GeoJournal (2024) 89:198
https://doi.org/10.1007/s10708-024-11172-w

Spatial distribution of light pollution severity through GIS & remote sensing: a study based on Rajshahi and Dhaka District in Bangladesh

Md. Raufur Rahim · Md. Alif-Al-Maruf · Foysal Malik Ibne Islam · Md. Mostafizur Rahman

Accepted: 11 July 2024

Abstract Artificial lighting is essential for supporting human activities during nighttime. Excessive artificial light causes pollution. This type of pollution impairs our ability to see the night sky clearly and results in the wasteful consumption of excessive energy. This research investigates the extent and impact of light pollution in the rapidly urbanizing cities of Rajshahi and Dhaka, employing Geographic Information Systems (GIS) and remote sensing techniques. The primary objectives of this thesis are to assess the extent and intensity of light pollution in the study areas. The authors utilized multi-temporal DMSP/OLS nighttime light satellite imagery spanning the period from 1992 to 2013. Additionally, VIIRS Day/Night Band (DNB) images from 2013 to 2022, accessed through Google Earth Engine, were employed to provide more recent data for analysis. These datasets were processed and analyzed within a GIS framework to delineate the extent of light pollution and its temporal evolution, allowing for the identification of hotspots and trends over the years. The findings of this study reveal the profound impact of urbanization on light pollution, with notable differences between the two cities. Despite the geographically smaller size of the Dhaka district than the Rajshahi district, the total amount of nighttime light is substantially larger in Dhaka. Light pollution, which differs in terms of spatial position, contributes to Dhaka City's rapid urbanization, which includes industrial and commercial activity and is located in the middle of Bangladesh. On the other side, Rajshahi, which is located in northern Bangladesh, has less light pollution than Dhaka because of its relative lack of industrial and commercial activity.

Keywords Artificial lighting · Light pollution · Nighttime light satellite · DMSP/OLS · VIIRS Day/Night Band (DNB)

M. R. Rahim (✉) · M. Alif-Al-Maruf · F. M. I. Islam · M. M. Rahman
Department of Urban and Regional Planning, Rajshahi University of Engineering and Technology, Rajshahi 6203, Bangladesh
e-mail: tahasinkhan469@gmail.com

Introduction

Background

Light pollution is the phenomenon of overly bright light sources produced by human activity. It disrupts the nighttime cycle of nature and can even harm biological clocks (Falchi et al., 2011; Fan & He, 2023; He et al., 2023). Over the natural nightly lighting levels provided by starlight and moonlight, their levels have been exponentially increasing (Falchi et al., 2011). Rajkhowa (2014) noted that light pollution can have an impact on people, animals, and plants. The brilliant night sky is the first observable effect of light pollution on astronomy, though. Astronomers who study the stars, galaxies, and other

Published online: 27 August 2024

celestial phenomena may be bothered by the brilliant night sky. Thumaty et al. (2009) showed that there is a close relationship between the increasing population and the increasing number of night lights. The increasing of night lights shows the technological development and expansion of a society or city. Dhaka's urban area, which increased at an average annual rate of 3.3% since 1999, was 36,541 hectares in 2014. With an average annual growth rate of 8.5% since 2000, Rajshahi's urban area reached 6,009 hectares in 2010 (Atlas of Urban Expansion, 2016). Light pollution is thought to be growing at a rate of 6% annually worldwide (Hölker et al., 2010).

The light pollution problem is a common issue all over the world. The region impacted by artificial lighting keeps expanding (Kyba et al., 2017). The technology of artificial evening lighting is indispensable to society and its nightly activities. However, the harmful side effects of this vital instrument have only recently come to light in the last 10 to 20 years. Sky glow is a landscape-scale phenomenon that is directly caused by point sources of light like streetlights and affects very broad areas. Indeed, one of the most significant changes to the biosphere today is sky glow. More than 60% of the world's population lives in areas with light pollution, which is defined as artificial sky brightness that is at least 10% higher on the horizon than natural sky brightness. Ninety-nine percent of people in the USA and Europe are unable to view a clear night sky, and about one-fifth of the world's territory is impacted by increased artificial sky brightness (Cinzano et al., 2001; Kyba & Hölker, 2013). China's light pollution expanded significantly in provincial capital cities over the past 21 years. Hot spots of light pollution were located in the eastern coastal region. Light pollution levels in the developed provinces (Hong Kong, Macao, Shanghai, and Tianjin) were higher than those of the undeveloped provinces (Jiang et al., 2017).

Bangladesh is a small country with a sizable population, and since 34% of its citizens live in cities, these metropolitan regions are among the most densely populated in the world. More than 3.3% of the population of cities continues to grow annually (World Population Review, 2023). Furthermore, 98.99% of the country's inhabitants have access to electricity (Trading Economics, 2021). Bangladesh has experienced extraordinary urbanization, which has led to massive power usage and several cities with lights on all night. 'Sleepless cities' is the term used to describe these locations (Cheon & Kim, 2020). Bangladesh's light pollution problem hasn't yet received much attention, though. Therefore, it is crucial to comprehend how laws governing Bangladesh's light pollution have changed to save the natural world and enhance urban dwellers' quality of life. As a result of the rising usage of artificial lights and lamps, nightlight emission has emerged as one of the primary causes of environmental pollution. For example, Darkness is used by plants in a variety of ways. Their growth, their life plans, and the regulation of their metabolism are impacted. Plants measure the length of the night, or the amount of darkness, and respond accordingly. Short-day plants therefore need long nights. Such a plant responds and interprets as though it had experienced two short nights rather than one long night with a disturbance if it is briefly lighted during a lengthy night. Its patterns of development and flowering may be completely disturbed as a result. Animal physiology can be impacted by light pollution, which can also confuse animal navigation and modify predator–prey relationships and competitive interactions (Rajkhowa, 2014). Sky glow is the phenomenon wherein the night sky becomes brighter, primarily above urban areas, as a result of electric lights from buildings, businesses, factories, streetlamps, cars, and outdoor advertisements. This phenomenon allows people to continue working and playing long after the sun sets. It is difficult for residents of cities with high sky glow levels to see more than a few stars at night. Skylight pollution is of special importance to astronomers because it makes it harder for them to see celestial objects (Brown, 2024). As, there is a potentiality to pollute the urban areas and their contexts in Bangladesh due to excessive use of lighting so the study is taken (Dhaka Tribune, 2022).

As the problem of light pollution increased day by day, to control the glare of lights The International Dark-Sky Association and International Commission on Illumination (CIE) established a broad framework. Lighting installations need to be functional, appropriately focused, able to achieve low brightness levels, controlled, and with suitable spectral power distributions (particularly for LED equipment) (Skarżyński & Rutkowska, 2023) .

All studies took Defense Meteorological Satellite Program Operational Linescan System (DMSP/OLS) images; are available from 1992 to 2013, but Soumi National Polar-orbiting Partnership (NPP) with the visible infrared imaging radiometer suite (VIIRS) imagery available from (2012-present). So, this research will integrate recent images of recent severity of light pollution. The objectives of this study are to assess the intensity and spatial distribution of light pollution in Rajshahi and Dhaka using the RS & GIS method.

Study area

Dhaka is situated in the central part of Bangladesh, along the banks of the Buriganga River. The cultural and economic center of Bangladesh is Dhaka. It serves as a center for commerce, finance, and trade. Rapid urbanization and industrial expansion have created problems including traffic congestion and environmental degradation in the city (Atlas of Urban Expansion, 2016). Although Dhaka is a large megacity with a sizable population, the bulk of people still reside in rural villages. 37.4% of the population, as of 2019, lives in urban areas. The urbanization rate is 3.13 percent change annually (as of 2019). Bangladesh is regarded as an urban nation due to its high population density. The total fertility rate and death rate of Dhaka are 1.71 per woman and 4.5 per 1000 population respectively. It ranks seventh in terms of population density and is the ninth-largest city in the world. As of 2022, Greater Dhaka had a population of over 22.4 million people, making Dhaka a megacity with a population of 10.2 million.

Rajshahi is a city in north-western Bangladesh, situated on the banks of the Padma River. In Rajshahi districts, Rajshahi City Corporation (RCC) is located on the Padma River's bank. The RCC was started in 1991. It has 30 wards and a 96.72 sq. km. total area. About 0.85 million people live in Rajshahi City Corporation, with a population density of 4,318 people per square kilometer. Rajshahi is known for its agricultural production, particularly in rice, mangoes, and silk. It's also central to several educational institutions. The total fertility rate and death rate of Rajshahi are 1.99 per woman and 5.4 per 1000 population respectively. Rajshahi also has several jute mills. There are currently numerous glass manufacturing facilities in Rajshahi. BSIC Industrial City-02 was built by Rajshahi City Corporation in Paba Upazila. A leather industrial area is also under construction. A 1,200-acre industrial zone will also be included in the Bangladesh Economic Zone (BEPZA). Rajshahi's IT industry would grow significantly with the help of Bangabandhu Hi-Tech Park. It will revolutionize information and communication technologies when it is finished, creating jobs for around 50,000 people in the area. According to the Rajshahi—Atlas of Urban Expansion, since 2000, Rajshahi's urban area has grown by an average annual rate of 8.5%, reaching 6,009 hectares in 2010. Its urban extent increased from 103 hectares in 1990 to 2,759 hectares in 2000, growing at an average annual rate of 31.3%. Approximately, 27 thousand lights are installed for public safety and beautification on different roads and roadsides (Rajshahi City Corporation, 2022) (Fig. 1).

