Mapping Environmental Quality Indices of Dhaka City by Using Geospatial Techniques

Asib Ahmed[1]* and Orna Rahman Onny[2]

[1]Department of Geography and Environment, University of Dhaka, Dhaka 1000, Bangladesh
[2]Department of Environment and Development Studies, United International University, Dhaka 1212, Bangladesh

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ABSTRACT: Dhaka, the city of over 10 million people is one of the most polluted cities due to rapid urbanization, commercial development and population pressure. The present study assessed an overall environmental quality of Dhaka South City Corporation (DSCC) and Dhaka North City Corporation (DNCC) using an Environmental Quality Index (EQI) based on five indices: Air Quality Index (AQI), Water Quality Index (WQI), Soil Quality Index (SQI), Noise Quality Index (NQI), and Vegetation Index (VI). The final EQI was determined through selecting components from background literature and an overlay analysis using predefined weights for each distinct indices. The study reveals that the west and west-central part of DSCC have experienced the most severe environmental degradation, affecting noise levels, vegetation cover, air, soil, and water quality. However, the air is less polluted especially in the peripheral zones of the city corporations. Overall, the study indicates that the environmental quality of DNCC is comparatively better than DSCC. The results of the study provides an insight on environmental quality of the city for legislators, urban planners, environmentalists, and researchers to monitor and preserve environmental quality in making the city livable, healthy and sustainable.

Keywords: Dhaka City; Environmental Quality Index; Geospatial Mapping; Sentinel-5P

INTRODUCTION

Environmental properties and characteristics are broad and can be described by a number of variables such as noise levels, access to open space, the aesthetics of buildings, and the potential effects of these factors that may affect both mental and physical health of human being. As a densely populated city in Bangladesh, Dhaka faces unique environmental challenges. Dhaka's rapid growth began in 1971, when it became the capital of Bangladesh. The increased construction activity for residences, commercial, and industrial needs has rendered the soil impenetrable. Human-induced factors such as construction activities, industrialisation, transportation, deforestation and unplanned rapid urbanization deteriorating the air, water and soil qualities of the city.

Dhaka has often been listed as one of the worst air-polluted cities in the world in recent years. In April 2021, Dhaka's score on the US Air Quality Index (AQI) was 193, putting it among the five or 10 worst cities for air quality (Hossain et al., 2021). According to a study published in March 2019 by the Department of Environment (DoE) and the World Bank, the three main sources of air pollution in Dhaka city are brick kilns, car fumes, and building sites dust. Dhaka appears to have higher carbon dioxide concentrations than other cities in Bangladesh (Asaduzzaman et al., 2019). Moreover, the quality of surface water in and around Dhaka city is polluting day-by-day due to discharge of untreated or inadequately treated water into rivers and lakes from industries and tanneries. Toxic elements are found to exist in water bodies of the city. Approximately 60,000 m^3/day of hazardous substance are dumped into the river Buriganga and connected rivers (Turag, Tongi Khal, Balu, Sitalakkhya, and Dhaleswari), largely from nine significant industrial clusters (i.e. Tongi, Hazaribagh, Tejgaon, Tarabo, Narayanganj, Savar, Gazipur, DEPZ, Ghorashal) (Uddin and Jeong, 2021). Soil becomes polluted by agricultural practices, urban waste, industrial waste, and radioactive waste in Dhaka city. Literature reveals that soils close to busy intersections and industrial zones have high levels of metalloids and heavy metals, and the concentrations of Pb (22.09 mg/kg), Cd (2.05 mg/kg), and Cr (7.58 mg/kg) are present in higher quantities in and around the water bodies and soils of the city (Islam et al., 2018). Furthermore, noise threatens mostly from the roadside contributed by vehicles, construction sites. Motorized traffic is the

*Corresponding Author: Asib Ahmed
E-mail: asib01geo@du.ac.bd
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main source of noise in Dhaka City (Chowdhury et al., 2010). Industrialization and technological advancement have led to noise pollution (Kpang and Dollah, 2021). Several industries, including textile mills, printing presses, engineering firms, and metalworks, greatly contribute to noise pollution of the city. According to Van Herzele and Wiedemann (2003) and Chiesura (2004), urban green spaces and healthy settings offer amenities and services that significantly improve the quality of urban life. However, one of the perturbing concerns of the city is the decrease in vegetation and open space. All of these parameters are in serious state of the city and there are flaws in infrastructure, and management which have already reached to an extent to envisage this as one of the top 7 least livable cities in the world (Karmaker et al., 2023). Hence, the evaluation of the environmental quality of Dhaka city is essential due to rapid degradation of the environmental quality (Islam et al., 2014).

Assessment of environmental quality is a continuous process that involves identifying and quantifying the impact of various environmental factors on human health. Negative environmental features such as landfills and industrial plants, are often found in areas with high minority and poor populations, while high-income neighborhoods often have health-promoting features. Clusters of environmental exposure may be found and linked to the existing state of environmental quality of an area (USEPA, 2014). EQIs help researchers to determine which domains contribute the most to the total environment and provide context for isolated risks and regulation for environmental quality. Moreover, mapping the spatial extent of the environmental quality is useful for further interventions in improving the quality of the environment. It is required to follow a methodological framework to assess and quantify the overall environmental quality of an area. An environmental component with multiple indicators is represented by an index. Even though this distinction is not generally accepted, it is useful to understand how hierarchical an environment is (Thomas, 1972). An Environmental Quality Index (EQI) considers various environmental domains where humans interact. Remote Sensing and Geographic Information System (GIS) approaches expedite, labor-intensive, and cost-effective use of geographic data (Cetin, 2015). El-Zeiny et al. (2023), highlight the effectiveness of geospatial methods in environmental quality assessment and variation detection, praising Landsat, Sentinel, and MODIS satellites for their mapping capabilities.

The environmental quality of various areas and regions is assessed by a number of studies that are carried out all over the world (Krishnan and Firoz, 2020). El-Zeiny et al., (2023) and Assaye et al., (2017), used observation data and geospatial tools to assess environmental quality in Assiut Governorate, Addis Ababa City and assessed ecological, meteorological, and socio-economic domains, to create an environmental quality index map.

