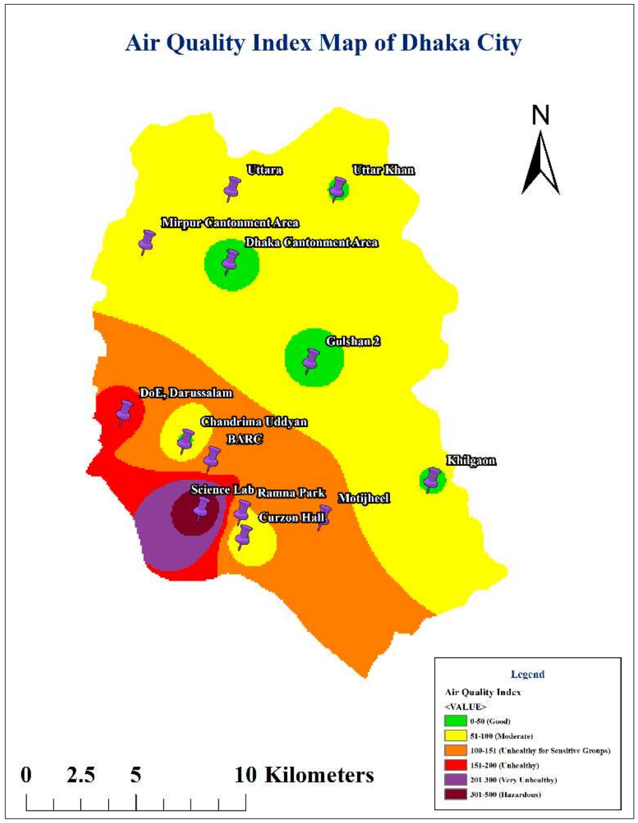

Figure 6: Spatial distribution of AQI in Dhaka city in Wet Season

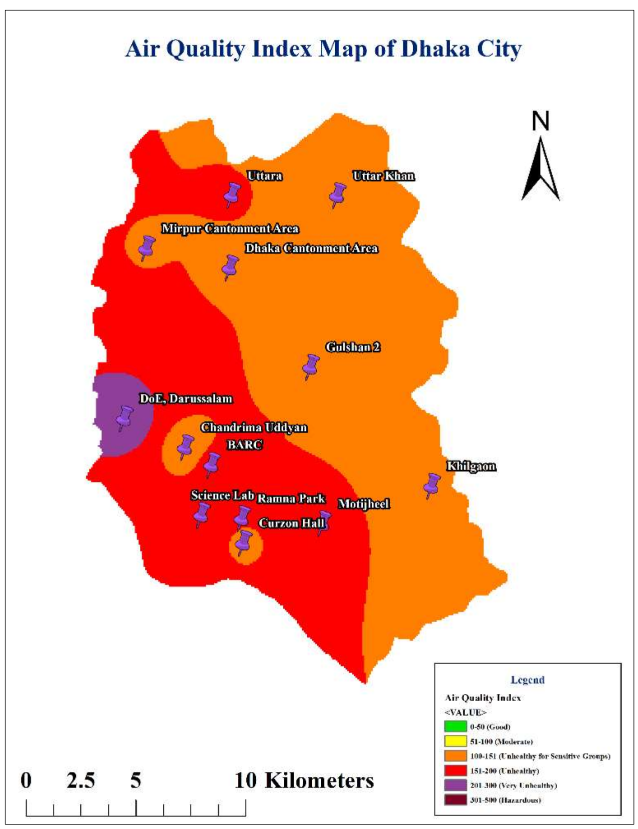

Figure 7: Spatial distribution of AQI in Dhaka city in Dry Season

3.3.3 Temporal Variation

The AQI value of the two seasons has mainly shown that there is increase in AQI i.e.; degradation in air quality in the dry season compared to the wet season. The percentage of increase of AQI in the dry season compared to the monsoon are provided in Table 3.
The table shows that only at Science Lab the Air Quality Index decreased during dry season compared to the monsoon. However, the extreme value of 500 observed at science lab during monsoon can also arise from any technical problem. The highest increase in AQI during dry was observed at Dhaka Cantonment area which was 332.35%. The lowest increase in AQI during dry was observed at BARC which was 42.61%. This indicates that AQI value increases about 0.4 to 3.3 times higher during dry season compared to the rainy season.

