TEMPORAL ANALYSIS OF VEGETATION COVER IN RELATION TO PM2.5 AND LAND SURFACE TEMPERATURE USING RS AND GIS TECHNIQUES: A CASE STUDY OF DHAKA CITY

Muhtasim Shahriar Mostafa*[1], Md. Shahariar Kabir[2] and Ahmed Shakik[3]

[1] *Postgraduate Student, Department of Civil Engineering, Bangladesh University of Engineering & Technology (BUET),Dhaka, Bangladesh, e-mail: 1601028.shahriar@gmail.com*
[1] *Graduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET),Khulna-9203, Bangladesh, e-mail: 1601028.shahriar@gmail.com*
[2] *Graduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna-9203, Bangladesh, e-mail: kabir.kuetce17@gmail.com*
[3] *Lecturer, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna-9203, Bangladesh, e-mail: shakik@ce.kuet.ac.bd*

ABSTRACT

The purpose of this research is to determine the temporal relationship between plant cover, land surface temperature, and air pollution in Dhaka. Land surface temperature (LST) and its association with the normalized difference vegetation index (NDVI) play an important role in environmental research. The goal of this work was to extract Dhaka City's LST and investigate its temporal correlations with vegetation area. Besides this study also aims to find out relationship between vegetation cover and air pollution. Of all regularly measured air pollutants, PM2.5 is typically recognized as the pollutant with the greatest health impact. It can arise from a variety of natural and man-made sources. Combustion (from car engines, industries, brick kilns, wood and coal burning) and other pollutants interacting in the atmosphere are common sources of PM. Landsat 8 satellite images were obtained from the USGS Earth Explorer website for NDVI and LST research. Land surface temperature and the Normalized difference vegetation index were obtained using the ArcGIS cloud computing platform. Particulate matter (PM2.5) statistics were gathered from the Dhaka-US consulate in Bangladesh from 2016 to 2022. The result showed inverse relationship of land surface temperature and air pollution data with Vegetation cover. The vegetation has decreased significantly from 2016 to 2022. It is noticeable that with the decrease in vegetation area, land surface temperature and PM2.5 have increased. It is also noticed that the winter season has experienced higher value of PM2.5 than summer season and this amount is increasing over time.

Keywords: *Air Pollution, GIS, LST, NDVI, PM2.5, RS*

1. INTRODUCTION

Dhaka, Bangladesh, is known for its heavy pollution and lack of green places due to its urbanization and pollution. This city is considered extremely urbanized (Dewan et al., 2021). Over the past 20 years, Dhaka has warmed by over 3 degrees Celsius; this development can be attributed to a number of factors, including the city's growing urbanization and loss of green area. This is important because the world community aims to limit the increase in temperature to no more than 1.5 degrees Celsius (Molla, 2021). Dhaka has only 8% of this kind of space, compared to the UNEP's (United Nations Environment Programme) recommendations that state that a sustainable urban region must include at least 25% open space (Islam et al., 2015). The Normalized Difference Vegetation Index (NDVI), which has a range of -1 to +1, is one of the metrics most frequently used to assess the growth and cover of vegetation and quantify how rough the land surface is present (Sun et al., 2011) as a result of a positive relationship with plant coverage attributes (Vlassova et al., 2014).

Land use and land cover (LULC) are changing as a result of high population density and quick infrastructure development (Haque & Basak, 2017). The flow of heat and energy between land surfaces and the atmosphere depends critically on the temperature of the earth's surface, or land surface temperature (LST) (Bechtel et al., 2015). As a result, LST may be considered a surface characteristic of the land and, as such, a crucial element in the interaction between the land and atmosphere. Depending on the kind of plant, the amount of water on the surface, the kind of soil, the terrain, and the weather, LST varies throughout time and space (Findell et al., 2007). Remote sensing allows for continuous tracking of changes on the planet's surface and change detection analysis. Furthermore, vegetation identification, species- or kind-based distinction, and condition assessment are all made possible by remote sensing. NDVI is a crucial component of LST derivation and is typically used in any research pertaining to LST (Smith & Choudhury, 1990). Since NDVI is directly used to calculate land surface emissions, it is crucial to LST estimation (Sobrino et al., 2004). Seasonal fluctuations have a significant influence on the NDVI because it is a vegetation index (Guha & Govil, 2020). As a result, the seasons also control LST.