To evaluate the environmental quality and create an index, previous studies have considered the environmental factors, such as the quality of the air, water, soil, vegetation, and noise separately. Taking urban environmental quality into consideration, only a few researches have incorporated these characteristics on a map (Nichol and Wong, 2009). Moverover, the evaluation of environment on a small scale can be useful in urban context (e.g. Dhaka city) in a developing country like Bangladesh in order to lessen the impact of issues that start at the local level. Thus, the purpose of the current investigation was to assess the quality of the environment of Dhaka city by developing domain-specific indices and overall Environmental Quality Index (EQI). The methods used to gather data for these particular domains from various locations throughout Dhaka city covers in the upcoming sections. Subsequently, the results section contains the development, application and analysis of the EQI.

MATERIALS AND METHODS

Study Area

The present study considered Dhaka as a study area to assess environmental quality of the city. The total area covered is 277 sq. km. which includes both the city corporations (i.e.DNCC and DSCC), each of which includes ten zones. The city is surrounded by three rivers and one canal such as Buriganga and Turag to the west, Tongi to the north, and Balu to the east.

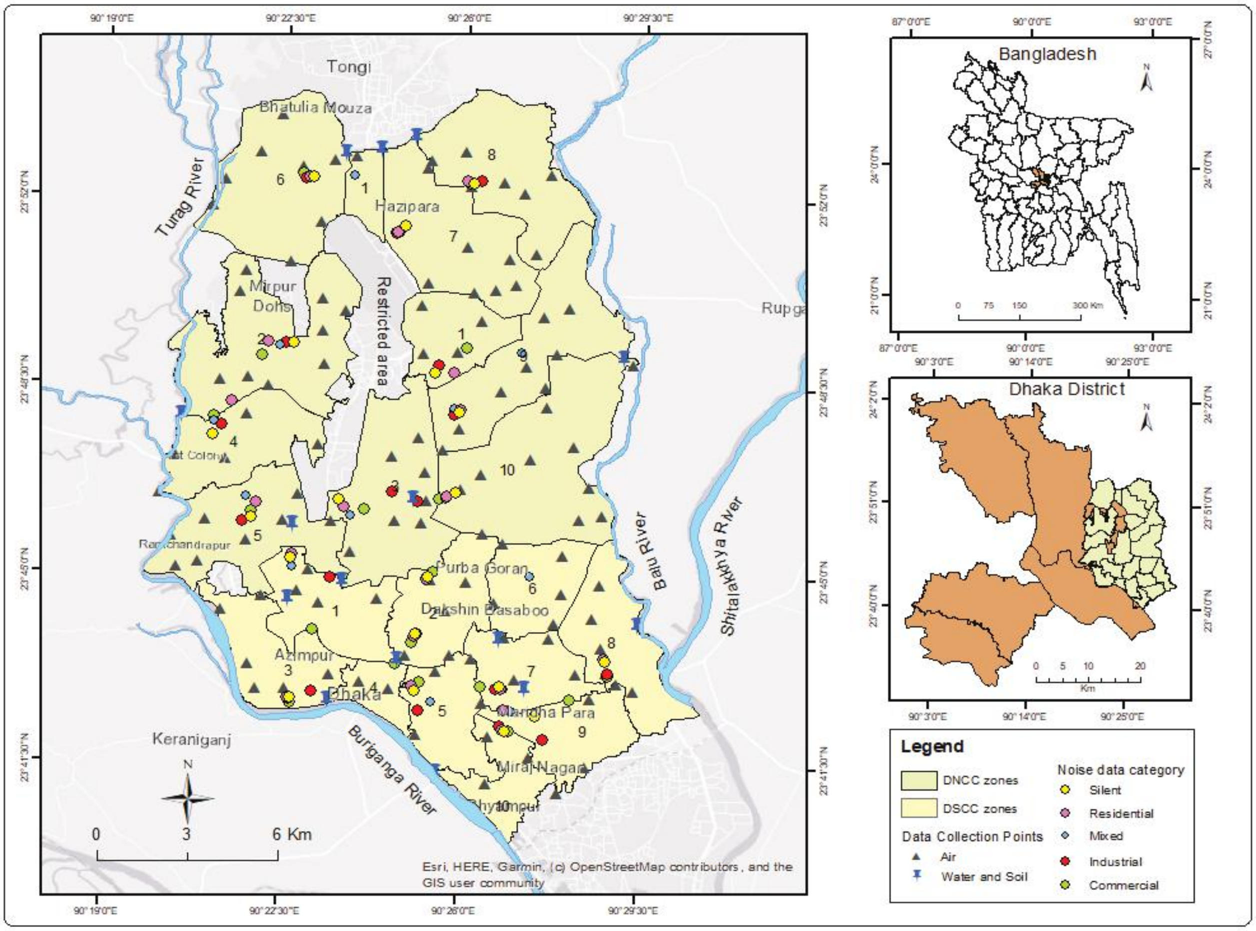

Figure 1: Study Area for the Application of Environmental Quality Index (EQI)

Data Used

The study developed an environmental quality index by considering five domains: air quality, water quality, soil quality, noise quality, and vegetation cover. Data were collected by using Google Earth Engine's Sentinel-5P mission sensors for air quality, Aeroqual Series 500 for primary pollutants, and 15 water samples from city corporation zones for water and soil quality. Noise levels were gathered from all six noise source areas, and Sentinel-2 data from Google Earth Engine was used for vegetation cover data.

Air Quality Data

The air quality index was created using primary and secondary data from Sentinel-5P mission sensors (TROPOMI) collected between November 2020 and February 2021. The chosen parameters were CO, SO_2, CO_2, NO_2, O_3, CH_4, $PM_{2.5}$, and PM_{10}. The secondary data were collected using Google Earth Engine, while the primary method was used for CO_2, $PM_{2.5}$, and PM_{10} due to data shortages. The shapefiles were digitally transformed using ArcMap software, and the minimum distance for data collection was 900m. The primary data were collected from a total number of 116 stations that cover major areas of the city except the restricted zones (e.g. Dhaka Cantonment).

Water Quality Data

The study collected water samples from 15 locations in Dhaka city that include various types of water bodies of DSCC and DNCC such as rivers, lakes, canals, and ponds.