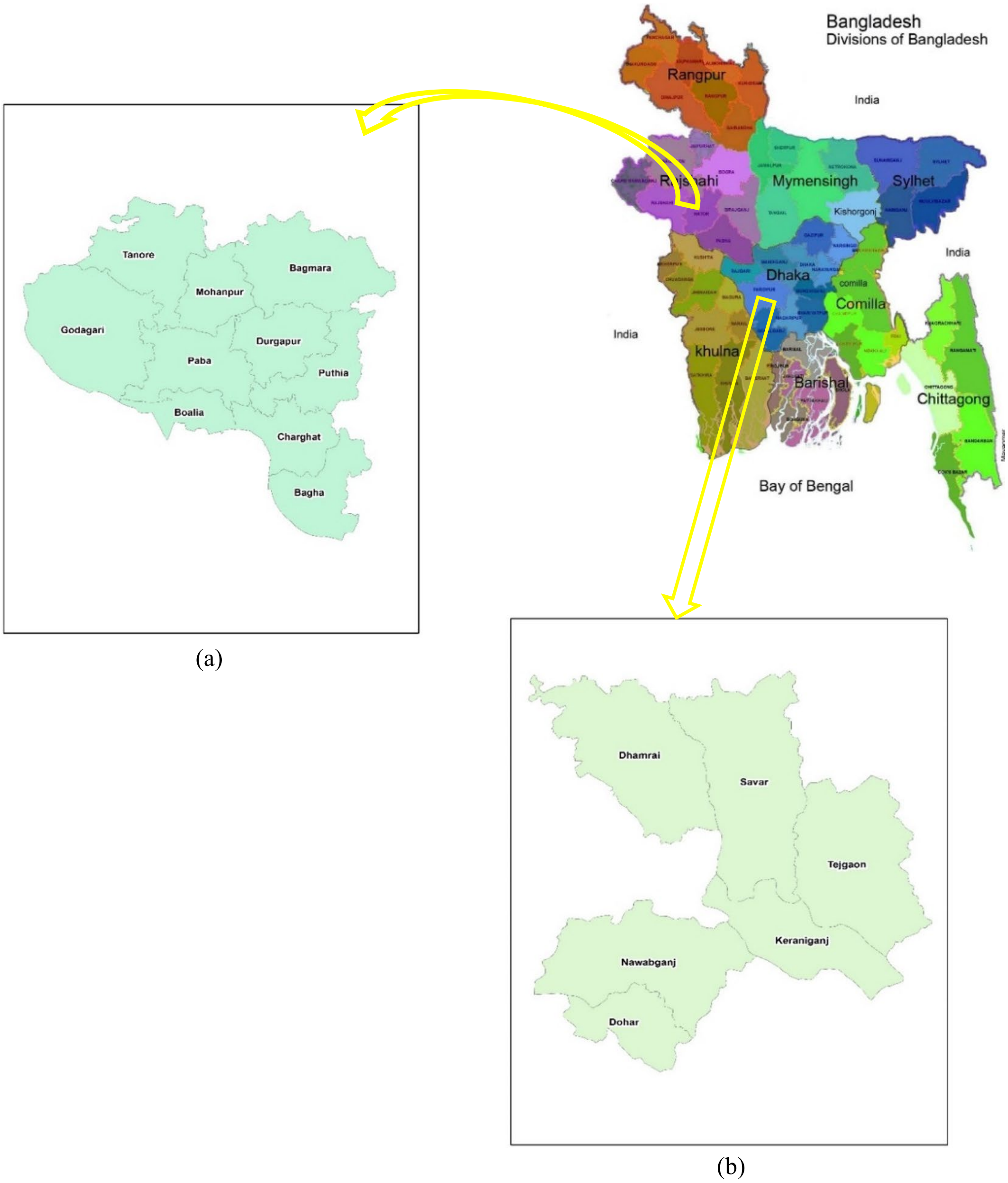
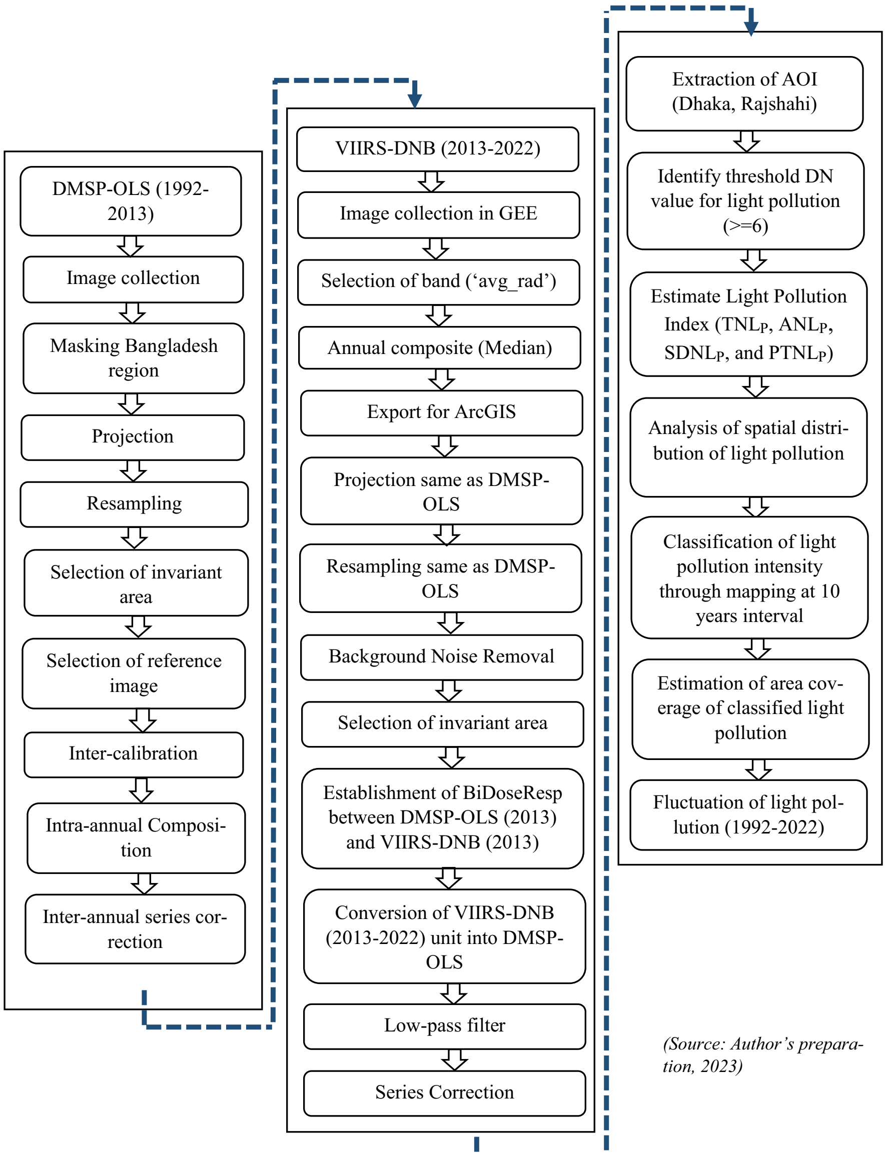


Fig. 1 Map of Rajshahi District, map of Dhaka District

Methodology

Methodological framework



(Source: Author's preparation, 2023)

Methodology interpretation

Nighttime light imagery (DMSP)

The experimental data for the research of light pollution in Bangladesh is taken from DMSP/OLS nighttime light satellite pictures from 1992–2013. Initiated in the 1970s, DMSP/OLS's first goal was to gather data on the spread of nighttime clouds. However, researchers discovered that DMSP/OLS could also record the nighttime light from cities in the absence of clouds. Six sensors are included in the DMSP/OLS photos used in this study, which are version 4 and were downloaded from the National Geophysical

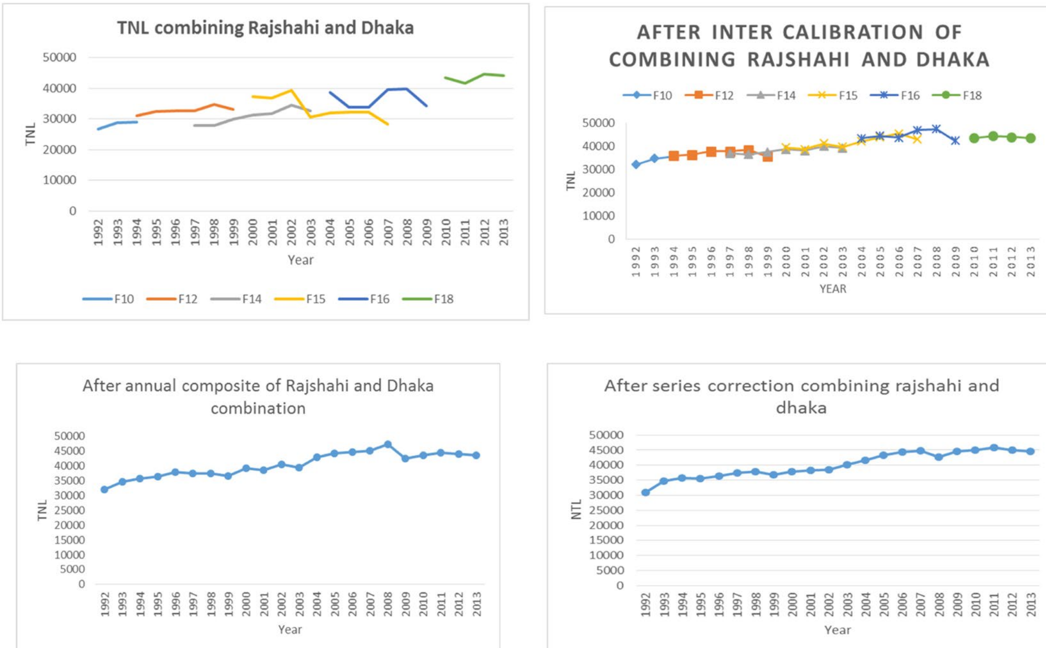


Fig. 2 **1** Before correction, **2** After inter-calibration, **3** After intra-annual composition, **4** After inter-series correction. (Source: Rahim et al., 2023)

Data Center (NGDC) website of the National Oceanic and Atmospheric Administration (NOAA). The average light product, stable nighttime light product, and cloud-free product frequencies are all included in the annual product of nighttime light, respectively. Because it eliminated background sounds like gas flare-ups, animal fires, and aurora, 5 periods of global stable nighttime light product photographs are chosen as the study dataset. Thus, the brightness in the artwork only depicts the lights that are used at night in homes. This imagery is divided into 30 arc-second grids that cover 180 to 180 degrees of longitude and 65 to 75 degrees of latitude. The DN value of pixels ranges from 0 to 63.

Since DMSP/OLS nighttime light images were collected by six satellites (F10, F12, F14, F15, F16, and F18) without onboard calibration, nighttime light imagery correction is required to increase data comparability and accuracy (Liu et al., 2012). Some steps need to be followed to process nighttime imageries, such as.