PM2.5 is a type of air pollutant composed of airborne droplets or particles measuring 2.5 microns or smaller in diameter. (Fan et al., 2015). Because of rapid industrialization and burning fossil fuels, PM2.5 levels rose quickly in many parts of the world, which was very bad for people's health and the environment (Hajiloo et al., 2018). In Bangladesh, ambient PM2.5 is now one of the major risk factors influencing cardiovascular morbidity and mortality (Islam et al., 2017). In Bangladesh, the problem of air pollution is mostly found in the country's cities (Hossain et al., 2019). Of all the big cities, Dhaka, which is the capital of Bangladesh and one of the world's most densely populated areas, has the worst air pollution. Dhaka's present population is around 21.7 million in 2021, a 3.5 percent rise from 2020 (Dhaka, Bangladesh Population 1950-2019, 2019). The third-most polluted megacity is Dhaka, according to rankings. (Rahman et al., 2019) and the capital with the second-worst air quality pollution (World Most Polluted Cities in 2018 - PM2.5 Ranking | AirVisual, 2018). A recent study by Tasmin et al. (2019) found a link between short-term exposure to PM and schoolchildren in Dhaka having worse lung function. The World Bank says that the economic costs of air pollution in Dhaka because of illness and death are about US$ 200–800 million per year (Islam et al., 2015).

There were a number of studies in recent years (Md. Kawser Alam & Majed, 2022; Hossain et al., 2022; Faisal et al., 2021; Imran et al., 2021) that looked into the NDVI and LST in the city of Dhaka. In addition, there were other studies (Rahman et al., 2021; Gupta et al., 2020; Rahman et al., 2020; Hossain, 2019; Rana et al., 2016) that investigated the concentration of PM2.5 pollutants. Nevertheless, no recent research was found in this area, despite several prior studies finding the use of GIS (Geographical Information System) and RS (Remote Sensing) techniques to the link between NDVI, LST, and PM2.5. The objectives of this study are (1) to determine the temporal changes in LST, vegetation cover and PM2.5 concentrations Dhaka city during the period of 2016-2022 (2) to develop a relation between vegetation cover, LST and PM2.5 concentrations in Dhaka city during the period of 2016-2022.

2. METHODOLOGY

The sequential process for of this study includes downloading of satellite images, analysis of satellite images using ArcGIS tools to determine NDVI and LST , reclassification of study area according to NDVI and LST, collection of PM2.5 historical data and finally invetigation and finding out correlation of vegetation cover with LST and PM2.5 data.

The process of this study is shown below in Figure 1:

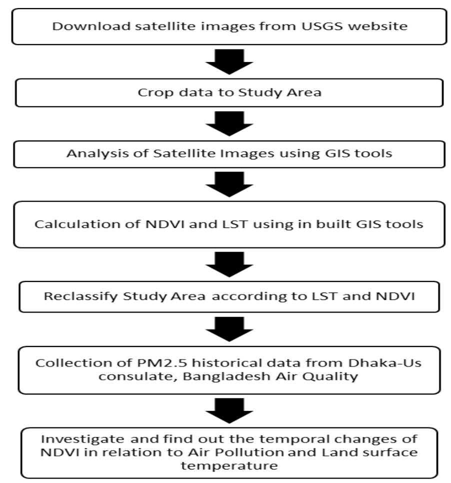

Figure 1: Flow Chart Showing Steps of the study

2.1 Selection of Study Area

Dhaka is the capital of Bangladesh. It is located at the center of the country at 23°42′N 90°22′E, on the eastern banks of the Buriganga River. Dhaka city is surrounded by the districts named Gazipur, Tangail, Munshiganj, Rajbari, Narayanganj and Manikganj. It is one of the most densely populated cities having a population about 22.4 million as of 2022. Besides the city is facing greater urbanization in recent years. But Dhaka is among the world's top five cities with the most poisonous air, reported by US-based organizations. Air quality in Dhaka is getting very poor and unhealthy day by day. Thus, air pollution has become a major concern now a days. Besides the temperature in Dhaka city is also on the rise. Greater urbanization, deforestation, unorganized constructional activities, uncontrolled emissions of fumes and other air pollutants to the atmosphere from industries and faulty vehicles are the main reasons behind this higher rate of pollution in Dhaka city. Among all the criteria pollutants, PM2.5 is found to be the deadliest pollutants playing a major role behind this higher pollution. This study was carried out to find out whether there is any effect of vegetation area or urbanization on PM2.5 concentration or not and also to find out the effect on surface temperature. Figure 2 below represents the location of the study area.

