

AIR QUALITY TRENDS AND THEIR ASSOCIATION WITH URBANIZATION IN MAJOR CITIES IN BANGLADESH: A REMOTE SENSING AND GIS-BASED STATISTICAL STUDY

Saiful Alam^{1,a)}, Md Sabbir Hossain^{2,b)}, Khalidur Rahman^{2,c)*}, and Md. Miraj Hossain^{2,d)}

¹Department of Civil & Environmental Engineering, Shahjalal University of Science and Technology, Sylhet, Bangladesh

² Department of Statistics, Shahjalal University of Science and Technology, Sylhet, Bangladesh

a) saiful.ceesust@gmail.com b) bmsabbirhossainsakib@gmail.com c) khalid_sust@yahoo.com d) mirajsust52@gmail.com

* Corresponding author

Abstract

Rapid urbanization has led to significant land cover changes and air quality challenges in many regions, including Bangladesh. This study aims to investigate the relationship between urban land use changes and air quality and analyze trends in air quality in Sylhet, Dhaka, and Chittagong. Urbanization was estimated using Landsat imagery, while air pollutant concentrations (PM_{2.5}, PM₁₀, CO, O₃, NO₂, SO₂) from 2003 to 2021 were collected from ECMWF EAC4 reanalysis data. GIS and remote sensing techniques were employed to visualize. Statistical analyses including Pearson correlation were used to explore the relationship between urban land use changes and air quality, alongside Mann-Kendall tests, and Sen's slope for trend analysis. Sen's Slope analysis revealed significant and concerning trends in air pollutant concentrations in the cities of Sylhet, Chittagong, and Dhaka. Notably, in Dhaka, PM_{2.5} and PM₁₀ levels exhibited alarming annual increases of 1.64 micrograms per cubic meter and 2.30 micrograms per cubic meter, respectively, while CO levels surged by a staggering 10.72 parts per million (ppm) per year. Similarly, in Sylhet, CO levels showed a concerning annual increase of 3.06 ppm. The air quality variables exhibited high averages in Dhaka, medium averages in Sylhet, and low averages in Chittagong. Chittagong had high levels of Ozone (O₃), while Sylhet had low levels. Moreover, the strong positive correlations (above 0.90) between urbanization and air pollutant levels emphasize the profound impact of urban expansion on worsening air quality in these Bangladeshi cities. The rate of urbanization was higher in Chittagong but significantly lower in Sylhet. The percentage of vegetation in Dhaka was relatively lower compared to other cities. Vegetation and water bodies were decreasing day by day. Findings from this study reveal alarming trends in air pollutant concentrations in major Bangladeshi cities, indicating a significant decline in air quality.

Keywords

Remote Sensing; Air Quality; Landsat; LULC

1. Introduction

Urbanization and the expansion of cities have traditionally been seen as significant indicators of a nation's economic advancement and progress. In recent decades, urban areas have been rapidly growing alongside population increases. This urbanization process has brought about substantial alterations in the land cover and landscape of the affected regions [1]. Over time, the evolution of a city and its construction activities significantly alter the topography of the area. These modifications exert an influence on the rate at which geomorphic processes like weathering and erosion occur [2].

As the population continues to grow, effective urban planning becomes increasingly essential to ensure long-term environmental sustainability in a specific region [3]. Towns and cities typically expand following the topography of the land, which adapts to meet the demands of planning and construction [4]. One of the foremost challenges confronting urban areas worldwide is the issue of poor air quality. Given that more than half of the world's population now lives in metropolitan regions, it is critical to take into account how poor air quality affects people's health [5]. The growth of cities, with their increased size and population density, has led to heightened energy use, industrial emissions, and automobile traffic, all of which can detrimentally affect air quality [6].