Model establishment The time series of nighttime light imagery 1992–2013 produced by six satellites without on-board calibration are collected from https://www.ngdc.noaa.gov/eog/dmsp/downloadV4composites.html, however as a result, the digital number (DN) values of these images are inconsistent and thus cannot be utilized to directly conduct comparative analysis. Therefore, a model needs to be created to enhance image comparability. At first, the whole region of Bangladesh was masked from the DMSP-OLS nighttime image from 1992 to 2013 and projected into WGS_1984_UTM_Zone_45N. The pixel size of each cell is resampled into 1000 m × 1000 m. The particular portion of the whole area has been little changed over time and needs to be selected as an invariant area which can be determined by the minimum coefficient of variation CV (<=0.22) of pixel value over the period. F18 2010 is selected as a reference image because it generates the highest total nighttime light value than the digital number values for each satellite compared to F18 2010 of that invariant area were studied in scattergrams (Wu et al., 2013). Additionally, a scatter gram-based second-order polynomial regression model was created, as seen below (Table 1):

$$DN_{ref} = C_0 + C_1 \times DN_t + C_2 \times DN_t^{\,2}$$

where DN_{ref} stands for the pixel value of the reference image, DN_t for the image's pixel value in year t, and

Table 1 Coefficient for inter-calibration of DMSP-OLS

DMSP	C_0	C_1	C_2	R^2
F10 1992	−0.077	1.490	−0.008	0.94
F10 1993	−0.295	1.551	−0.009	0.92
F10 1994	0.020	1.503	−0.008	0.96
F12 1994	0.525	1.237	−0.004	0.96
F12 1995	0.524	1.162	−0.003	0.97
F12 1996	0.395	1.284	−0.005	0.96
F12 1997	0.265	1.345	−0.006	0.96
F12 1998	0.157	1.190	−0.003	0.97
F12 1999	0.752	1.021	−0.001	0.94
F14 1997	0.242	1.714	−0.012	0.96
F14 1998	−0.009	1.760	−0.013	0.93
F14 1999	0.075	1.553	−0.009	0.95
F14 2000	−0.345	1.538	−0.008	0.97
F14 2001	0.189	1.420	−0.007	0.97
F14 2002	0.389	1.325	−0.006	0.97
F14 2003	−0.327	1.516	−0.008	0.97
F15 2000	−1.144	1.349	−0.006	0.94
F15 2001	−1.056	1.335	−0.006	0.94
F15 2002	−1.152	1.300	−0.005	0.95
F15 2003	−0.632	1.793	−0.013	0.96
F15 2004	−0.127	1.743	−0.012	0.97
F15 2005	−0.343	1.870	−0.014	0.95
F15 2006	0.422	1.766	−0.012	0.98
F15 2007	−0.430	2.122	−0.018	0.98
F16 2004	−1.348	1.536	−0.009	0.95
F16 2005	−1.119	1.844	−0.013	0.96
F16 2006	−0.867	1.768	−0.012	0.98
F16 2007	−0.894	1.553	−0.009	0.97
F16 2008	−1.509	1.672	−0.011	0.97
F16 2009	−0.652	1.683	−0.011	0.98
F18 2010	0	1	0	1
F18 2011	−0.537	1.277	−0.005	0.96
F18 2012	−0.264	1.073	−0.002	0.97
F18 2013	0.582	0.934	00	0.97

(Source: Rahim et al., 2023)

C_0, C_1, and C_2 for the regression model's coefficients. This model allows for the empirical derivation of C_0, C_1, and C_2, and R^2 expresses how well the regression model fits the data.

Calibration Inter-calibration, Intra-annual Composition, and Inter-annual series correction have been operated for post-processing of DMSP/OLS images.

Image correction result The level of inconsistency appeared before correction which is shown in Fig. 2.1 where the pixel value of different years' nighttime images do not follow any specific curve and are distributed in a scattered way. The implementation of image correction procedures such as inter-calibration, intra-annual composition, and inter-series correction all the image pixel values are brought consistent through curve fitting.

The TNLs of various sensors among the original photos (Fig. 2.1) demonstrate notable variations within the same year. However following the inter-calibration (Fig. 2.2), the TNL is more constant across years, and the outcome demonstrates that the sensor error was successfully removed. Additionally, the inter-annual composition method was used to rectify the images, and Fig. 2.3 demonstrates that during the study year, the annual volatility of TNL has been growing. As a result, the pictures were corrected using the inter-annual series correction approach, and the results are displayed in Fig. 2.4. The growing trend of TNL was more stable once the inter-annual series adjustment had been implemented. This shows that the image rectification performs well, and it can be applied to examine the spatial and temporal aspects of nighttime light pollution in the districts of Rajshahi and Dhaka.

VIIRS image

Composite images of monthly average radiance are produced by using data from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB). Since these data are combined monthly, it is impossible to provide high-quality data coverage in many parts of the world. This may be because of cloud cover, particularly in tropical areas, or because of solar illumination, as it is during the summer months at the poles. The DNB data is filtered to exclude information affected by stray light, lightning, lunar illumination, and cloud cover before averaging (Li et al., 2013; Jing et al., 2015).

VIIRS image collection and pre-processing VIIRS Day/Night Band (DNB) images of 2013–2022 are collected from the Google Earth engine which (ee.ImageCollection("NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG")) includes a band called 'avg_rad'. As those images are monthly composite images, seasonality is removed by using the 'median' function and creating an annual composite VIIRS Day/Night Band (DNB) image as well as clipped desired portion (Geographical area of Bangladesh) in the Google Earth engine platform (Mncube & Xulu, 2022). Typically, seasonal variations cause repeated patterns in the data throughout specified periods, such as months. Seasonal changes are less noticeable when the median is calculated over 12 months, and each month's central tendency can be seen (Ma & Li, 2018; Ma et al., 2020). The collected images are projected into WGS_1984_UTM_Zone_45N and resampled the cell size 1000 m × 1000 m. Background noise was eliminated by applying a thresholding technique. Specifically, a value of zero was assigned to pixels having DNB values less than 0.5. Second, the pixels with extremely high DNB values that might not have been caused by human activity were eliminated. The greatest pixel value of a picture is typically thought to be in the area with the most development. The radiance value up to 90 is seen as consistent because the interval from one pixel value to another is small. The abrupt fluctuation of the pixel value is noticed above 90 where few pixels hold a value more than 200. This situation could be brought on by other factors, such as gas flares, which were given the pixel value zero (Maghsoodi et al., 2019; Yuan et al., 2019; Hidayat et al., 2021).

BiDoseResp It is necessary to lessen the discrepancies between the dynamic range and luminance distribution of DMSP-OLS and NPP-VIIRS before developing a calibration function because the unit of pixel value for DMSP-OLS and VIIRS DNB are different where DMSP-OLS images expressed its pixel value in DN and VIIRS DNB images are indicated its pixel value in nanoWatts/cm2/Sr.

Post-processing Due to the apparent over-glow effect of DMSP-OLS, there is still a disparity between the calibrated VIIRS-DNB and DMSP-OLS. To enhance the consistency between the two, it is required to smooth the calibrated VIIRS-DNB to respond to the over-glow effect. Low-pass filter

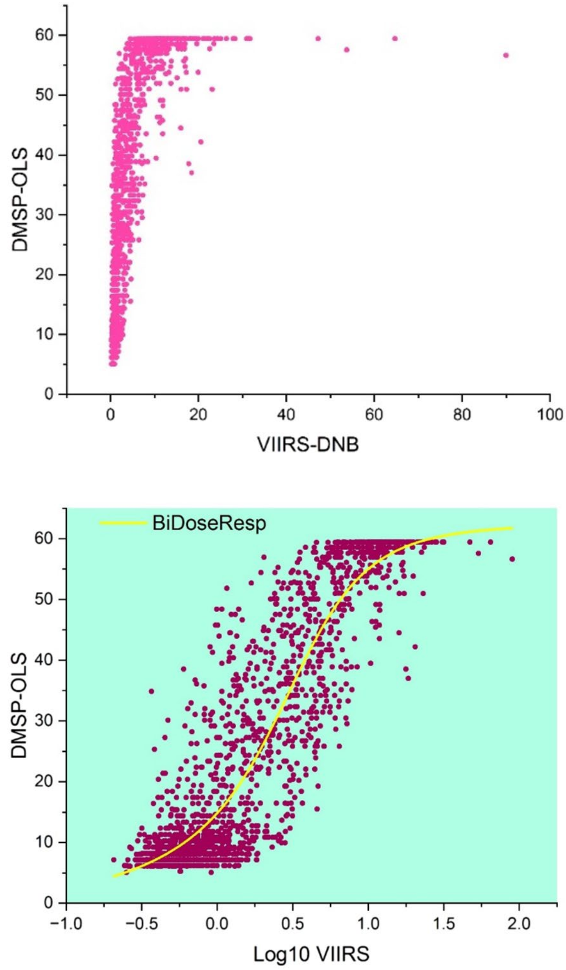


Fig. 3 **1** Before BiDoseResp application, **2** After BiDoseResp application. (Source: Rahim et al., 2023)

Table 2 Parameters of BiDoseResp application

Parameters	Value
A1	0.051
A2	62.424
LogMean1	0.09822
LogMean2	0.48855
h1	0.84062
h2	1.8445
p	0.367
R^2	0.86

(Source: Rahim et al., 2023)

operation is accomplished to bring more consistency and smoothness between VIIRS-DNB and DMSP-OLS data (Jeswani et al., 2019; Zuo et al., 2022).

Result of VIIRS-DNB image The original VIIRS-DNB and DMSP-OLS pixel pairings in the invariant site are illustrated in Fig. 3.1. Since every pair of pixels is focused along the y-axis, it is hard to do a successful regression analysis directly. However, it is found that these pixel pairings exhibit a substantial S-shaped distribution in the scatter plot of Fig. 3.2 following the logarithmic translation of VIIRS-DNB. The S-shaped distribution, which is different from the previous one, illustrates the potential relationship between DMSP-OLS and VIIRS-DNB and enables the construction of a mathematical expression to achieve the inter-calibration.

The BiDoseRsep model's regression curve is represented by the yellow curve in Fig. 3.2, and its parameters are listed in Table 2. Finally, the model was applied to the VIIRS-DNB data collected throughout the study area to produce the BiDoseResp-calibrated VIIRS (BDRVIIRS).