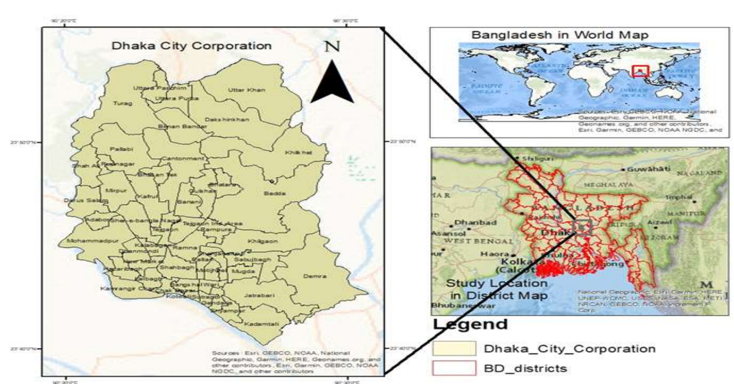

Figure 2: Study area “Dhaka City Corporation”

2.2 Data Source and Collection

The Land Surface Temperature and Vegetation cover are determined by analysing Landsat 8 satellite images collected from USGS Earth Explorer website using ArcGIS tools. Landsat images are collected for the months May and December to know the seasonal variation. Daily data of PM2.5 are collected from Dhaka-US consulate, Bangladesh Air Quality Data measured from 2016 to 2022.

Table 1: Data and Data Source

Description	Type of Data	Source	Frequency	Analysis Sofware
Air Quality	PM2.5 concentration	Dhaka-US consulate, Bangladesh Air Quality Data	Daily	Excel
Normalized Difference Vegetation Index	Landsat 8 Satellite Image (Level 1 Collection Level 2)	USGS Earth Explorer	Monthly	ArcGIS
Land Surface Temperature	Landsat 8 Satellite Image (Level 1 Collection Level 2)	USGS Earth Explorer	Monthly	ArcGIS

2.3 Normalized Differenced Vegetation Index and Land Surface Temperature

A recent study in south central China investigate that vegetation cover has a significant effect on PM2.5 concentrations (Wei et al., 2022). Several studies have been carried out to find out the effect of green spaces in improving air quality and reducing temperatures up to 2°C (Diener & Mudu, 2021). Another study was found out to establish a relationship between LST and PM2.5 ranging from 2001 to 2016 (Song et al., 2018). According to a different study, increased PM2.5 can lower the amount of solar radiation that reaches the ground by reflecting more of it back into space. However, PM2.5 may also lessen latent and long-wave surface heat.

Landsat 8 images were collected from USGS Earth Explorer website and then study area was clipped from the images using Arc tools in GIS environment. To calculate land surface temperature at first Band 10 was used to find out Top of Atmosphere (TOA) spectral radiance using Eq. (1) and the Brightness Temperature (BT) was calculated according to Eq. (2).

$$TOA = M_L \times Q_{cal} + A_L - 0.29 \quad \textbf{(1)}$$

$$BT = \left(\frac{k_2}{ln\left(\frac{k_1}{TOA}+1\right)}\right) - 273.15 \quad \textbf{(2)}$$

Here ML denotes multi-band 10 radiance value amd Qcal means the Band 10 radiance add value for LANDSAT 8 image. Besides, k1 and k2 used in Eq. (2) are the constants. Then Normalized Difference Vegetation Index (NDVI) for landsat 8 images were calculated using Band 4 and Band 5, where Band 4 and Band 5 represents Red Light and Near Infared Radiation (NIR) respectively. The value for normalized difference vegetation index ranges from -1 to +1. The green color form the analysis represents vegetation area, yellow color represents bare land and blue color shows the water body. The more the value get closure to +1, the more will be the vegetaion area. Features other than vegetation lies between -1 to 0, bare land lies between 0 to 0.15 and vegetation ranges from 0.15 to 0.7 or more. The NDVI for the study were calculated using Eq. (3).