Particulate matter (PM), a prominent and regulated air pollutant, is a significant concern. While primary sources of air pollution are well-documented, there are also secondary sources of particle pollution resulting from chemical interactions in the lower atmosphere. When assessing air pollution in a specific area, proximity to sources such as factories and power stations, as well as traffic, all of which are byproducts of urbanization, must be considered. [7]. The World Health Organization (WHO) has underscored that regular contact with PM_{2.5} is associated with a higher risk of lung cancer, cardiovascular diseases, and respiratory ailments. The concentration and composition of particulate matter (PM) can vary by location, with the most significant disparities typically observed in densely populated urban areas [8].

Over the past few decades, developing countries have experienced a shift from rural to urban land use due to the process of urbanization [9]. The increasing socioeconomic demands and population growth exert substantial pressure on land use and land cover [10]. Remote sensing and Geographic Information Systems (GIS) serve as robust tools for acquiring fast and accurate data on the geographic distribution of LULC changes over extensive areas (Carlson & Sanchez-Azofeifa, 1999). As the population continues to rise, sources of air pollution such as industries, motorized vehicles, and urban settlements are becoming more concentrated in urban areas, particularly in major metropolitan cities. The prevailing indicators of air quality suggest that the overall situation has already reached alarming levels. In recent years, a staggering 97 percent of cities worldwide have failed to meet recommended air quality standards [15].

In recent decades, the rapid urbanization observed in developing countries, such as Bangladesh, has resulted in substantial changes in landscape patterns and land cover in these regions (Huang et al., 2013). This urbanization trend has been particularly pronounced in several major districts of Bangladesh, resulting in notable alterations in land use and land cover (LULC). These changes have had implications for variations in land surface temperature (LST) and the intensity of the urban heat island (UHI) effect. However, our understanding of the impact of rapid urbanization on UHI intensity during the winter dry period in these districts remains limited. Several studies (*2020 Environmental Performance Index / Yale Center for Environmental Law & Policy*, 2020.) have identified a positive association between changes in land use patterns and variations in air quality.

Air quality is a critical environmental and public health concern, especially in rapidly urbanizing countries like Bangladesh. The quality of air in urban areas is influenced by various factors, including industrial emissions, vehicular traffic, and changes in land use due to urbanization. Poor air quality poses significant health risks to the population, with detrimental effects on respiratory and cardiovascular health. Understanding the trends in air quality and their association with urbanization is crucial for addressing public health challenges and guiding urban planning and policy decisions. Bangladesh has experienced rapid urbanization in recent decades, with a significant increase in population density and industrial activities in urban areas [21]. This urban growth has led to changes in land use and land cover patterns, resulting in altered atmospheric conditions and air quality[22]. Urbanization contributes to elevated levels of air pollutants such as carbon monoxide (CO), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), particulate matter with a diameter of 2.5 micrometers (PM_{2.5}), and particulate matter with a diameter of 10 micrometers (PM₁₀) [23]. Numerous health issues, such as cardiovascular disorders, respiratory illnesses, and even early mortality, have been connected to these pollutants [24]. Monitoring air quality and assessing the trends in pollutant concentrations are essential for developing effective air quality management strategies. Understanding the relationship between urbanization and air quality can help policymakers make informed decisions to mitigate air pollution in rapidly growing urban centers.

This study aims to investigate air quality index trends (CO, SO₂, NO₂, PM_{2.5}, and PM₁₀) in major urban areas of Bangladesh over a specific period and explore their relationship with urbanization levels. Bangladesh facing rapid and unplanned urbanization and some of the world's poorest air quality, this research seeks to fill a critical knowledge gap, offering valuable insights to policymakers striving for healthier urbanization and improved environmental performance in the country's major cities.

2. Materials and Methods

2.1 Study Area

Bangladesh is a Southeast Asian nation located between India and Myanmar. Its geographical coordinates are 20°34' – 26°38'N latitude and 88°01'–92°41'E longitude. Three major cities were used for this research, namely

Dhaka, Sylhet, and Chittagong. Dhaka City Corporation and Chittagong City Corporation were utilized. Due to the small area of Sylhet City Corporation, Sylhet Sadar Upazila was considered.