Low-pass filter The application of low-pass filter operation creates a more coherent relationship between DMSP-OLS and BDRVIIRS-DNB images that are exhibited in Fig. 4.1 (before the filter) and Fig. 4.2 (after the filter) where Fid d shows more consistent calibration. Figure 4.1, displays the scatter density plot of BDRVIIRS-DNB and DMSP-OLS for the entire Bangladesh without a low pass filter indicating very discrete scatter distribution. This is because of the over-glow effect of DMSP-OLS and the high precision of unsmoothed BDRVIIRS-DNB. BDRVIIRS-DNB can adapt to DMSP-OLS as much as feasible using the low pass filter. According to Fig. 4.2, the smoothed BDRVIIRS-DNB greatly lowers the scatter dispersion. It currently displays a highly substantial positive association with DMSP-OLS, enhancing the correlation coefficient (r^2) from 0.83 to 0.9095.

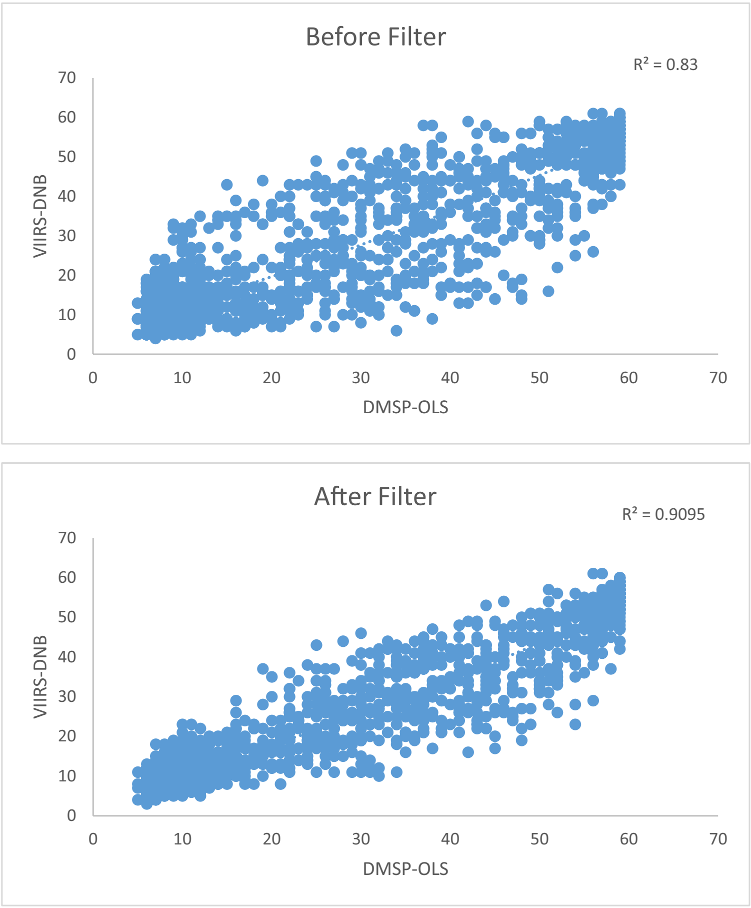


Fig. 4 **1** Before filter, **2** After filter. (Source: Rahim et al., 2023)

Table 3 Light pollution index

Indicator	Formula	Interpretation
Total Night Light Pollution (TNL_P)	$TNL_P = \sum_{i=6}^{63} C_i \times DN_i$	Relates to the overall level of light pollution in the relevant statistical area. DN_i is the ith gray level, and C_i is the number of pixels that make up that gray level
Average Night Light Pollution (ANL_P)	$ANL_P = \left(\sum_{i=6}^{63} C_i \times DN_i\right) / \sum_{i=6}^{63} C_i$	Refers to the statistical area's average degree of light pollution. DN_i is the ith gray level, and C_i is the number of pixels that make up that gray level
Standard Deviation of Night Light pollution ($SDNL_P$)	$SDNT_P = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(DN_j - ANL_P\right)^2}$	Refers to the statistical area's differentiating level of light pollution. ANL_P is the night light average, and DN_j is the jth gray level
Proportion of Total Night Light Pollution ($PTNL_P$)	$PTNL_P = TNL_P / TNL_{P\,(all)}$	Refers to the ratio of TNL_P in a specific district to the national average. $TNL_{P\,(all)}$ is the country's total night light, whereas TNL_P is the total night light of a particular district

(Source: Rahim et al., 2023)

Light pollution index

The threshold value for identifying light pollution is reached when the DN (pixel value) is greater than or equal to 6 (Butt, 2012). Four Light Pollution indices, including total night light (TNL_P), night light mean (ANL_P), night light standard deviation ($SDNL_P$), and the proportion of total night light ($PTNL_P$), were created to assess the spatial and temporal aspects of light pollution. ArcGIS 10.3 was used to extract the values for the TNL_P, ANL_P, $SDNL_P$, and $PTNL_P$ indexes. Table 3 displays the indices value formulas and descriptions.

Fluctuation of light pollution

The varying trends of each pixel during the study can be calculated using a linear regression trend approach. The variations in the trends that are unique to each pixel can be used to fully expose the spatial–temporal pattern. This method can objectively identify temporal changing trends of light pollution since it has the benefit of removing DN outliers by fitting time-series DN values.

$$\text{Slope} = \frac{t \times \sum_{i=1}^{t} i \times DN_i - \sum_{i=1}^{t} i \sum_{i=1}^{t} DN_i}{t \times \sum_{i=1}^{t} i^2 - \left(\sum_{i=1}^{t} i\right)^2}$$

where t represents the length of time (in this study, t = 31 years) and DN_i denotes the DN value in the year i.

If the slope is greater than zero, light pollution is increasing, and the greater the slope value, the more significant the increase; if the slope is less than zero, light pollution is declining, and the smaller the slope value, the more significant the decline; if the slope is equal to zero, light pollution is stable.

Result and discussion

Region based light pollution

The TNL and PTNL indices were used to comprehend the evolving characteristics of light pollution on a regional scale in Bangladesh. Figure 5.1, 5.2, and 5.3) displays the final result from 1992 to 2022, the TNL in two regions which are Dhaka and Rajshahi revealed an escalating tendency.

Dhaka had the biggest TNL range, while Rajshahi had the smallest TNL range (Fig. 5.1). This is because Dhaka is the capital city which encountered rapid urbanization, and an increment of population density that turned into flourishing industrial and commercial activities with government and non-government investment to address the population demand (Economic Census, 2013, 2015, 2016a, b). On the other hand, Rajshahi is mostly an under-developed region where urbanization tendency is lower than Dhaka which keeps lower emission of light. After 2017, some industrial and commercial developments as well as using of intense road lighting occurred indicating a

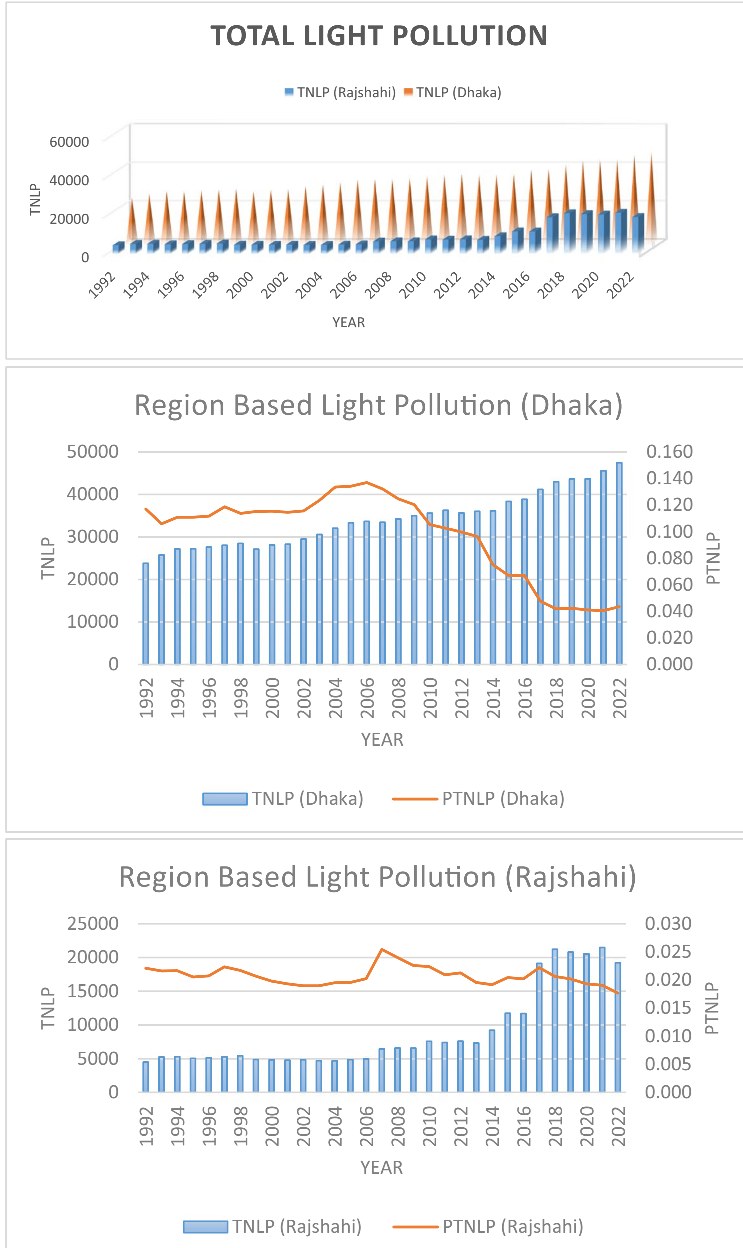
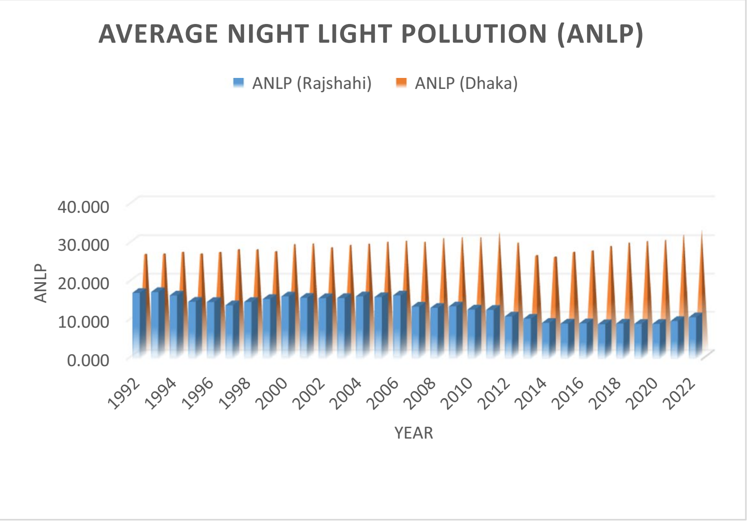