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \quad \textbf{(3)}$$

By analyzing Landsat satellite images using raster calculator for NDVI, raster data were produced which privide the maximum and minimum value of NDVI. These values were then used to calculate the vegetation portion (Pv) from Eq. (4) and emissivity from Eq. (5)

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad \text{...... } \mathbf{(4)}$$

$$\varepsilon = 0.004 \times P_v + 0.986 \quad \text{...... } \mathbf{(5)}$$

Finally, following Eq. (**6**) was used to calculate the Land Surface Temperature for study area.

$$LST = \left(\frac{BT}{\left(1 + \left(\frac{0.00115 \times BT}{1.4388}\right) \times ln(\varepsilon)\right)}\right) \quad \text{...... } \mathbf{(6)}$$

3. RESULTS & DISCUSSION

3.1 Temporal Distribution of PM 2.5

Historical PM2.5 concentration data were obtained from the US Consulate in Dhaka, Bangladesh. Daily PM2.5 data were gathered from 2016 to 2022. Summer average PM2.5 values were produced by averaging three months of data from March, April, and May. For winter, the average value of the months November and December was used.For the summer season, average PM2.5 values were computed as 74 μg/m^3, 86 μg/m^3, 68 μg/m^3, and 90 μg/m^3, and for the winter season, 134 μg/m^3, 144 μg/m^3, 146 μg/m^3, and 150 μg/m^3, respectively for 2016, 2018, 2020, and 2022. The maximum permissible concentration of PM2.5 in the air, according to the national ambient air quality standard (NAAQS), is 15 μg/m^3. PM2.5 levels are much higher than the permitted threshold in both the summer and winter seasons. It is found that in winter PM2.5 concentrations are much higher comparing to summer.So, it has been discovered that the air quality in Dhaka is extremely harmful and hazardous to human health. Figure 3 below represents the temporal variation of PM2.5 both for summer and winter season:

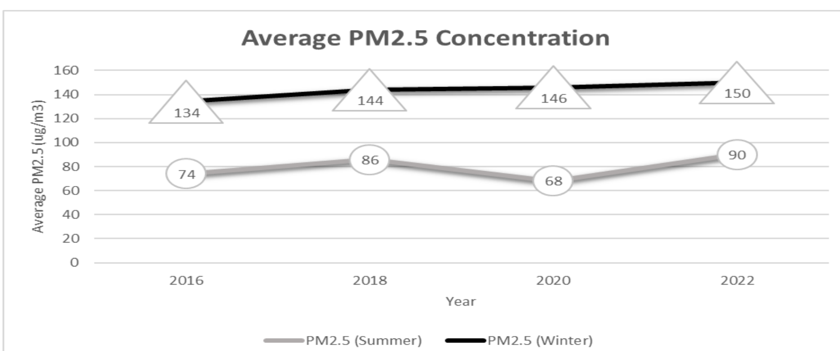

Figure 3: Temporal variation of PM2.5 concentration

3.2 Temporal variation of Vegetation Cover

NDVI were calculated by taking monthly data. Landsat 8 satellite images were collected for the month of May to have the data of summer season and images were collected for the month of December to have the data for winter season. These landsat images were analysed using GIS tools. The total vegetation area during the summer season were found 151.369 sq.km, 148.467 sq.km, 147.501 sq.km and 100.913 sq.km respectively for 2016, 2018, 2020 and 2022. Figure 4 below is showing NDVI for summer season for different years. Again vegetation cover during the winter season were estimated 127.584 sq.km, 125.34 sq.km, 124.78 sq.km and 100.91 sq.km respectively. Figure 5 below represents the NDVI for winter season.

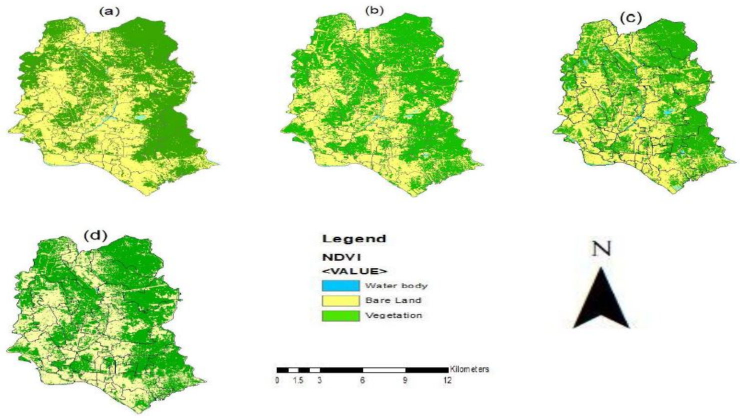

Figure 4: Normalized Difference Vegetation Index (NDVI) for summer season (a) 2016; (b) 2018; (c) 2020 and (d) 2022