Soil Quality Data

The study aimed to determine the Soil Quality Index (SQI) using various parameters such as nickel, cadmium, copper, chromium, and lead. Eight and seven soil samples from DNCC and DSCC were taken respectively to analyze pH levels and metalloid contaminants in the city's soil.

Noise Quality Data

Sound level meters were used to measure noise quality in twenty zones for both the city corporations. Daytime data (i.e. 06 am to 09 pm considered for noise level) were collected for two days (one weekday and one weekend) at different intervals (i.e. 6:00 am, 9:00 am, 12:00 pm, 3:00 pm, 6:00 pm, and 9:00 pm) and categorized into "Commercial," "Industrial," "Mixed," "Residential," or "Silent." Each category had 20 locations in 20 zones of the city, and each point was averaged across all timings. This produced 20 different data, which were then processed further.

Vegetation Index Data

To prepare the vegetation index of the city Sentinel-2 datasets were used which were collected through USGS Earth Explorer. The dataset, consisting of two polar-orbiting satellites and a Multi-spectral Instrument sensor, provides high-resolution optical imagery with 0% cloud coverage. The dataset includes 12 spectral bands, with Band-4 representing the red spectrum and Band-8 representing the near-infrared (NIR) spectrum. The images were collected during the spring season on March 3rd, 2022.

Methodology

Development of EQI

To evaluate the present overall environmental condition of the city, the EQI was developed by following four steps: (1) identifying the domains of environment (i.e. 5 domains-air, water, soil, noise, and vegetation); (2) locating and reviewing the data for each of the five domains; (3) developing environmental variables from the data sources; and (4) combining the data in each of the environmental domains. In preparation of the EQI, five indices such as air quality index (AQI), water quality index (WQI), noise quality index (NQI), vegetation index (VI) and soil quality index (SQI) were developed by measuring the quality of air, water, soil, noise and vegetation cover. The individual indices were standardized with the same resolution and coordinate system. They were all reclassified at the same scale (1-100). Finally, all the indices (AQI, WQI, NQI, VI, SQI) were processed for calculating the EQI. Overlay analysis was used to find the EQI based on the predefined weights.

The local Air Quality Index (AQI) was determined by using "Weighted Overlay" method (Formula 1). This technique enables users to extract weights for all air pollutants while layering them on top of one another and to build influence variables based on actual circumstances. The following is a general formula for this analysis:

$$AQI = \sum_{i=1}^{n} w_i c_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here,

'w' signifies the weights assigned to each parameter or influencing factor

'c' is the the parameter's cell value

'n' is the parameter's number

The ratings for each pollutant were generated using Principal Component Analysis (PCA) from the Dimensionality Reduction tool in QGIS (version 3.22.7) software. The displaying scores define the link between the pollutants in question (Siswadi et al., 2012).

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

The loading scores were used to generate the ranks for each pollutant (Table 1). The percentages in PC1 column were utilized as the ratings for the specific pollutants in equation (1).

Table 1: Loading Scores for All Pollutants (in descending orders) ('λ' relates to eigenvalues) (Ahmed et al., 2022)

Parameters	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	**0.004**	0.011	0.007
CO_2	**0.000**	0.000	-0.005

The quality index for water (WQI) and soil (SQI) were calculated based on the collective impacts of these parameters. Thus, a score for each parameter was determined as the WQI and SQI of the respective points in the area (Formula 2,3).

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

$$SQI = \sum_{i=1}^{n} w_i c_i \text{..........................(3)}$$

The weights of these equations were adopted using comparative significance of the parameters; more significant parameters were assigned more weights (Osmani et al., 2015). The weights aggregate to a 100%, where the weight of Nickel, Chromium and suspended solid is 25%, total phosphate 18% and Lead only 7%. For SQI, almost 70% of the weight was assigned to Cr and Pb together. Cd and pH each had 5% while Cu and Ni each had 1%. Using this equation via the 'Calculate Field' tool, a new field could be generated as a score. Circles in SQI and WQI maps represent the scores for each sample location of the data, where the color ranges present the value of the scores. The computed WQI values were classified using the 'Natural Breaks' method as follows: < 30: Least Polluted; 31-50: Less Polluted; 51-70: Fairly Polluted; 71-90: Polluted; >90: Most Polluted. The computed SQI values were also classified using 'Natural Breaks' as follows: < 300: Least Polluted; 301-700: Less Polluted; 701-1400: Fairly Polluted; 1401-2000: Polluted; >2000: Most Polluted.

WQI = {(0.25) ×(Ni)} + {(0.25) ×(Cr)} + {(0.25) × (SS)} + {(0.18) × (TP)} + {(0.07) ×(Pb)}

SQI = {(0.05) × (pH)} + {(0.4) × (Cr)} + {(0.3) × (Pb)} + {(0.01) × (Ni)} + {(0.01) × (Cu)} + {(0.05) × (Cd)}

The Weighted Overlay approach was utilized in the study to construct the noise quality index because it can obtain weights for each contaminant when stacking in layers and users can choose influencing parameters based on actual situations before conducting the analysis (Formula 4).

$$NQI = \sum_{i=1}^{n} w_i c_i \text{..........................(4)}$$

NQI = {(0.20)×(Residential)} + {(0.20)×(Commercial)} + {(0.20)×(Industrial)} + {(0.20)×(Mixed)}+ {(0.20)×(Silent)}

Thus, they all have the same influence or weight in the EQI algorithm . The output image was classified in equal intervals of 20%. Moreover, Normalized Difference Vegetation Index was used to characterize the density of vegetation in the study area. Band 4 (Red) and Band 8 (NIR) of Sentinel-2 datasets were incorporated to perform NDVI for the city (Formula 5).

$$NDVI = \frac{NIR-Red}{NIR+Red} \text{...............(5)}$$

Finally, to construct the EQI (Formula 6), the weights for each of the indices were assigned as 30% for AQI, 25% for NQI, 25% for VI, 10% for SQI and 10% for WQI. These weights were determined using the feasibility of the collected data and the impact of the respective indices on the environment.

$$EQI = \sum_{i=1}^{n} w_i c_i \ldots\ldots\ldots\ldots\ldots (6)$$

Thus, the calculation of the final output was as follows:

EQI = {(0.3)×(AQI)} + {(0.25)×(NQI)} + {(0.25)×(VI)} + {(0.1)×(SQI)}+ {(0.1)×(WQI)}

The output of the Weighted Overlay or Scores were divided into 5 classes according to their natural breaks of 20, thus the 'Least Polluted' zones would have an index of 0-20, 'Less Polluted' would have 21-40, 'Fairly Polluted' would have 41-60, 'Polluted' would have 61-80 and lastly, 'Most Polluted' would have 81-100 values.