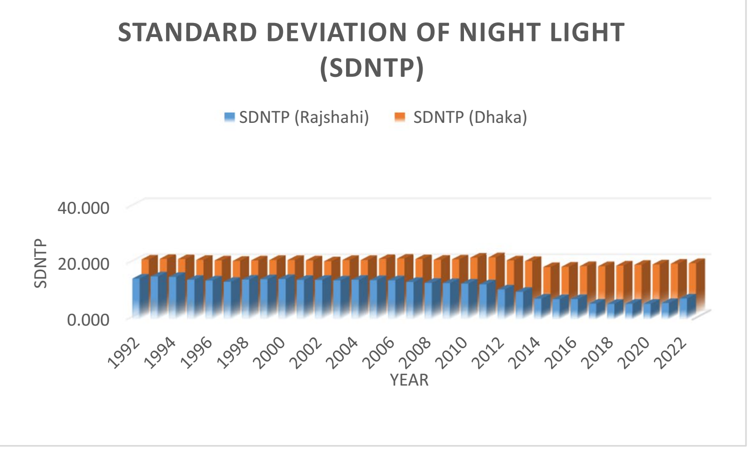
Fig. 5 **1** Total light pollution, **2** Dhaka, **3** Rajshahi, **4** Average night light pollution (ANLP), **5** Standard Deviation of Night Light (SDNTP). (Source: Rahim et al., 2023)

higher TNL range in Rajshahi. The Rajshahi district has confronted a 328% TNL growth range from 1992 to 2022 whereas Dhaka has a growth range of almost 100%. This doesn't mean Dhaka is the less light emitted area than Rajshahi rather it indicates the changing characteristics are significant for Rajshahi. As Dhaka become a more highly lit area than Rajshahi since 1992, it shows less growth range than Rajshahi.

PTNLP (Proportion of Total Night Light Pollution) for two regions (Dhaka, Rajshahi) are also demonstrated in Fig. 5.2 and 5.3. PTNLP for Dhaka district (Fig. 5.2) is decreasing which indicates light pollution increment is slower compared with national increment of light pollution in Bangladesh. This is because, with time the development of Bangladesh has been decentralized, and more infrastructural, and economic development occurred in other districts of Bangladesh with

Fig. 5 (continued)





Dhaka making the growth trend slower for Dhaka. In 2022, Dhaka generated almost 6% of light pollution overall in Bangladesh which was almost 13% in 1992. This analysis can be validated according to the BBS economic census 2013, where the annual growth rate of the total establishment (infrastructure, economic, industrial) for Dhaka was 5.58% which is less than for overall Bangladesh at 6.78%. On the other hand, Rajshahi (Fig. 5.3) has also a slower trend of light pollution with the national increment of light pollution of Bangladesh because another part of Bangladesh has encountered development activities which were under-developed at initial stages (1992) that forced to increase fastest trend of light pollution of these regions in Bangladesh. In 2022, Rajshahi produced almost 1.8% light pollution concerning overall Bangladesh which was almost 2.4% in 1992. This analysis can be justified according to the BBS economic census 2013, where the annual growth rate of the total establishment (infrastructure, economic, industrial) for Dhaka was 6.01% which is less than for overall Bangladat esh 6.78%.

The total nighttime light typically is influenced administrative area which indicates larger area should give more amount of total light than a smaller area. The average nighttime light eliminates that issue which defines nighttime light as affected by economic, and infrastructural development regardless of the administrative area. Dhaka has illustrated more ANLP where the average DN value ranges from 25 to 34 during study periods which indicates serious light pollution associated with economic and other development exists in this region (Fig. 9). Rajshahi has lots of non-luminous areas that indicate a lower degree of light pollution and the average DN value in Rajshahi ranges from 10 to 17 during study years.

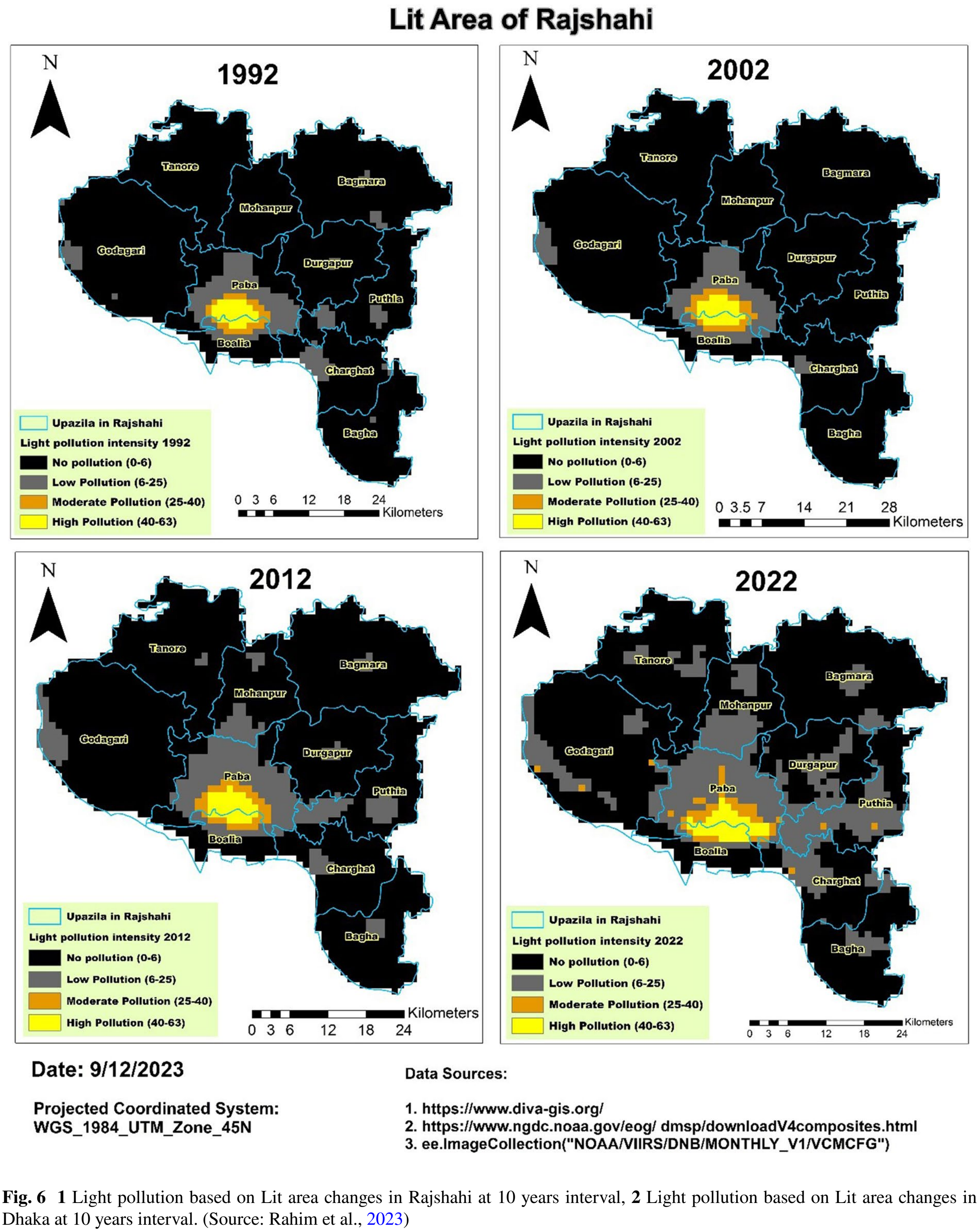


Fig. 6 **1** Light pollution based on Lit area changes in Rajshahi at 10 years interval, **2** Light pollution based on Lit area changes in Dhaka at 10 years interval. (Source: Rahim et al., 2023)