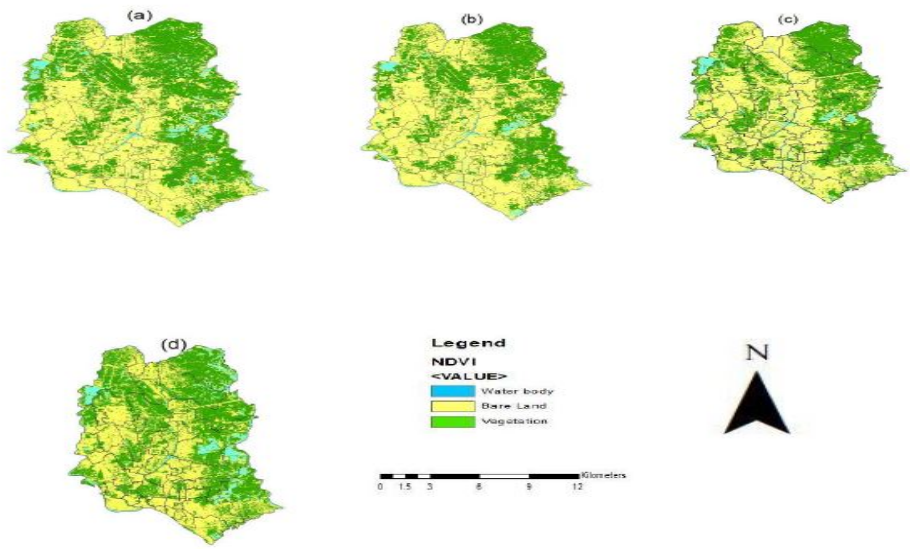

Figure 5: Normalized Difference Vegetation Index (NDVI) for winter season (a) 2016; (b) 2018; (c) 2020 and (d) 2022

3.3 Temporal Variation of Land Surface Temperature

LST were also calculated by taking monthly data. Landsat 8 satellite images were collected for the month of May to have the data of summer season and images were collected for the month December to have the data for winter season. These Landsat images were analysed using GIS tools. In 2016 the average land surface temperature for summer was found 29 ℃ and for winter 21 ℃. The land surface temperature was found 28 ℃ for summer and 20.5 ℃ for winter in 2018. The land surface temperature in 2020 was found 32 ℃ for summer and 21.5 ℃ for winter. And finally in 2022 average land surface temperature was recorded 34 ℃ in summer and 22 ℃ in winter. It is noticeable that the land surface temperature of Dhaka city is increasing. Greater urbanization, less vegetation, increasing air pollution and combustion are the main causes of this increment in temperature. Figure 6 and Figure 7 are representing land surface temperature for summer and winter season.

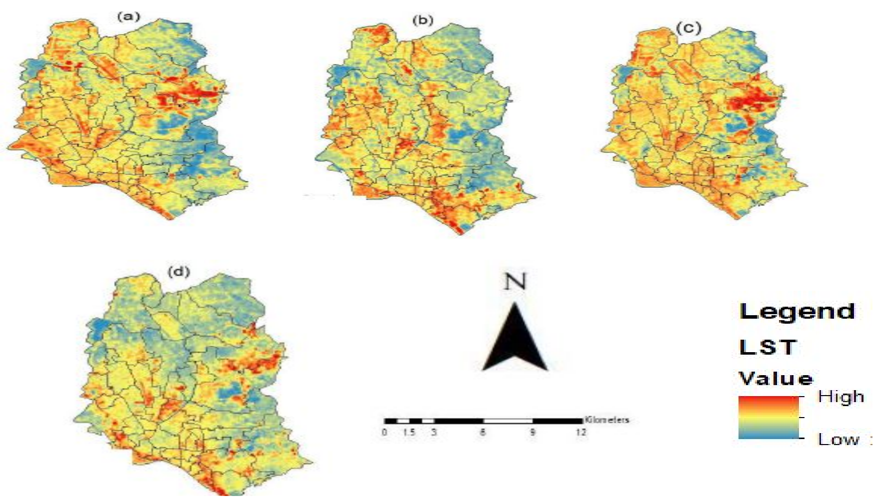

Figure 6: Land Surface Temperature (LST) for summer season (a) 2016; (b) 2018; (c) 2020 and (d) 2022