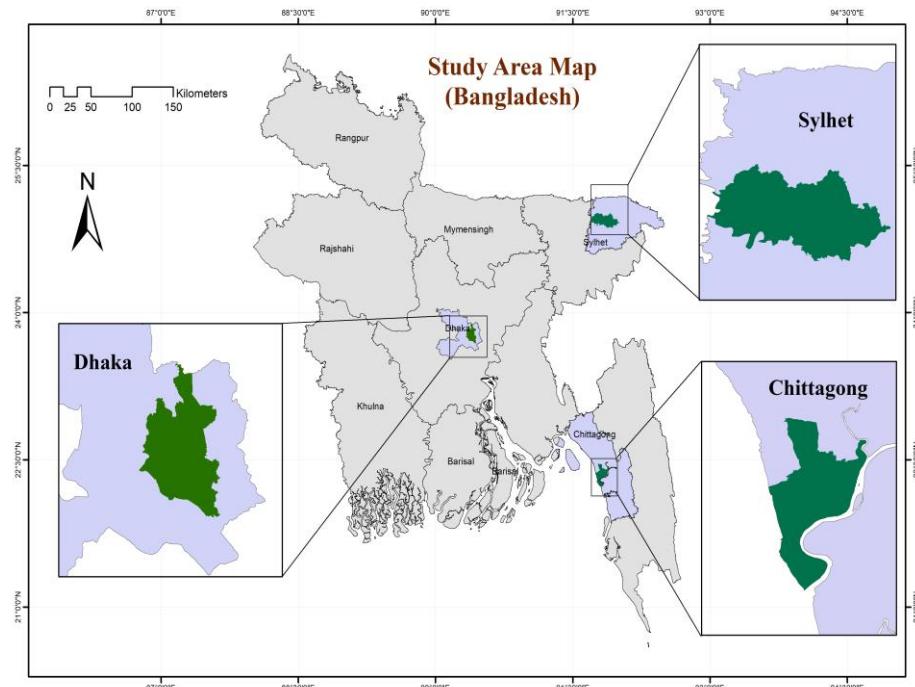


Figure 1: Area of Interest Map (Map has been created using ArcMap 10.8)

2.2 Data Collection

To estimate urban expansion, cloud-free dry season Landsat data were collected from the USGS (United States Geological Survey) source from 2000 to 2022. All the imagery was readily available for download and already georeferenced in the UTM (Universal Transverse Mercator) projection system. Landsat 4-5 TM C2 L1 images were downloaded for data before 2014, and Landsat 8-9 OLI/TIRS C2 L1 images were used for data after 2014. Data were collected at 5-year intervals to check for differences in vegetation and urbanization. The EAC4 (ECMWF Atmospheric Composition Reanalysis 4) global reanalysis dataset produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) from the Copernicus Atmosphere Monitoring Service (CAMS) was collected for 24-hour ambient concentrations of air pollutants (PM_{2.5}, PM₁₀, CO, O₃, NO₂, and SO₂) for the period from January 2003 to December 2020.

2.3 Methodology

2.3.1 Mann-Kendall Test and Sen's Slope Analysis

To rigorously analyze trends in air quality parameters over time, the Mann-Kendall (M-K) test and Sen's Slope analysis were employed. The Mann-Kendall test is a non-parametric method used to identify monotonic trends in time series data, assessing whether a trend is statistically significant. Sen's Slope analysis complements this by estimating the magnitude of the trend, providing a robust measure of the slope even in the presence of outliers. Together, these methods offer a comprehensive approach to trend detection and analysis in environmental data.