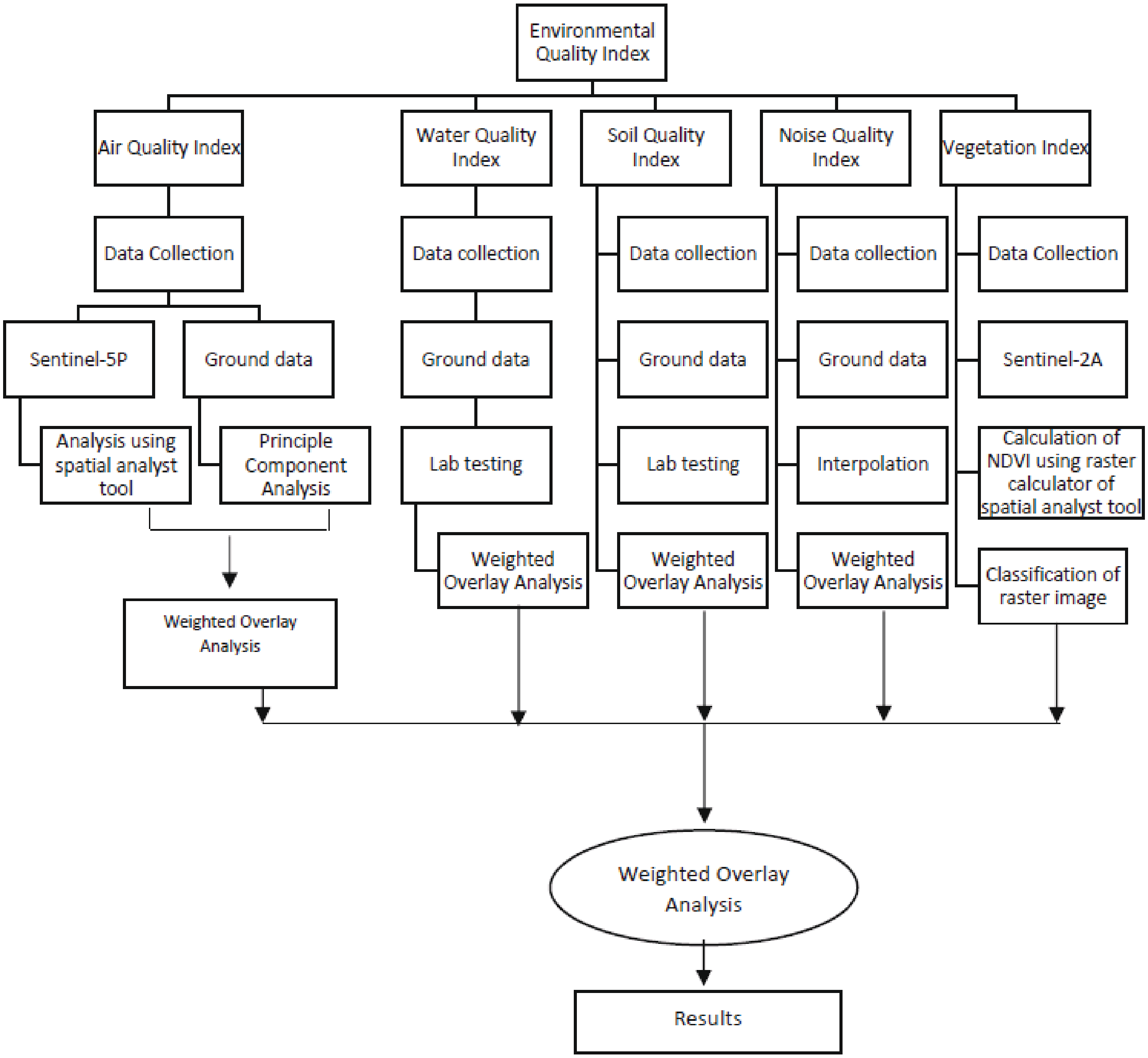

Figure 2: Workflow of the Methods Used on the Development of EQI

RESULTS

Air Quality Index

Using all the eight contaminants, the AQI was calculated and the raster surface for air quality were divided into six unique classes (Fig. 2). The result on AQI demonstrates a remarkable decline in air quality in the southwest zones of the city. The Zones 1, 2, 3, 4, and 5 in DSCC were identified as "Extremely Polluted." The Southeast part of the city was classified into two regions: "Lowest contaminated" and "Lesser contaminated," with zones 8 and 9 of DSCC. The zones 2, 4, and 5 of the DNCC were identified as "Extremely Polluted" since they correspond to zone 1 of the DSCC (Ahmed et al., 2022). However, other zones of DNCC indicate fewer areas with high pollution level.