Table 3: Percentage of change in AQI during dry season

Monitoring Location	**Increase/Decrease in AQI during dry season**	**Percentage of increase/decrease in AQI during dry season**
Curzon Hall	103 (Increase)	234.09 % (Increase)
Ramna Park	59 (Increase)	64.84 % (Increase)
Chandrima Uddyan	82 (Increase)	210.26 % (Increase)
BARC	49 (Increase)	42.61 % (Increase)
Uttara	58 (Increase)	61.70 % (Increase)
DoE, Darussalam	86 (Increase)	51.81 % (Increase)
Uttar Khan	64 (Increase)	132.65 % (Increase)
Dhaka Cantonment Area	113 (Increase)	332.35 % (Increase)
Khilgaon	56 (Increase)	116.67 % (Increase)
Science Lab	351 (Decrease)	-66.60 % (Decrease)
Mirpur Cantonment Area	68 (Increase)	140.32 % (Increase)
Gulshan 2	133 (Increase)	306.25 % (Increase)

3.4 Relation Between AQI and NDVI

3.4.1 Monsoonal Period

During the monsoonal period, the AQI of Dhaka decreases with the increase of NDVI. Figure 8 shows the correlation between AQI and NDVI of Dhaka for wet season. The Air Quality Index reaches a value of 100 when the NDVI value is 0.13 as per correlation of the graph. This interprets that a vegetation density of 10% or above will keep AQI within safe limits in Dhaka.
From the spearman rank correlation, it was observed that the relation between NDVI and AQI has a spearman rank of -0.76 and a R^2 value of 0.5999. This indicates a significant negative correlation (AQI increases with decrease of NDVI).

3.4.2 Dry Period

During the dry period, the AQI of Dhaka decreases with the increase of NDVI. Figure 9 shows the correlation between AQI and NDVI of Dhaka for dry season. The Air Quality Index reaches a value of 100 when the NDVI value is 0.41 as per correlation of the graph. This interprets that a vegetation density of 39.7% or above will keep AQI within safe limits in Dhaka.
From the Spearman rank correlation, it was observed that the relation between NDVI and AQI has a Spearman rank of -0.90 and a R^2 value of 0.5706. This indicates a negative correlation (AQI increases with decrease of NDVI), which is a significant relation