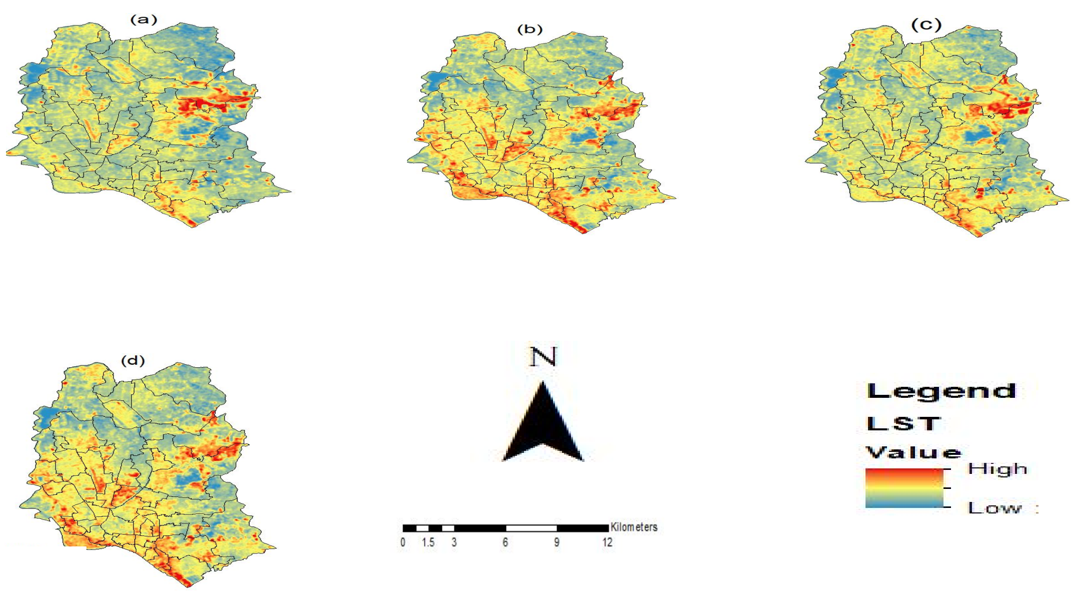

Figure 7: Land Surface Temperature (LST) for winter season (a) 2016; (b) 2018; (c) 2020 and (d) 2022

3.4 Relationship of Vegetation cover and PM2.5

Summer season: The temporal relationship of vegetation cover and PM2.5 concentration was analysed at Dhaka using data from 2016 to 2022. For summer season it is found that in 2016 total vegetation cover was 151.369 sq.km. Average PM2.5 concentration during this time was found 74 $\mu g/m^3$. In 2018 vegetation cover was decreased to148.467 sq.km while average PM2.5 value was increased to 86 $\mu g/m^3$. The value of vegetation cover was estimated 147.501 sq.km in 2020 and PM2.5 concentration was found 68 $\mu g/m^3$. It is noticed that PM2.5 concentration became lower in 2020 though the vegetation cover has decreased. This is due to COVID-19 pandemic situation. During that time all industrial, constructional and outside activities were stuck and most of the people used to stay at home. That is why the emission of particulate matter was found lower comparing to other times. In 2022 the green area was decreased to 100.913 sq.km and the PM2.5 concentration become maximum 90 µg/m^3. From the analysis it is to be noted that there is a negative corelation in between vegetation cover and PM2.5 concentration. Figure 8 shows temporal variation of Vegetation cover to PM2.5.