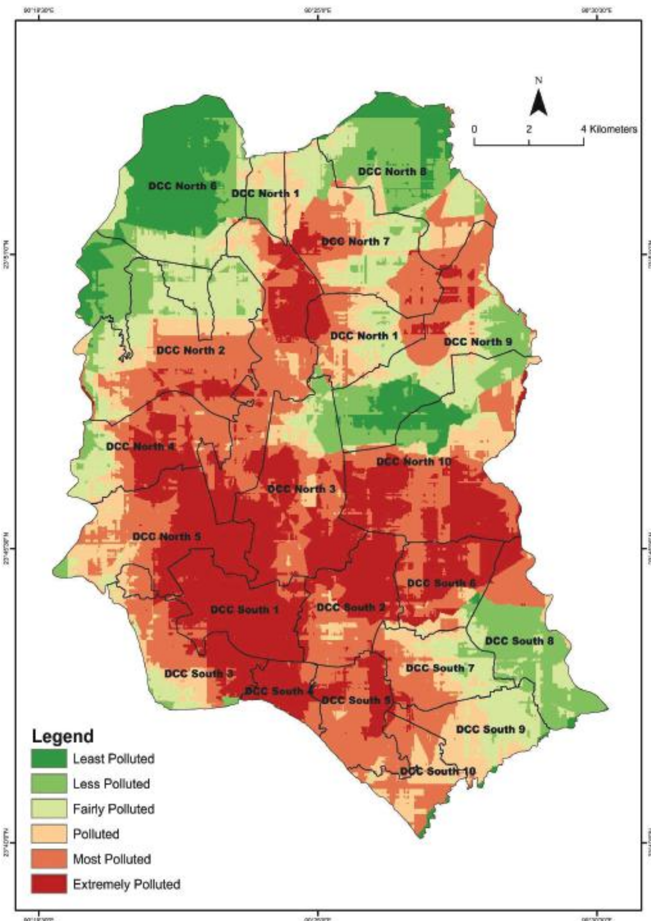

Figure 3: Output on the Status of Air Quality from Weighted Overlay Analysis for Dhaka City Using All the Eight Pollutants (Ahmed et al., 2022)

Water Quality Index

The WQI was derived as scores from the aforementioned equation (Formula 2) which is included in the method section. A map was generated based on based on the obtained scores for WQI (Fig. 4). The WQI scores are mentioned in descending order in the table 2.

Table 2: WQI Scores Obtained for Different Locations in the Study Area

Location	**WQI score**	**Location**	**WQI score**
North Zone 3(B)	14745.60	South Zone 9	37335.07
North Zone 9 & 10	8784.02	South Zone 5&10	9983.22
North Zone 7 & 8	8708.7	South Zone 7	9809.25
North Zone 6	8649.04	South Zone 1	7687.59
North Zone 3(A)	8598.01	South Zone 2	7027.12
North Zone 5	8411.87	South Zone 1(A)	6731.01
North Zone 1	7899.97	South Zone 3 & 4	4813.98
North Zone 4 & 2	6421.59		

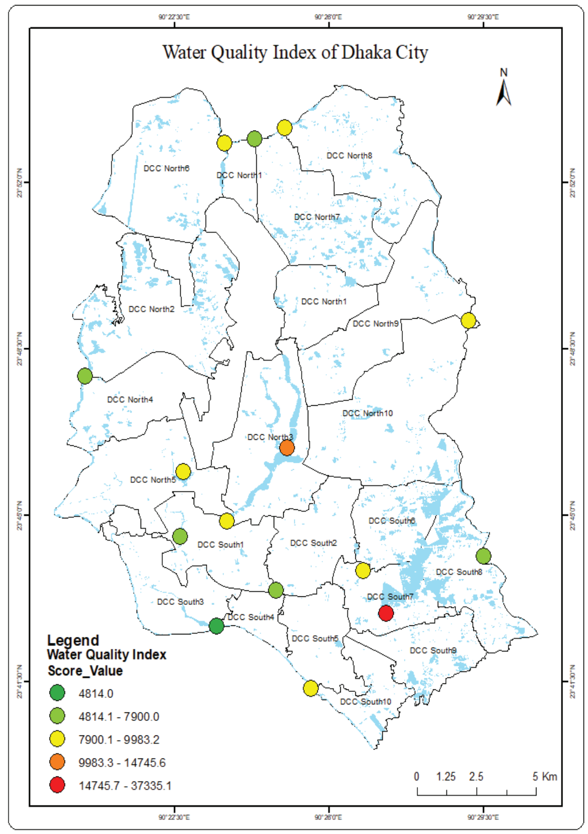

Figure 4: Water Quality of the Selected Sites in the Study Area

Soil Quality Index

The SQI was derived as scores from the equation (Formula 3) mentioned in the method section. According to the scores, a map was generated mapping the SQI score (Fig. 5). The SQI scores are mentioned in descending order in the table 3.

Table 3: SQI Scores Corresponding to the Sample Locations

Location	SQI score	Location	SQI score
North Zone 6	3040.15	North Zone 1	1077.91
South Zone 7	2915.49	North Zone 9 & 10	971.37
South Zone 6 & 8	1931.2	South Zone 5 & 10	966.71
North Zone 3(B)	1822.74	South Zone 3 & 4	721.81
South Zone 1(A)	1429.15	North Zone 7 & 8	339.43
South Zone 2	1424.13	North Zone 3(A)	328.68
North Zone 4 & 2	1228.46	South Zone 9	213.25
North Zone 5	1182.07		

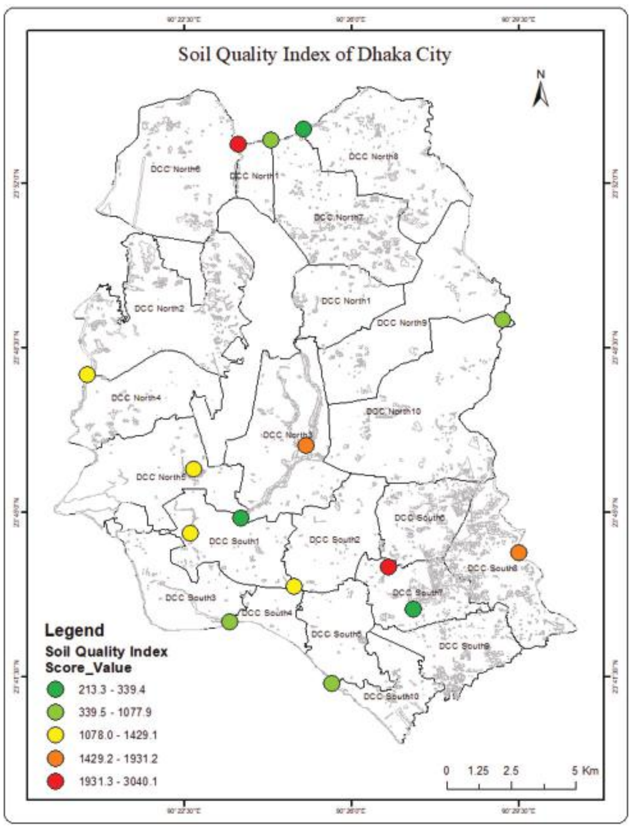

Figure 5: The Map Represents the Soil Quality of the Selected Sites in the Study Area

Noise Quality Index

The Quality Index for noise (Fig. 6) shows that the northern and southern parts have least and less noise pollution respectively than that of the central part of the city. The pollution level differs in areas accordingly, for commercial, industrial, and residential purposes. The southern and south-western part of the city showed the most noise pollution induced by commercial areas. As Motijheel is the main commercial area of Dhaka City, this area shows higher noise level compared to surrounding areas. Dhanmondi is a step ahead commercial area and Mirpur is a promising yet underrated commercial area. Both of the areas show higher values and somehow the northern part of Dhaka city exhibited less pollution. The eastern part showed moderate noise pollution. Sound level is higher in the western part and in the middle part in Mirpur and Tejgaon Industrial areas due to the placement of some small industries (i.e. garments and manufacturing industries).