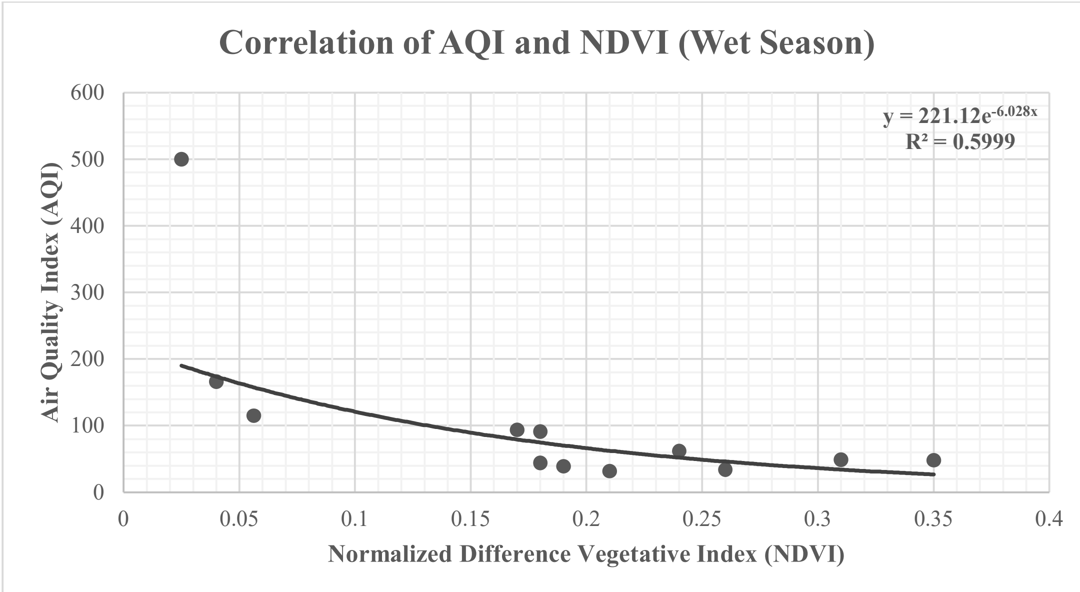

Figure 8: Correlation between AQI and NDVI during the Monsoonal Period

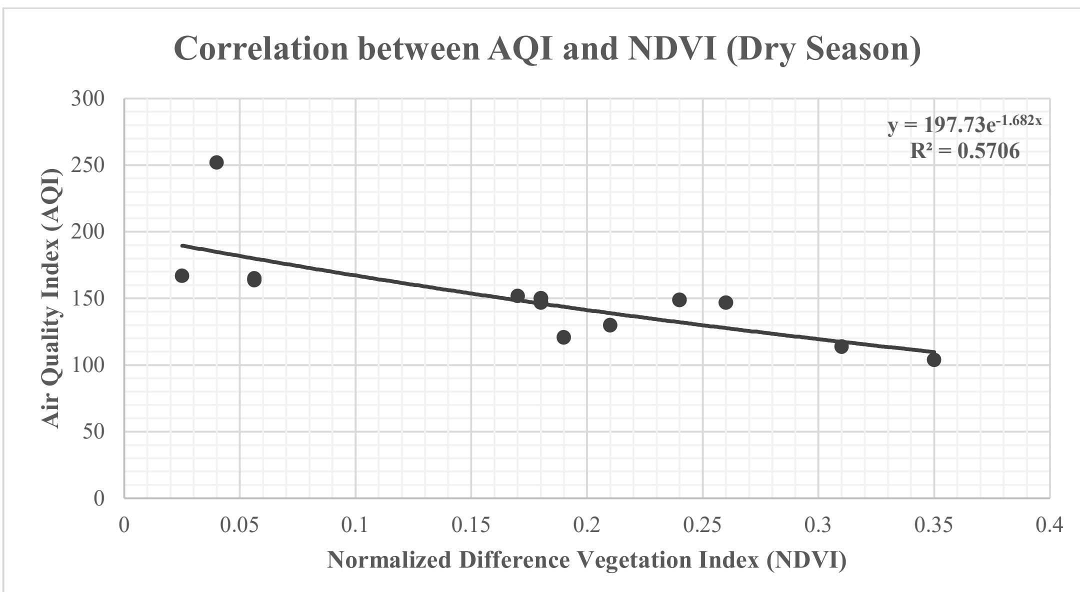

Figure 9: Correlation between AQI and NDVI during Dry Season

4. CONCLUSION

The air quality improves with the increase of vegetation cover (NDVI) in Dhaka city. It was observed that uniformly distributed vegetation of density of 10% (NDVI value of 0.13) or more will be required to keep the air quality at safe levels during monsoon and uniformly distributed vegetation of density of 39.7% (NDVI value of 0.41) or more will be required to keep the air quality at safe levels during the dry period in Dhaka. Although results have been derived from the study, there are some limitations prevalent in this research. The study was based on the monitoring of criteria air pollutants. However, the monitoring of ground-level Ozone (O_3) and Lead (Pb) was not possible due to the absence of monitoring provisions for these two pollutants. This research can be taken as a foundation for future studies. As a recommendation, the actual vegetation density calculated through field measurements instead of Normalized Difference Vegetation Index (NDVI) can yield more accurate results to quantify the relationship between vegetation cover and air quality. In such cases, a study of climatic variables and meteorological factors can provide a better understanding of pollutants which vary on a spatiotemporal basis. Continuous monitoring of air pollutant concentrations can also help to provide more accurate results. The Community Multiscale Air Quality (CMAQ) modelling system can be utilized in future studies for air quality monitoring and modelling.

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REFERENCES

Baldauf, R. (2017). Roadside vegetation design characteristics that can improve local, near-road air quality. *Transportation Research Part D: Transport and Environment*, *52*, 354–361.

Barwise, Y., & Kumar, P. (2020). Designing vegetation barriers for urban air pollution abatement: A practical review for appropriate plant species selection. *Npj Climate and Atmospheric Science*, *3*(1), Article 1.

Cha, S. S., Li, Z., & Brown, K. E. (1992). A conversion scheme for the ISC model in odor modeling. *A AND WMA ANNUAL MEETING*, *1*, 92–153.

Deshmukh, P., Isakov, V., Venkatram, A., Yang, B., Zhang, K. M., Logan, R., & Baldauf, R. (2019). The effects of roadside vegetation characteristics on local, near-road air quality. *Air Quality, Atmosphere & Health*, *12*(3), 259–270.

Duan, C., Wu, Z., Liao, H., & Ren, Y. (2023). Interaction Processes of Environment and Plant Ecophysiology with BVOC Emissions from Dominant Greening Trees. *Forests*, *14*(3), Article 3.

Fitzky, A. C., Sandén, H., Karl, T., Fares, S., Calfapietra, C., Grote, R., Saunier, A., & Rewald, B. (2019). The Interplay Between Ozone and Urban Vegetation—BVOC Emissions, Ozone Deposition, and Tree Ecophysiology. *Frontiers in Forests and Global Change*, *2*.

Kulsum, U., & Moniruzzaman, M. (2021). Quantifying the Relationship of Vegetation Cover and Air Pollution: A Spatiotemporal Analysis of PM2.5 and NDVI in Greater Dhaka, Bangladesh. *Jagannath University Journal of Science 07*, 54–63.

Office of the Federal Register, N. A. and R. A. (2023). Uniform Air Quality Index and Daily Reporting. *Title 40—Protection of Environment, Chapter I (C), Part 58, Appendix G.*

Schwaab, J., Meier, R., Mussetti, G., Seneviratne, S., Bürgi, C., & Davin, E. L. (2021). The role of urban trees in reducing land surface temperatures in European cities. *Nature Communications*, *12*(1), Article 1.

Simon, H., Fallmann, J., Kropp, T., Tost, H., & Bruse, M. (2019). Urban Trees and Their Impact on Local Ozone Concentration—A Microclimate Modeling Study. *Atmosphere*, *10*(3), Article 3.

Zheng, T., Jia, Y.-P., Zhang, S., Li, X.-B., Wu, Y., Wu, C.-L., He, H.-D., & Peng, Z.-R. (2021). Impacts of vegetation on particle concentrations in roadside environments. *Environmental Pollution*, *282*, 117067.