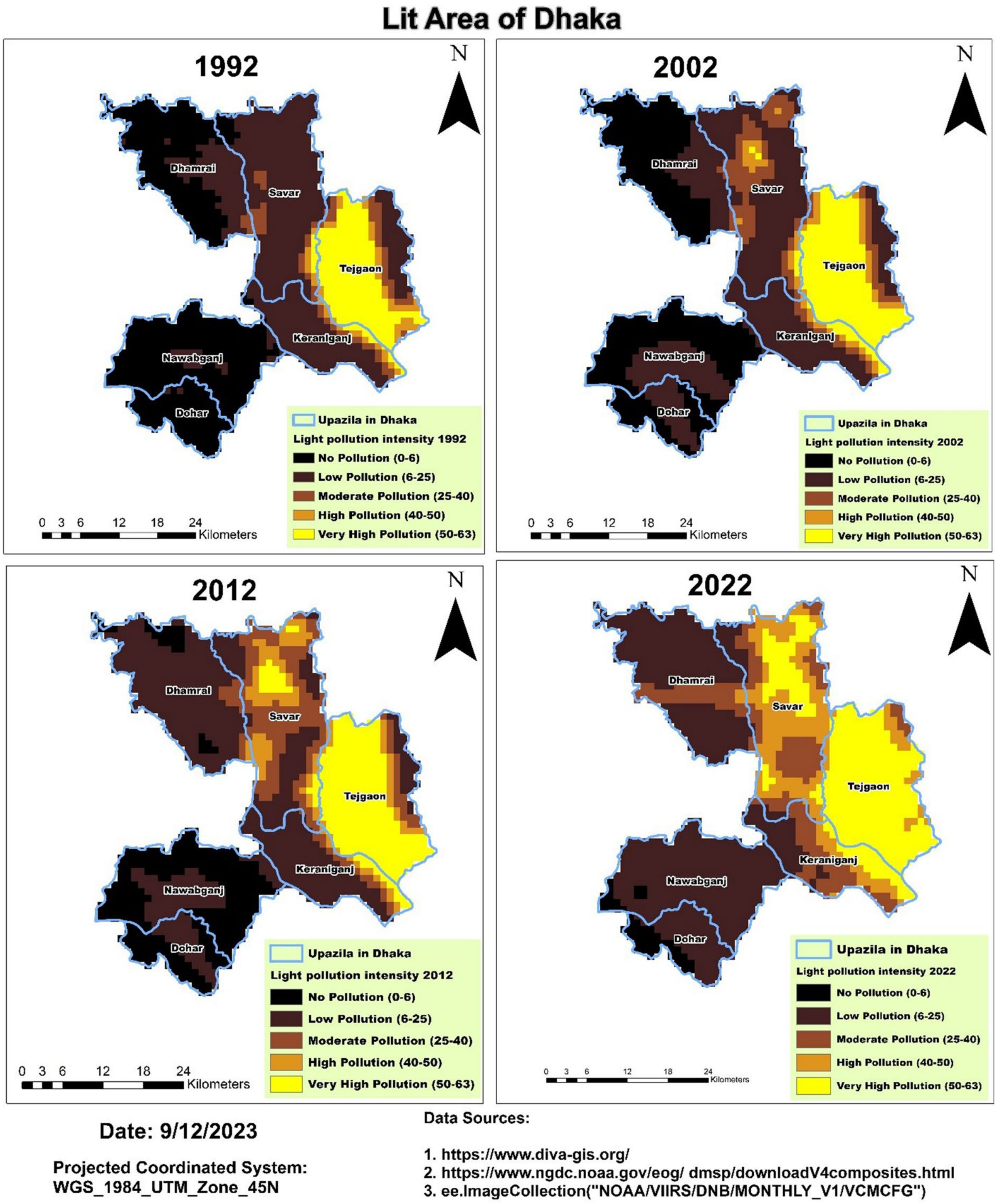


Fig. 6 (continued)

Regional heterogeneities might be shown in the standard deviation of night light pollution (SDNTP) which is higher for Dhaka district than Rajshahi (Fig. 5.5). This outcome demonstrates that there is more variation in light pollution in developed locations. This is because ANLP in the developed region has a high value while the value (non-luminous) in the suburbs of that region is much smaller, leading to increased heterogeneities over the entire region. Since most of the dark areas in undeveloped provinces have low ANLP, the region as a whole experiences less varied light pollution. SDNTP for Dhaka varies with the ranges of 19 to 21 and for Rajshahi 9 to 14 during the study years. SDNTP drops to 11% in 2022 for Rajshahi and increases to 7% for Dhaka. These findings demonstrate a rise in the imbalance of light pollution in developed areas during the research period.

Spatial distribution of light pollution through the map

The map for Dhaka and Rajshahi district illustrates the spatial distribution of light pollution by computing the area covered by various intensities of light pollution, which is crucial for identifying areas with higher and lower light pollution (Fig. 6).

Area coverage (km^2) of light pollution

$$\text{Coverage area} = \text{Number of pixel under each category} \times \text{pixel area} \ (km^2)$$

Area coverage for very highly polluted areas in Dhaka was 370 km^2 in 2022 and the increment from 1992 was almost 92%. Area coverage of high light pollution for Dhaka district in 2022 was 215 km^2 which is much greater than Rajshahi district which holds only 45 km^2 area. The increment rate of high light pollution for Dhaka district from 1992 to 2022 was almost 306% which is far ahead compared with Rajshahi district where the increment rate was only 50%. The drawdown of no polluted area due to rapid urbanization and the flourishing of several activities such as industrial, and commercial justifies that overall light pollution has increased in both areas during the study period. The reduction rate of no polluted area in Rajshahi district was almost 24% which is much lower than in Dhaka district where declination rate of no polluted area was almost 93%.

Classification of light pollution severity

Most of the Boalia and some portions of the Paba upazila of the Rajshahi district fall in a very highly polluted area (Fig. 6.1). Boalia upazila consists of intense commercial development with greater luminosity of road light and Paba upazila comprises some industrial activities that produce a greater amount of light pollution. Tejgaon in Dhaka district reveals a very high light pollution area due to the presence of abundant industries and commercial activities (Fig. 6.2). Tejgaon holds industrial activities of almost 45% of the total employment field (Bangladesh Bureau of Statistics, 2022). High-intensity lighting is frequently used in commercial locations, such as retail malls, business hubs, and entertainment districts, to draw customers and assure nighttime safety. Light pollution can be considerably increased by the heavy use of bright signage, ornamental lights, and lighted shops. Due to the requirement for considerable outdoor illumination, particularly in manufacturing and processing plants, industrial locations can also produce a significant amount of light pollution. Strong illumination may be used in factories, warehouses, and logistical hubs for safety and operational reasons. Additionally, more light pollution is produced by powerful and unshielded road lights.

The potential for light pollution in residential settings can vary. There may be more outdoor lighting fixtures and a higher possibility of lights that are poorly shielded or misdirected in neighborhoods as well as urban or suburban residential areas that are densely populated may have less strong lighting, but if lighting fixtures are not properly planned or controlled, they can still contribute to local light pollution (Xiang & Tan, 2017). Dhaka produced a great deal of light pollution more than 350 square kilometers in 2022 due to its large metropolitan population (Fig. 7.2).

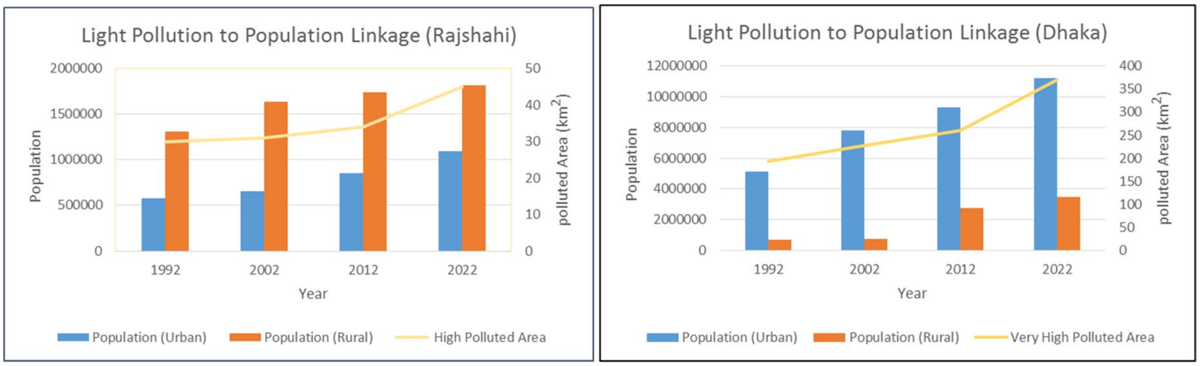


Fig. 7 **1** Light pollution to population (Rajshahi), **2** Light pollution to population (Dhaka). (Source: Author's preparation, 2024)

Light pollution is also impacted by remote rural places with inadequate outdoor lighting systems. The bulk of Rajshahi's population resides in rural areas, where 30% of the total area is composed of less and moderate light pollution, while just 1.91% of the land is composed of high light pollution, which is concentrated in urban areas (Table 4; Fig. 7.1).

Green space, vegetation, agricultural land, water bodies, forests, and other natural areas produce no light pollution (Fig. 10.3 and 10.4) (Table 5) .

Fluctuation of light pollution

The variable characteristics of light pollution in Dhaka and Rajshahi from 1992 to 2022 were revealed using a linear regression trend approach, as illustrated in Fig. 8. Tejgaon is in the center of Dhaka and its development process was initiated in the 1950s. Most of the Tejgaon thana are highly polluted areas and showed stable nighttime light from 1992 to 2022 because of development process was conducted a long time ago (Das et al., 2016). There are two instances of this stable trend: stable light pollution in rural and stable light pollution in urban areas. The former situation is mostly related to the fact that light pollution in urban core areas was high in 1992 and stable from 1992 to 2022; as a result, the trend of light pollution change was stable. The latter situation is mostly because there is essentially no human activity at night in rural areas, which is why these areas have not experienced light pollution over the previous 31 years (Figs. 9, 10.3 and 10.4).

Savar thana is a new growing force of producing nighttime light due to rapid urbanization and several development schemes were undertaken after 1992. The emerging industrial and commercial establishments are forced to use more artificial lights. The partial reduction of light occurs after construction projects are completed due to intense light pollution caused by the use of powerful searchlights during construction, such as the Dhaka metro rail project, which started in 2013 and was completed in 2020 (Hossain et al., 2021). After the project was finished,

Table 4 Area coverage in Rajshahi district

Rajshahi District					
Intensity of light pollution	Year				% of change
	1992	2002	2012	2022	
High polluted area	30 km^2	31 km^2	34 km^2	45 km^2	50%
Moderate polluted area	26 km^2	29 km^2	34 km^2	46 km^2	76.92%
Less polluted area	203 km^2	249 km^2	611 km^2	662 km^2	226.11%
No polluted area	2094 km^2	2044 km^2	1674 km^2	1600 km^2	−23.60%

(Source: Rahim et al., 2023)

Table 5 Area coverage in Rajshahi district

Dhaka District					
Intensity of light pollution	Year				% of change
	1992	2002	2012	2022	
Very high polluted area	193 km^2	228 km^2	261 km^2	370 km^2	91.71%
High polluted area	53 km^2	63 km^2	116 km^2	215 km^2	305.66%
Moderate polluted area	78 km^2	143 km^2	203 km^2	215 km^2	175.64%
Less polluted area	602 km^2	739 km^2	769 km^2	676 km^2	12.29%
No polluted area	594 km^2	347 km^2	171 km^2	44 km^2	−92.59%

(Source: Rahim et al., 2023)

the need for searchlights was eliminated, and the amount of nighttime light decreased, which resulted in a downward trend in the amount of light pollution. The major parts of the Rajshahi district have held stable nighttime light through the years. The Paba upazila has experienced increased lighting for industrial development such as BSCIC. The Boalia upazila also demonstrates intense lighting but most of the part shows stable and little change because those portions are already developed from the beginning of the study period as well a small portion in the Paba upazila shows decreasing light due to increased wetlands (Hossain & Moniruzzaman, 2021). The