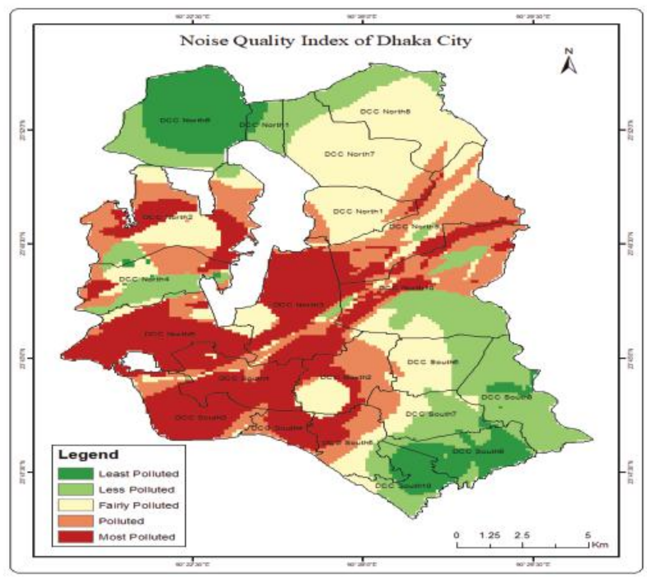

Figure 6: Spatial Distribution of the Categories of Values Obtained by Noise Quality Index

Vegetation Index

The Normal Difference Vegetation Index of the City is shown in (Fig. 7). The result shows that the vegetative areas are very low where the urban built-up land is high in the city. The whole Dhaka city is divided into 5 classes according to the result of NDVI. The first two classifications were identified as no vegetation areas and the last two classes were detected as vegetative areas along with a fifth classification of sparse vegetative area.

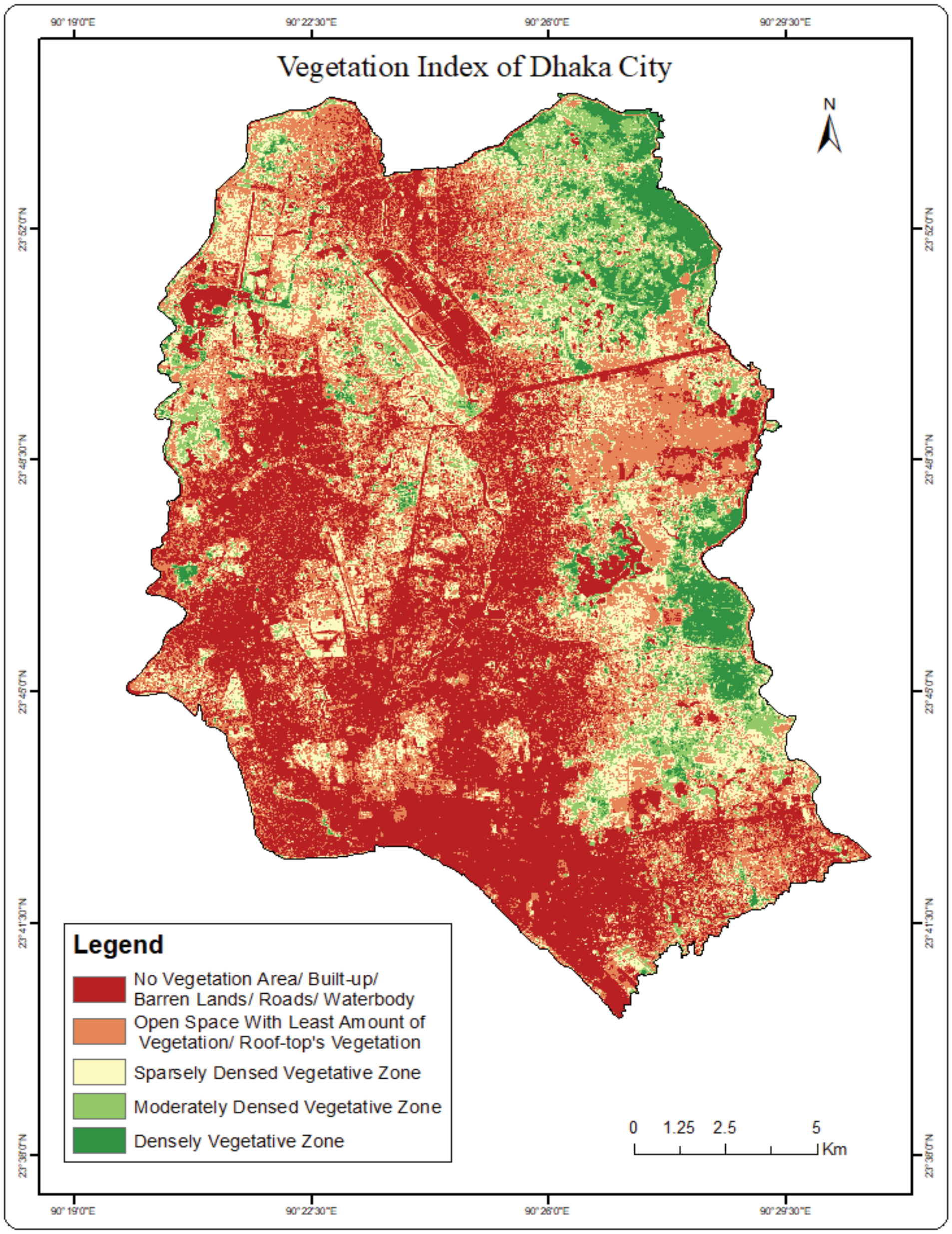

Figure 7: Spatial Distribution of the Values of Vegetation Index of Dhaka City Under Five Classes

Overall EQI

The overall outputs of EQI (Fig. 8) were presented in five different categories. The outputs were classified in intervals of geometric progression. The results show that more polluted the south-western part of Dhaka city has the highest index value and hence, indicates deteriorating environmental quality in that part of the city.