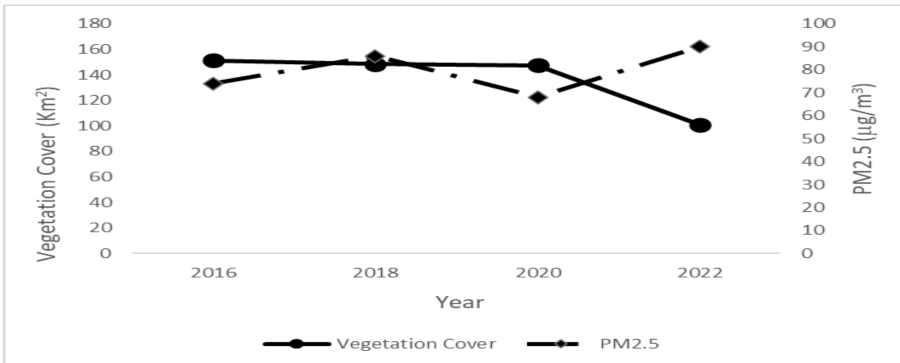

Figure 8: Temporal variation of vegetation cover and PM2.5 during summer season

Winter Season: The total vegetation cover for the winter season in 2016 was reported to be 127.584 square kilometers. During this period, the average PM2.5 concentration was reported to be 134 µg/m^3. 2018 had 125.345 square kilometers of vegetation cover and an average PM2.5 concentration of 144 µg/m^3. In 2020 vegetation cover was projected 124.788 square kilometers with a PM2.5 concentration of 146 µg/m^3. By 2022, there was only 110.167 square kilometers of vegetation, and the highest PM2.5 concentration during the study period was found 150 µg/m^3. This analysis in winter season also represents a inverse relation between vegetation cover and PM2.5 cncentration. The temporal change of vegetation cover to PM2.5 is depicted in Figure 9

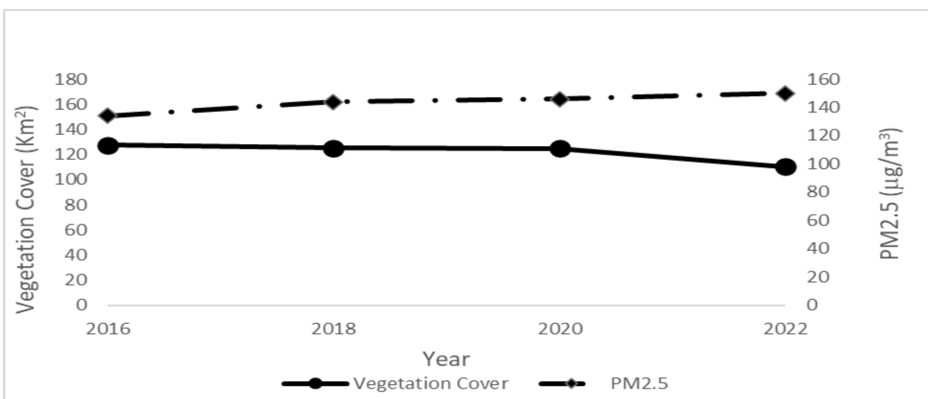

Figure 9: Temporal variation of vegetation cover and PM2.5 during winter season

3.5 Relationship of Vegetation cover and Land Surface Temperature

Summer season: Using data from 2016 to 2022, the temporal link between vegetation cover and LST was examined in Dhaka. The total vegetation cover for the summer season in 2016 was reported to be 151.3692 sq. km. The average LST for this period was 29°C. In, 2018 saw 148.467 sq. km of vegetation cover, with an average LST value of 28°C. In 2020, the estimated value of the vegetation cover was 147.501 sq. km, with an LST of 32°C. With the LST 34°C in 2022, the vegetation has shrunk to 100.913 sq. km. It is to be noted that the land surface temperature was gradually increased during the study period with the decrease in green area which indicates a negative corelation between vegetaion cover and land surface temperature. The temporal fluctuation of vegetation cover to LST is shown in Figure 10