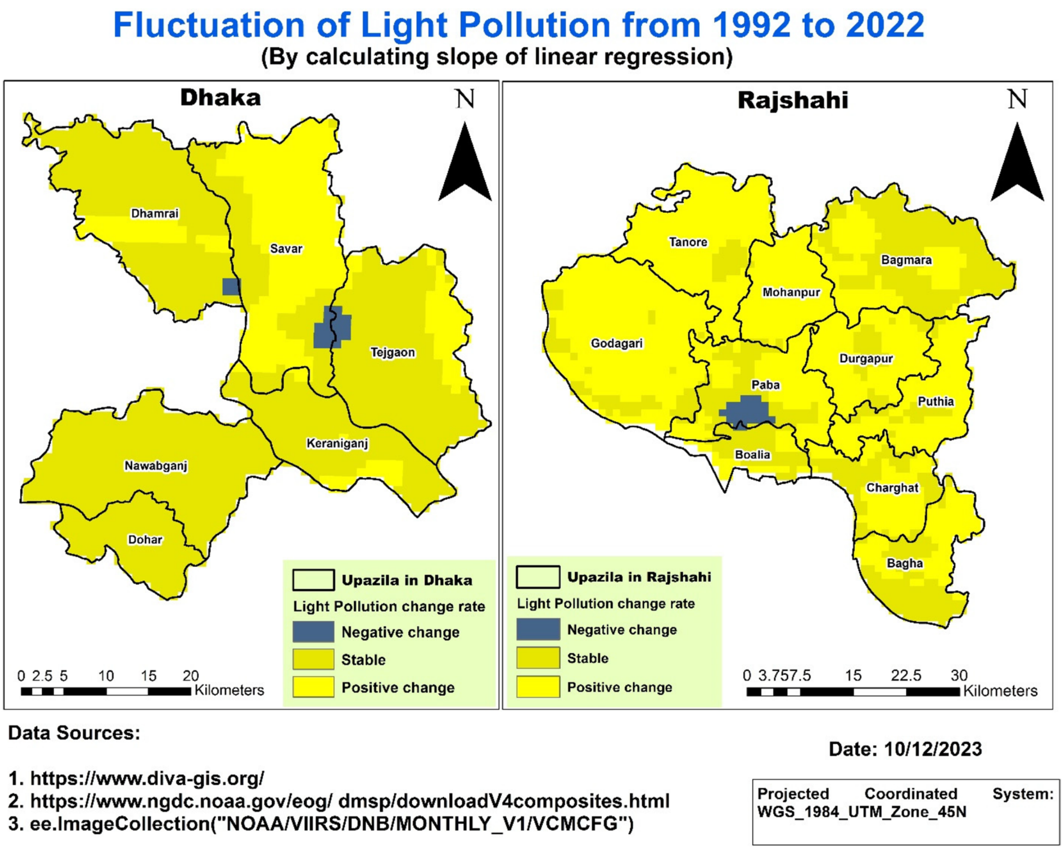


Fig. 8 Fluctuation of light pollution in Dhaka and Rajshahi. (Source: Rahim et al., 2023)

(a) Rajshahi 2001

(d) Dhaka 2001

(b) Rajshahi 2011

(e) Dhaka 2011

(c) Rajshahi 2022

(f) Dhaka 2022

Fig. 9 Demonstration of urbanization growth. (Source: Google Earth, 2023)

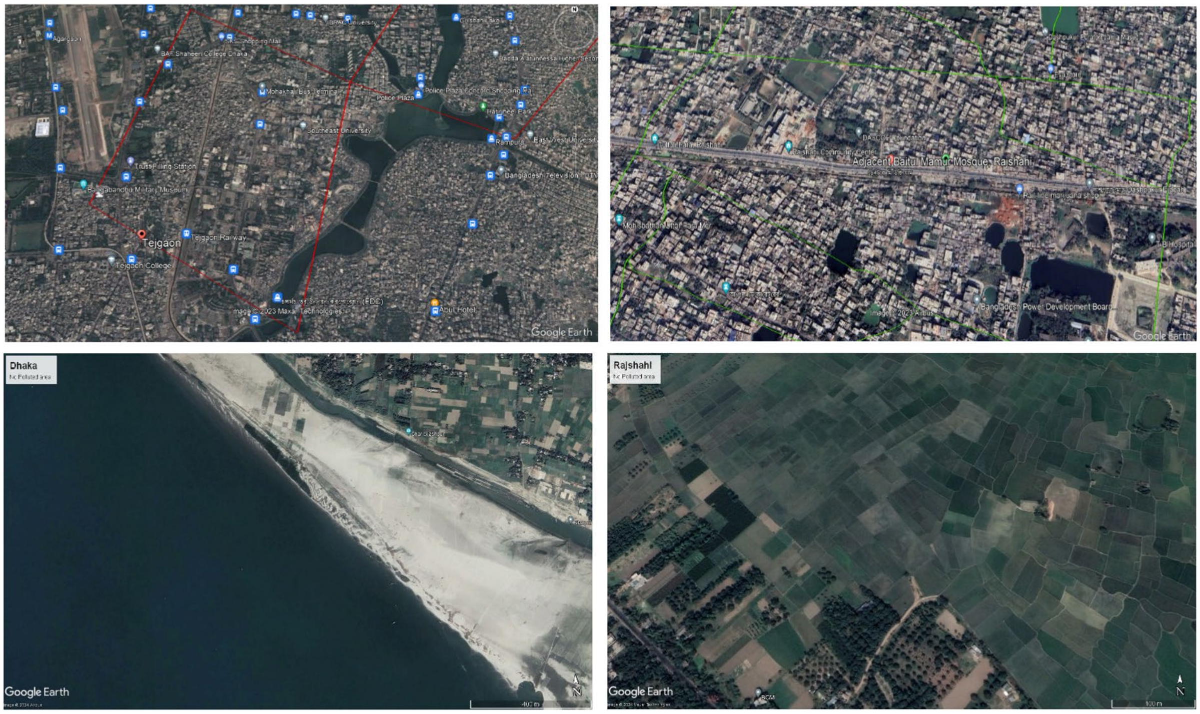


Fig. 10 **1** Most light polluted area in Dhaka, **2** Most light polluted area in Rajshahi, **3** Area free of light pollution in Dhaka, **4** Area free of light pollution in Rajshahi. (Source: Google Earth, 2023)

urbanization and use of highly powered road lights in some parts of other upazila have shown an increase in artificial light generation and the rest of the part exhibited stable light through the years.

Findings and conclusion

Despite the geographically smaller size of the Dhaka district than the Rajshahi district, the total amount of nighttime light is substantially larger in Dhaka. Light pollution, which differs in terms of spatial position, contributes to Dhaka City's rapid urbanization, which includes industrial and commercial activity and is located in the middle of Bangladesh. On the other side, Rajshahi, which is located in northern Bangladesh, has less light pollution than Dhaka because of its relative lack of industrial and commercial activity. For both districts, the percentage of light pollution growth that is correlated with national growth is on the decline. This happened as a result of the decentralized development of Bangladesh as a whole, which slowed the expansion of light pollution in the study period in the districts of Dhaka and Rajshahi. Rajshahi has a lot of non-luminous areas which indicates a lower degree of light pollution and average DN value in Rajshahi ranging from 10 to 17 during study years. Dhaka has illustrated more ANLP where the average DN value ranges from 25 to 34 during study periods which indicates serious light pollution associated with economic and other development exists in this region. The majority of the Boalia upazila and a small portion of the Paba upazila in the Rajshahi district are located in an extremely polluted area, with the Boalia upazila featuring intense commercial development and higher levels of road light pollution. Tejgaon in the Dhaka district shows unusually high levels of light pollution as a result of the numerous industrial and commercial activities there (Hossain, 2020). Light pollution is not created by greenery, vegetation, agricultural land, water bodies, forests, or other natural regions. In Dhaka, the area covered by the most polluted area in 2022 was 370 km2, an increase from 1992 of over 92%.In contrast, Rajshahi district, which has a 45 km2 size and a growth rate from 1992 of only 50%, would have high levels of light pollution in 2022. Because of the presence of governmental structures or services, as well as the city's entry and embankment side, respectively, Saheb Bazar Road and Laxmipur were found to be well-lit than other locations.

Using sophisticated Geographic Information Systems (GIS) and remote sensing techniques, this major study on light pollution in the urban areas of Rajshahi and Dhaka has highlighted the serious issues related to excessive artificial lighting in our cities. Between 1992 and 2013, there has been a worrying increase in the amount and severity of light pollution, as revealed by the research. The way that formerly dark places are now lit landscapes is a reflection of the significant influence that urbanization has had on our evening environment. Furthermore, the addition of more recent VIIRS Day/Night Band (DNB) images spanning the years 2013 to 2022 shows that this rising trend is continuing, underscoring the pressing need to solve this issue as cities continue to grow. The GIS framework's detailed mapping of the spatial distribution of light pollution has shown a non-uniform pattern throughout these cities with recognizable hotspots. Numerous factors, such as urban planning techniques, economic activity, and population density, might be responsible for these spatial variations. Delineating these hotspots is crucial for focused action and resource distribution. For example, the main road networks and the central commercial sector in Rajshahi have been identified as major sources of light pollution. Dhaka, on the other hand, has a more complex pattern, with its extensive urban growth related to several hotspots.

Acknowledgements I am expressing special gratitude to website https://www.ngdc.noaa.gov/eog/dmsp/downloadV4composites.html as well as Google earth engine for supplying adequate data to conduct this study.

Author's contribution All authors contributed to the study conception and design. The manuscript has been read and approved by all named authors and there are no others person who satisfied the criteria for authorship but are not listed. The order of authors listed in the manuscript has been approved by all of us. The individual contribution of the authors is given herewith: Introduction, Data collection [Md. Alif- Al- Maruf], Data analysis, Mapping, Methodology [Md. Raufur Rahim], Conceptualization, Formatting table, chart, conclusion [Foysal Malik Ibne Islam], Correction, Supervision [Dr. Md. Mostafizur Rahman].

Funding I declare that this research is not supported or funded by any organization or individual. Authors bear all the expenses of this study by themselves. So, this research is the self-funded research of the authors.

Data availability I declare that the collected data are original and all the data are collected by authors.