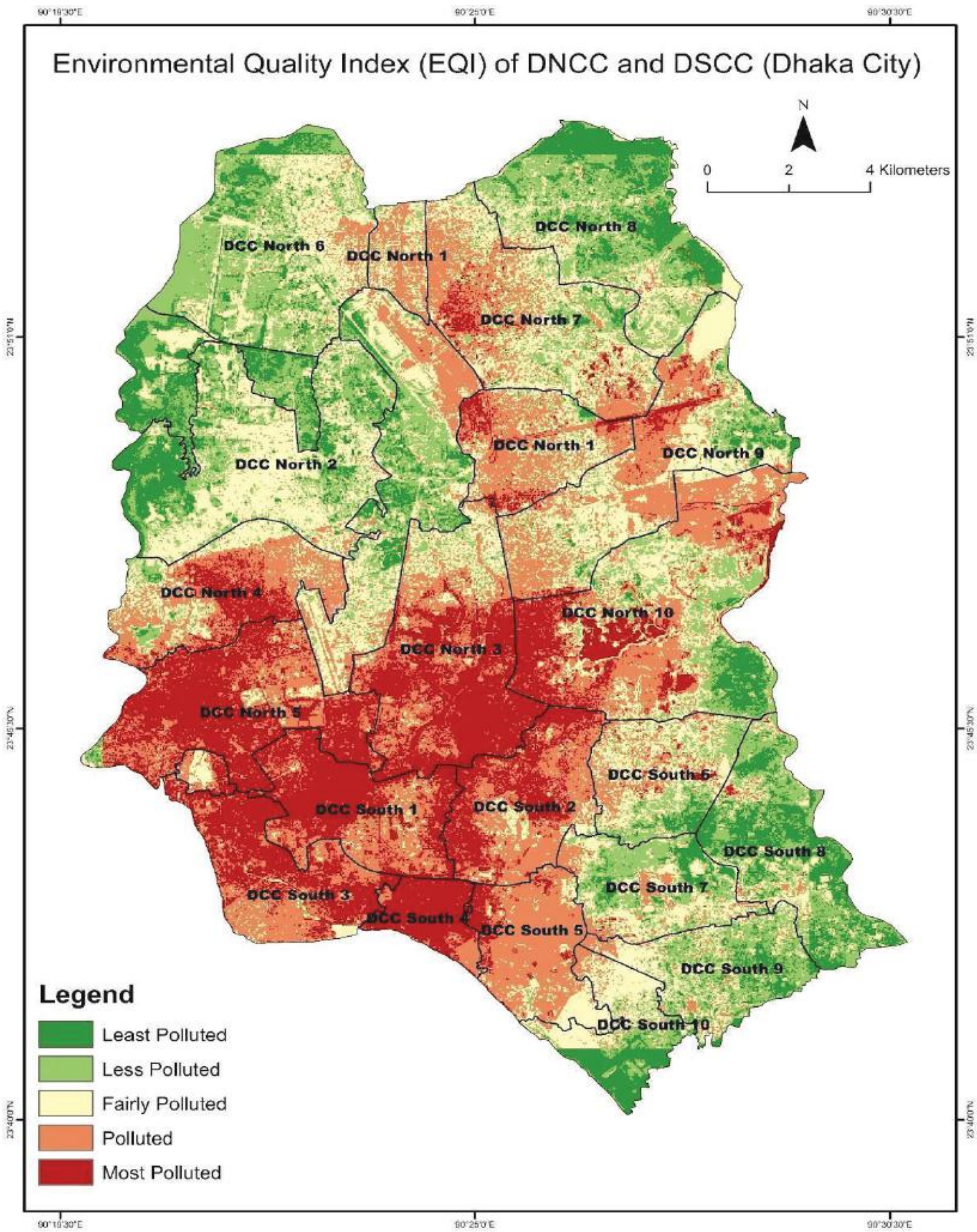

Figure 8: Environmental Quality of Dhaka City Presented in Five Categories from Least Polluted to Most Polluted Areas

DISCUSSION

The results of the study indicate that DCC North 3 and North 5 and DCC South 1 have the highest environmental pollution as shown in the map and graph (Fig. 8 and Fig. 9). The DCC North 3, 4, 5 and 10 have demonstrated high AQI value (Fig. 3), high NQI (Fig. 6) and low VI (Fig. 7). The study indicates that the contaminated areas caused by air pollution correspond the city's road networks thematically and are significantly more consistent with the settings, such as industrial sites in Tejgaon, parallel highway systems, and railway tracks. Mohammadpur, Hazaribag, Farmgate areas of these zones have 'Extremely Unhealthy' air. Noise level shows higher value in Motijhil commercial area compared to the surrounding areas as it is one of the commercial hubs of Dhaka city. Moreover, Mohammadpur, Dhanmondi and Tejgaon industrial areas show the most noise pollution due to the localization of residential, commercial and industrial activities.

Similarly, DCC North 8 has low EQI which can be attributed to low AQI and NQI with high VI. It is to be considered that these individual indices bear more weights among all. Uttarkhan in DCC North, where the air quality labeled as ‘least polluted’/or ‘less polluted’. The existence of water bodies in the north-eastern region of the city might reduces air pollution since, free water bodies consume excess pollutants and hence, the substances and the existence of water bodies are negatively correlated (Zhu and Zhou, 2019). According to NQI, Uttarakhan and its surrounding area shows ‘less polluted’ to ‘fairly polluted’ since, settlements of this area are sporadically distributed along wetlands. The DCC North 8 has low SQI score (Fig. 5) specifically for Pb (Lead) and Chromium (Cr) since, there are no heavy metal industries located in that area. Moreover, the area is near riverside and hence, pH value remains neutral in the area. In this zone, the SQI and WQI scores indicate lowest values (Fig. 4).