2.3.1 Land use and land cover change detection

TM, ETM+, and OLI are the satellites from which the images were collected. All the spectral images from the Landsat satellite. All spectral bands were stacked together to get a single image by using the band composition tool from ArcMap 10.8. The study area was snipped from the composite image. The ArcMap 10.8 program was used to classify the land cover using the supervised classification approach and maximum likelihood methodology. The chance that a pixel member of a particular class is the foundation of this method. The fundamental theory presupposes that all classes have identical probabilities and that input bands have normal distributions. The post-

classification change detection technique in GIS and a supervised classification algorithm were both applied. One of the most widely used techniques for supervised classification is the maximum likelihood algorithm.

3. Results and Discussions

3.1 Trend Analysis

Sen's Slope analysis and the Mann-Kendall(M-K) Test showed substantial upward trends in a number of air quality indices in Sylhet, Dhaka, and Chittagong, pointing to a deteriorating state of air quality. Significant increases in CO and PM₁₀ were observed in Sylhet, while dangerous increases in CO, PM_{2.5}, and PM₁₀ were seen in Dhaka. Pollution levels increased in Chittagong as well, however CO did not exhibit a significant trend. These results highlight how urgently these cities need to implement effective pollution control and air quality management strategies.

Table 1: MK Trend Analysis of Air Quality Data

Area	Chittagong			Dhaka			Sylhet			
	M-K test	Sen's Slope	Kendall's τ	p-value	Sen's Slope	Kendall's τ	p-value	Sen's Slope	Kendall's τ	p-value
PM _{2.5}	0.22020	0.221	0.221	<0.183	1.6385	0.579	<0.01	0.6277	0.579	<0.01
PM ₁₀	0.31945	0.232	0.232	<0.163	2.3004	0.6	<0.01	0.9083	0.6	<0.01
O ₃	0.63622	0.611	0.611	<0.01	0.1294	0.474	0.05	0.2347	0.474	<0.01
CO	-0.83175	-0.095	-0.095	0.581	10.7218	0.326	<0.01	3.0582	0.326	0.04
NO ₂	0.05162	0.495	0.495	<0.01	0.4825	0.821	<0.01	0.2657	0.821	<0.01
SO ₂	0.06241	0.716	0.716	<0.01	0.4129	0.937	<0.01	0.2235	0.937	<0.01

The trend analysis of air quality parameters from 2003 to 2022 revealed distinct patterns across three major cities: Sylhet, Dhaka, and Chittagong. In Sylhet, PM₁₀ and PM_{2.5} had decreased in the early years but began a significant upward trend around 2018, peaking in 2021, indicating worsening particulate matter pollution. Dhaka exhibited a consistent rise in PM₁₀ and PM_{2.5}, with fluctuations but a clear upward trend in recent years, highlighting persistent fine particulate matter pollution.