Declarations I the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

Consent for publication All participants have given their consent regarding publishing their statement and data.

The data presented in this manuscript is accurate and has not been manipulated or fabricated in any way. All sources of information have been appropriately cited.
All pertinent ethical standards have been followed to during the conduct of this research.

Conflict of interest/Competing interest The authors declare that there is no competing interest associated with this publication.

References

Atlas of Urban Expansion. (2016). Retrieved from http://atlasofurbanexpansion.org/cities/view/Rajshahi. Accessed 2022

Bangladesh Bureau of Statistics (BBS) (2022) population Census-2011. preliminary report. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka. - references - scientific research publishing. Available at: https://www.scirp.org/reference/referencespapers?referenceid=1878161. Accessed 05 Aug 2024.

Brown, T. (2024). Light pollution. Retrieved from https://education.nationalgeographic.org/resource/light-pollution/. Accessed 2022

Butt, M. (2012). Estimation of light pollution using satellite remote sensing and geographic information system techniques. *GIScience & Remote Sensing*, *49*. https://doi.org/10.2747/1548-1603.49.4.609

Cheon, S., & Kim, J.-A. (2020). Quantifying the influence of urban sources on night light emissions. *Landscape and Urban Planning, 204*, 103936. https://doi.org/10.1016/j.landurbplan.2020.103936

Cinzano, P., Falchi, F., & Elvidg, C. D. (2001). The first world atlas of the artificial night sky brightness. *Monthly Notices of the Royal Astronomical Society, 328*(3), 689–707.

Das, A., Haque, A., & Salam, Md. A. (2016). A study on development trend of Tejgaon industrial area. *Bangladesh Planning Research Conference (BPRC)*.

Dhaka Tribune. (2022). Light pollution in Bangladesh: A big blow to nature. Available at: https://www.dhakatribune.com/bangladesh/2022/02/04/light-pollution-in-bangladesh-a-bigblow-to-nature. Accessed 05 Aug 2024.

Economic Census 2013: District Report. (2016a). Dhaka: Reproduction, Documentation & Publication (RDP) section, Bangladesh Bureau of Statistics.

Economic Census 2013: In Abridged Form. (2015). Reproduction, Documentation & Publication (RDP) Section, Bangladesh Bureau of Statistics.

Economic Census 2013: District Report. (2016b). Rajshahi: Reproduction, Documentation & Publication (RDP) Section, Bangladesh Bureau of Statistics.

Falchi, F., Cinzano, P., Elvidge, C. D., et al. (2011). Limiting the impact of light pollution on human health, environment and stellar visibility. *Journal of Environmental Management, 92*(10), 2714–2722. https://doi.org/10.1016/j.jenvman.2011.06.029

Fan, H., & He, S. (2023). Control light pollution by genetic algorithms. *Highlights in Science, Engineering and Technology, 35*, 233–241. https://doi.org/10.54097/hset.v35i.7059

He, Z., & Guo, R., & Yang, H. (2023). A light pollution risk model based on improved assessment and prediction methods. *E3S Web of Conferences*, *375*. https://doi.org/10.1051/e3sconf/202337503015

Hidayat, R. A., Hanif, M., Amor, G., & Hafizuurahman, H. (2021). Utilization of VIIRS imagery in analyzing light pollution as the threat towards bird sleep performance in the regional of Medan, North Sumatra, *EasyChair Preprint*.

Hölker, F. et al. (2010). Light pollution as a biodiversity threat. *Trends in Ecology & Evolution*, *25*(12), pp. 681–682. https://doi.org/10.1016/j.tree.2010.09.007

Hossain, F., & Moniruzzaman, M. (2021). Modelling agricultural transformation: A remote sensing-based analysis of wetlands changes in rajshahi, Bangladesh. *Environmental Challenges*, *5*. https://doi.org/10.1016/j.envc.2021.100400

Hossain, A. S. M. F., Sultana, N., Javed, A.-M., & Khan, A. B. (2021). The first Mass Rapid Transit (MRT) in Bangladesh, its impacts and overcomes. *Journal of Recent Activities in Infrastructure Science, 6*(2), 46–56.

Hossain, S. T. (2020). Critical review of street connectivity between Tejgaon Industrial Area and adjacent hatirjheel development. *Creative Space, 8*(1), 1–13. https://doi.org/10.15415/cs.2020.81001

Jeswani, R., Kulshrestha, A., Gupta, P. K., & Srivastav, S. K. (2019). Evaluation of the consistency of DMSP-OLS and SNPP-VIIRS night-time light datasets. *Journal of Geomatics, 13*(1), 98–105.

Jiang, W., He, G., Long, T., Wang, C., Ni, Y., & Ma, R. (2017). Assessing light pollution in China based on nighttime light imagery. *Remote Sensing, 9*(2), 135. https://doi.org/10.3390/rs9020135

Jing, X., Shao, X., Cao, C., Fu, X., & Yan, L. (2015). Comparison between the Suomi-NPP day-night band and DMSP-Ols for correlating socio-economic variables at the provincial level in China. *Remote Sensing, 8*(1), 17. https://doi.org/10.3390/rs8010017

Kyba, C. C. M., & Hölker, F. (2013). Do artificially illuminated skies affect biodiversity in nocturnal landscapes? *Landscape Ecology, 28*, 1637–1640.

Kyba, C. C. M., Kuester, T., Sánchez de Miguel, A., Baugh, K., Jechow, A., Hölker, F., Bennie, J., Elvidge, C. D., Gaston, K. J., & Guanter, L. (2017). Artificially lit surface of Earth at night increasing in radiance and extent. *Science Advances, 3*(11), e1701528. https://doi.org/10.1126/sciadv.1701528. Bibcode:2017SciA....3E1528K.

Li, X., Xu, H., Chen, X., & Li, C. (2013). Potential of NPP-viirs nighttime light imagery for modeling the regional economy of China. *Remote Sensing, 5*(6), 3057–3081. https://doi.org/10.3390/rs5063057

Liu, Z., He, C., Zhang, Q., Huang, Q., & Yang, Y. (2012). Extracting the dynamics of urban expansion in China using DMSP-OLS nighttime light data from 1992 to 2008. *Landscape and Urban Planning, 106*(1), 62–72. https://doi.org/10.1016/j.landurbplan.2012.02.013

Ma, J., Guo, J., Ahmad, S., Li, Z., & Hong, J. (2020). Constructing a new inter-calibration method for DMSP-OLS and NPP-viirs nighttime light. *Remote Sensing, 12*(6), 937. https://doi.org/10.3390/rs12060937

Ma, W., & Li, P. (2018). An object similarity-based thresholding method for urban area mapping from Visible Infrared Imaging Radiometer Suite Day/Night Band (VIIRS DNB) data. *Remote Sensing, 10*(2), 263. https://doi.org/10.3390/rs10020263

Maghsoodi, M. O., Kazemi, A., HedayatiAghmashadi, A., & Gili, M. R. (2019). Survey of light pollution of Arak city by using of DMSP and Suoni-NPP satellite imagery. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-4/W18*, 693–696. https://doi.org/10.5194/isprs-archives-xlii-4-w18-693-2019

Mncube, Z., & Xulu, S. (2022). Progress of nighttime light applications within the Google Earth Engine Cloud Platform. *Geocarto International*, 1–22. https://doi.org/10.1080/10106049.2022.2120550

Nation, T. N. (2015). Retrieved from https://thedailynewnation.com/print-a-news/65602/new-industrial-estate-set-up-in-paba.html. Accessed 2022

Nurbandi, W., Yusuf, F. R., Prasetya, R., & Afrizal, M. D. (2016). Using Visible Infrared Imaging Radiometer Suite (VIIRS) imagery to identify and analyze light pollution. *IOP Conference Series: Earth and Environmental Science, 47*, 012040. https://doi.org/10.1088/1755-1315/47/1/012040

Rahim, M., Alif-Al-Maruf, M., Islam, F., & Rahman, M. (2023). Author's Preparation of Various Graphs, Charts, Table, and Maps.

Rajshahi City Corporation. (2022). Available at: https://erajshahi.portal.gov.bd/. Accessed 05 Aug 2024.

Rajkhowa, R. (2014). Light pollution and impact of light pollution. *International Journal of Science and Research, 3*(10), 861–867.

Skarżyński, K., & Rutkowska, A. (2023). The interplay between parameters of light pollution and energy efficiency for outdoor amenity lighting. *Energies, 16*, 3530. https://doi.org/10.3390/en16083530

Trading Economics. (2021). Bangladesh - access to electricity (% of population) 2024 data 2025 forecast 1990-2022 historical, Bangladesh - Access To Electricity (% Of Population) -2024 Data 2025 Forecast 1990-2022 Historical. Available at: https://tradingeconomics.com/bangladesh/

access-to-electricity-percent-of-population-wb-data.html. Accessed 05 Aug 2024.

Thumaty, K. C., Badarinath, K., Elvidge, C., & Tuttle, B. (2009). Spatial characterization of electrical power consumption patterns over India using temporal DMSP-OLS nighttime satellite data. *International Journal of Remote Sensing., 30*, 647–661. https://doi.org/10.1080/01431160802345685

World Population Review. (2023). Population of cities in Bangladesh 2023. Available at: https://worldpopulationreview.com/countries/cities/bangladesh. Accessed 05 Aug 2024.

Wu, J., He, S., Peng, J., Li, W., & Zhong, X. (2013). Intercalibration of DMSP-OLS night-time light data by the invariant region method. *International Journal of Remote Sensing, 34*(20), 7356–7368. https://doi.org/10.1080/01431161.2013.820365

Xiang, W., & Tan, M. (2017). Changes in light pollution and the causing factors in China's protected areas, 1992–2012. *Remote Sensing, 9*(10), 1026. https://doi.org/10.3390/rs9101026

Yuan, X., Jia, L., Zhou, J., Menenti, M., & Chen, Q. (2019). A new method for noise removal in NPP-viirs monthly nighttime light imagery over the sahel region. *IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium*. https://doi.org/10.1109/igarss.2019.8897941

Zuo, C., Gong, W., Gao, Z., Kong, D., Wei, R., & Ma, X. (2022). Correlation Analysis of CO2 concentration based on DMSP-OLS and NPP-viirs integrated data. *Remote Sensing, 14*(17), 4181. https://doi.org/10.3390/rs14174181