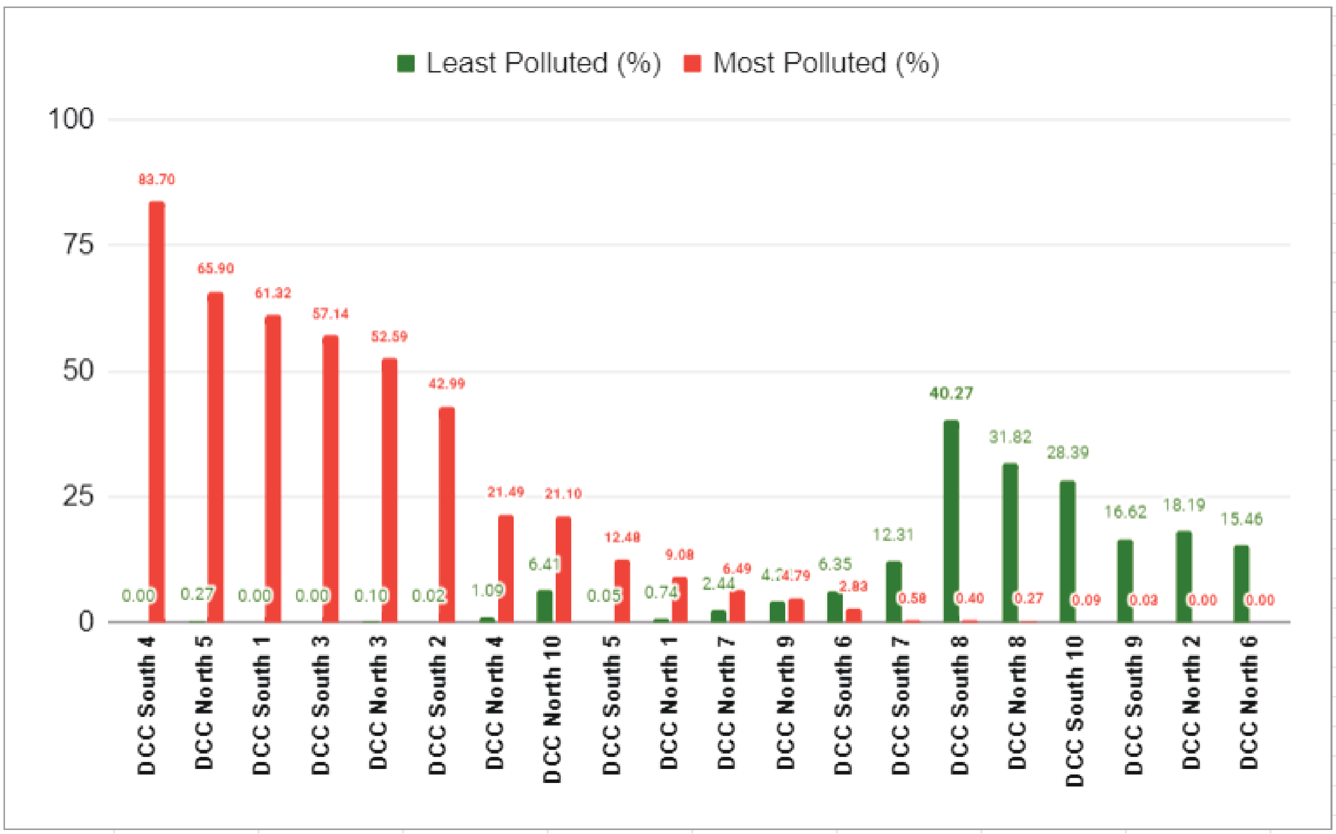

Figure 9: The Area (in percentage) Under Least Polluted and Most Polluted Status of DCC Zones

The DCC South 3 and 4 obtained high EQI that might be attributed to low VI score in the zones. The areas such as Bangshal, Lalbagh, Chawkbazar fall within these zones. Most of those areas are highly urbanized by highrise buildings. The presence of water bodies and open spaces is very less in these zones. On the other hand, DCC South 10 scored low EQI value which was attributed by low AQI and low NQI scores. However, these zones have low VI score since, DSCC is densely populated area. The DCC North 7 which includes Dakkhinkhan and DCC South 9 which includes Demra and Jatrabari areas, where the EQI values were quite low in respect of all the indices except VI. These zones contain a large amount of open spaces with grasses and rooftop vegetation, parks, nursery, road side vegetation, and healthy urban vegetation areas. Air quality of these areas are labeled as 'fairly polluted' to 'less polluted' due to the moderate presence of factories and industries in these areas, Consequently, the NQI score was also low in these zones.

CONCLUSION

The main aim of this research was to develop an Environmental Quality Index for the city of Dhaka utilizing data on the environmental factors that were determined to be most responsible for the severe deterioration of the environment's condition, including noise, air pollution, soil quality, and lack of vegetation. However, the purpose of developing the EQI for Dhaka city was to show the general pattern of environmental quality of the area so that it can identify the areas with least and most pollution. From the analysis and map interpretation, it can be inferred that, alarmingly, the condition of environmental quality in some areas of the city deteriorated more than the others. Nearly the environmental quality of the entire west part and west-central DSCC is highly deteriorated because of the massive use of transportation and vehicles, industrial zones, tanneries, densely populated urban households, and clustering of major industries. DNCC on the other hand, is still under expansion and has the presence of water bodies, farming and barren lands. Furthermore, Government headquarters and restricted area such as Cantonment are located here and hence, the air quality is lesser contaminated, especially in fringe zones, thus DNCC has less pollution than DSCC. The more expanding areas of both DSCC and DNCC have the slowest increase of pollution but with transportation routes being developed subsequently, the pollution rates may increase in a faster rate in near future. The noise level, vegetation cover, air, soil, and water quality at all points in the study area indicate the fact that the more commercialized areas of the city has the worst environmental conditions. The study demonstrates that a more distinct spatial pattern might be created utilizing the EQI that better matches the actual environment. The present study would be seminal work for the environmentalists, urban planners, and researchers to maintain the environmental quality of the city. Whether they are Ready Made Garment (RMG) producers or tiny tanneries, the authority must use more effort to monitor pollution levels and penalize offenders financially. Simple measures such as taxing polluters, funding eco-friendly projects, and improving accountability are crucial for the city in bringing about positive environmental change.

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