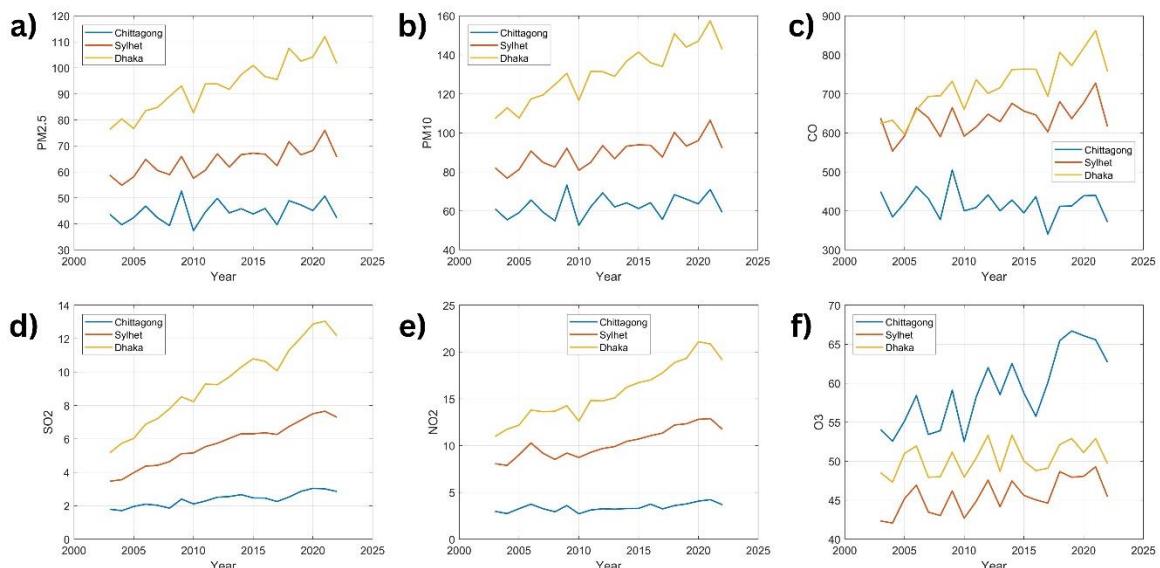


Figure 2: Trend Analysis of Air Quality Data: a) PM_{2.5}, b) PM₁₀, c) CO, d) SO₂, e) NO₂, f) O₃. Yellow line for Dhaka, Red line for Sylhet, and Blue line for Chittagong.

In Chittagong, PM₁₀ and PM_{2.5} showed a gradual decline until 2010, followed by stable but slightly fluctuating levels. Ozone (O₃) levels consistently increased in all three cities, with the highest concentrations observed in Chittagong. Carbon monoxide (CO) initially fluctuated in Sylhet and Dhaka, stabilizing in later years, while Chittagong saw a moderate rise after an initial decline. Nitrogen dioxide (NO₂) consistently increased across all cities, indicating ongoing pollution challenges. Sulfur dioxide (SO₂) showed a continuous decline until 2010, followed by stabilization and minor fluctuations in all cities.

Overall, the levels of these pollutants were highest in Dhaka, moderate in Sylhet, and lowest in Chittagong, with none of the pollutants within the safe limits set by the Department of Environment (DoE). These trends underscored the importance of continuous air quality monitoring and targeted interventions to address the increasing pollution levels.

3.2 Land Use and Land Cover (LULC) Change

Landsat satellite images were used to detect land use and land cover changes across three main classifications: vegetation, built-up areas, and water bodies, with an additional category of barren land for Sylhet.