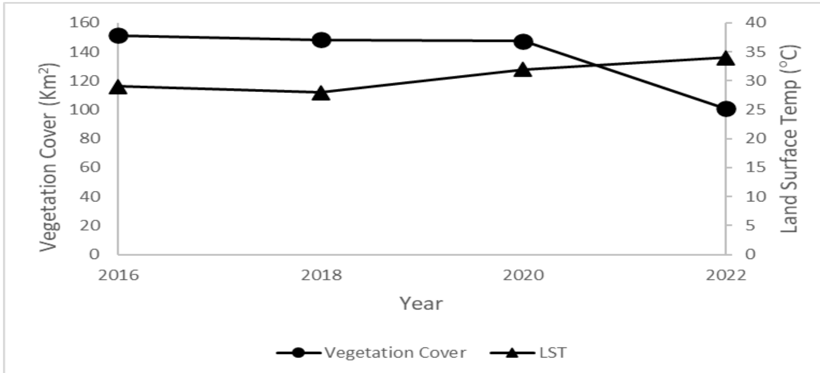

Figure 10: Temporal variation of vegetation cover and LST during summer

Winter Season: It was claimed that 127.584 sq. km of vegetation covered the winter season in 2016. For this time period, the average LST was 21°C. 2018 witnessed an average LST value of 20.5°C and 125.345 sq. km of plant cover. The vegetation cover was decreased to 124.788 sq. km in 2020, with an increase in LST to 21.5°C. The vegetation was decreased to 110.167 sq. km with the LST at 22°C in 2022. Figure 11 displays the vegetation cover's temporal variation in relation to LST.

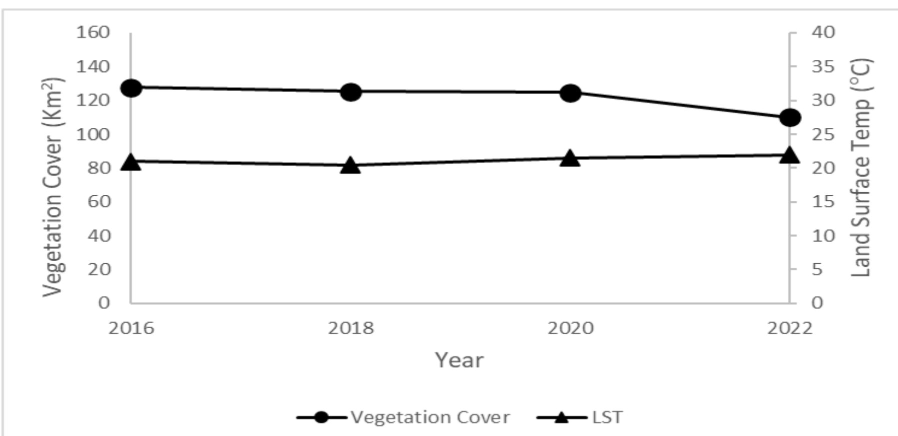

Figure 11: Temporal variation of vegetation cover and LST during winter season

From the analysis it is to be noted that there is an inverse relationship between NDVI and PM2.5. Vegetation cover has shown a decreasing phenomenon over the study period where PM2.5 value is on the rise. So lower value of vegetation results into higher value of PM2.5. So, measure should be taken to enhance green area to mitigate the effect of PM2.5 air pollutant. Vegetation has also an inverse effect on land surface temperature. During the study period the land surface temperature is also increased by 2 to 4 degrees Celsius with the decrease in vegetation cover. It can be concluded that vegetation cover has an effect on both land surface temperature and PM2.5. As green area is declining from time to time the value of LST and PM2.5 is on the rise. Greater urbanization, unorganised constructional work, deforestation and higher combustion rate are main reasons behind less vegetation. So, measures should be taken to enhance green area to lessen the surface temperature as well as concentration of air pollutants.

4. CONCLUSIONS

This study examined the temporal patterns in Dhaka city's air quality, vegetation cover, and land surface temperature between 2016 and 2022. The study assessed how plant cover affected land surface temperature and PM2.5 levels in Dhaka city. During the summer and winter seasons, the amount of vegetation cover decreases, while the level of Land surface temperature (LST) showing increasing trend. During the summer, vegetation covers drop by 33.33 percent between 2016 and 2022 because of environmental pollution, rapid construction. There is a 3.5degree Celsius increase in the LST during the summer months in Dhaka city between the years 2016 and 2022. The findings indicate that, in both the winter and summer seasons, there is an inverse correlation between NDVI and PM2.5. Winter season experienced higher PM2.5 because of temperature inversion, lower dispersal, stagnant conditions, emissions from vehicles. The national ambient air quality standard (NAAQS) states that the maximum allowable concentration of PM2.5 in the air is 15 $\mu g/m^3$, although in the summer months of 2016 and 2018, Dhaka city recorded 139 $\mu g/m^3$ and 163 $\mu g/m^3$, respectively. According to US AQI level, Dhaka city is categorized very unhealthy zone. A complex strategy is needed to save Dhaka city, including increasing green areas and afforestation, urban planning, emission reduction techniques, air quality monitoring, public awareness campaigns, and the implementation of policies. Policy makers, agriculturists, public health officials, environmental scientists, and urban planners can all benefit from this study.

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