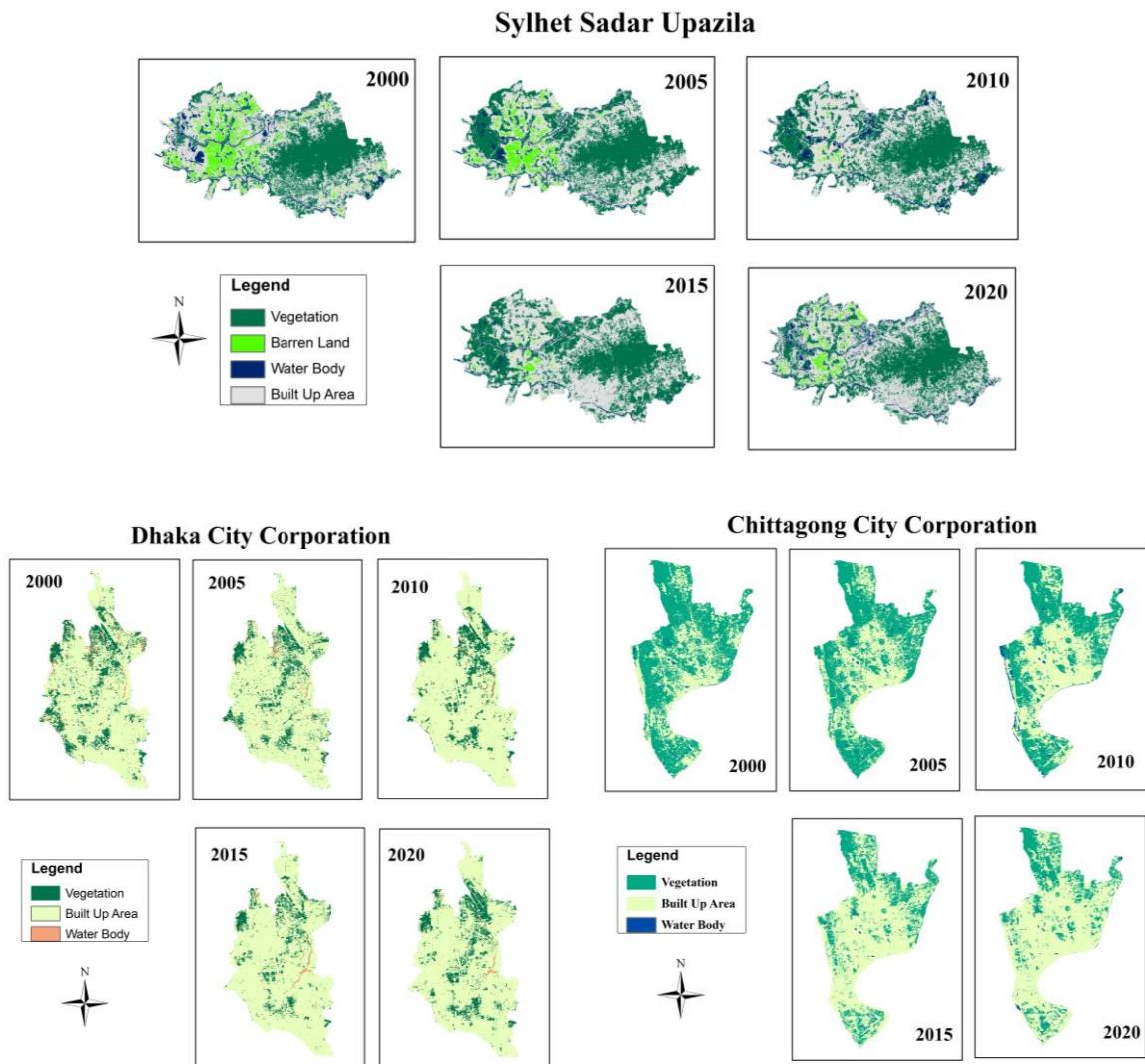


Figure 3: Land Use and Land Cover Map for Sylhet (Upper), Dhaka (Left), and Chittagong (Right) for 2000, 2005, 2010, 2015, and 2020

Table 2: Statistics of LULC Map

Area	Sylhet			Dhaka			Chittagong			
	Year	Vegetation (%)	Built Up Area (%)	Water Body (%)	Vegetation (%)	Built Up Area (%)	Water Body (%)	Vegetation (%)	Built Up Area (%)	Water Body (%)
Sylhet	2000	48.75	46.9	4.35	18.66	78.16	3.18	60.76	37.89	1.35
Sylhet	2005	49.94	47.68	2.38	16.47	81.42	2.1	55.83	42.9	1.42

2010	49.81	48.02	2.17	14.97	83.6	1.43	46	50.88	2.76
2015	49.6	48.37	2.03	11.5	87.13	1.36	27.76	71.54	0.84
2020	48.83	49.19	1.98	7.53	91.04	1.43	23.67	75.37	1.1

The analysis showed that urbanization progressed more rapidly in Chittagong compared to Sylhet. Between 2000 and the latest assessment, built-up areas increased significantly in all cities, with the most dramatic rise in Dhaka. Meanwhile, the percentage of vegetation, particularly in Dhaka, was lower compared to the other cities, and both water bodies and vegetation consistently declined over time.

3.3 Correlation with Urbanization and Air Quality

The analysis of urbanization and air quality in Sylhet, Dhaka, and Chittagong highlighted key trends. In Sylhet, urbanization was moderately positively correlated with particulate matter (PM_{10} and $PM_{2.5}$), indicating that increased urbanization was linked to higher levels of these pollutants. Dhaka showed a strong positive correlation between urbanization and particulate matter, suggesting a robust association with elevated pollution levels. Chittagong also exhibited a moderate positive correlation with particulate matter, similar to Sylhet and Dhaka. Correlations with other air quality indices like ozone, carbon monoxide, nitrogen dioxide, and sulfur dioxide were generally weak across all cities, underscoring the need for focused air quality management strategies.

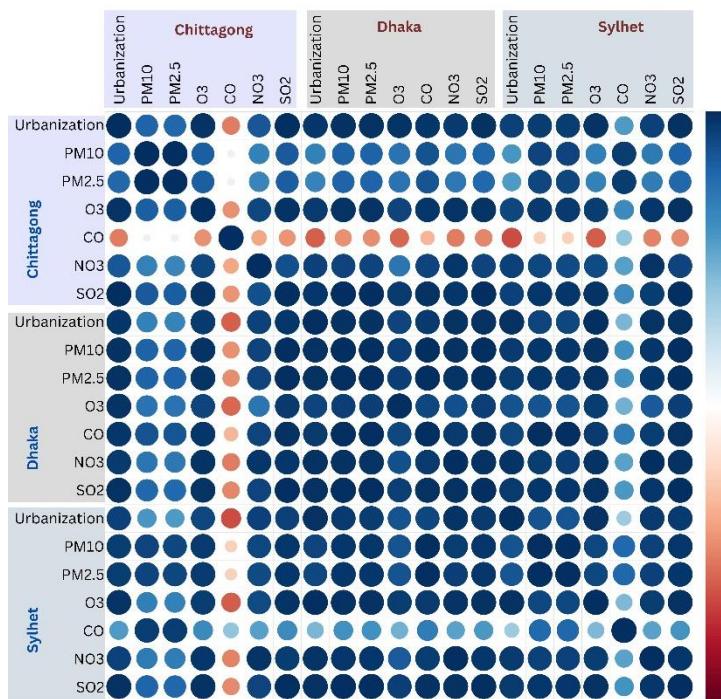


Figure 4: Correlation matrix between Urbanization and Air Quality Data

4. Conclusion

The following conclusions were observed: Air quality variables in all cities exhibited an increasing trend with some fluctuations. In 2022, reductions in concentration levels were noted, likely due to decreased vehicle use and lockdown measures during the COVID-19 pandemic. The Sen's Slope analysis revealed an increasing rate of concentration for all variables, with a significantly higher increase observed in Dhaka. High average levels were recorded in Dhaka, medium averages in Sylhet, and low averages in Chittagong, though Chittagong showed high levels of Ozone (O_3) while Sylhet had low levels. Urbanization rates were higher in Chittagong and lower in Sylhet, while Dhaka had a lower percentage of vegetation compared to other cities. Declines in both water bodies and vegetation were noted. A strong positive correlation was found between urbanization and particulate matter (PM_{10} and $PM_{2.5}$) in Dhaka, Sylhet, and Chittagong, but the correlation with other AQI components, including O_3 ,

CO, NO₂, and SO₂, was weak. cities can bolster green spaces, encourage sustainable urban design techniques, and impose stronger automobile emission laws to lessen the negative effects of urbanization on air quality.

5. Further research

Future research could expand on the current findings by exploring the impact of urbanization on water quality in the Sylhet region. Given the extensive body of literature addressing water quality [25–28], a focused study examining how urban expansion and associated land-use changes affect water resources in this area would offer valuable insights. Additionally, integrating water quality indicators with land cover dynamics using remote sensing and GIS could reveal spatial correlations, providing a more comprehensive understanding of urbanization's environmental impact. These findings could guide sustainable urban planning efforts, ensuring the protection of vital water resources as urbanization continues to intensify in Bangladesh.

6. Acknowledgement

All praises are due to Almighty Allah for enabling me to successfully complete and submit this work, and we extend our gratitude to the SUST Research Center for their support and funding under the project PS/2022/1/35.

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