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Nexus between Light Pollution and Air Temperature: A Study of Bangladesh

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Abstract

Rapid urbanization and population growth have introduced a new phenomenon called "light pollution", which is the result of ungoverned use of artificial lighting. Natural land cover is being replaced by impervious surface to meet the growing demand. As a result, urban areas are getting warmer compared to the surrounding rural areas. Scholarly literature confirms the relationship between light pollution and air temperature. However, the nature of direct relationship is yet to be explored. Using remote sensing and weather station data, this research reveals the nature of relationship between these two variables. The analysis confirms that a significant relationship exists which can be explained by geographically weighted regression (GWR) in a far better way compared to ordinary least square (OLS) regression. According to the GWR, overall 50% change in air temperature is influenced or affected by light pollution, where in urban areas the impact of light pollution on air temperature is higher compared to rural areas. This research also unearths that light pollution is increasing at a dissolute rate, four-fold in 10 years. With this said, considering the nexus between light pollution and air temperature along with its other negative effects the authorities are expected to take measures to reduce light pollution.

Introduction

The people inhabit only 5% of the world's total land area, where more than 50% of the total world population is living in urban areas. Recently, the developing countries are experiencing the fastest growth of the urban population compared to the developed countries (Elvidge et al., 2007a; Elvidge et al., 2007b). As a result, urban areas are becoming more impervious than ever (Sinha et al., 2016). With rapid urbanization and economic development, the use of artificial night light is also increasing responding to a higher extent of human activities at night (Jiang et al., 2017). Nevertheless, poor design and unregulated use of artificial light are creating a phenomenon called 'Light Pollution' (LP) (Gallaway, 2010). LP is the unwanted, unintended and obtrusive aspects of artificial lighting, which largely results from bad lighting design and has negative impacts on the environment (Olsen et al., 2014).

Humans have altered the natural land cover (LC) type to meet their various needs from the beginning of time. With the increasing number of people, LC is changing drastically. Previous studies have found that different LC types have different relationships with land surface temperatures (LST) (Dontree, 2010). For example, naturally vegetated areas have a negative relation with LST whereas, the impervious surface has a positive relation

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with LST (USGS, 2016; Zeng et al., 2010). In response to LC change caused by rapid urbanization, LST is changing dramatically (Islam and Islam, 2013) and widening the gap between urban and rural temperature (Zhou and Wang, 2011). This is threatening urban habitats by raising mortality rate, increasing energy consumption and carbon emission, hence fueling global warming. All of which are damaging both the sustainability and livability of cities (Li et al., 2018; Sidiqui et al., 2016). Recent studies on continuous air temperature mapping have identified that LST and LC are significantly related to air temperature. Air temperature (ArT) measured at weather stations cannot depict the spatial variation of ArT over a large area because of the limited number. As a solution to this problem, Huang et al., (2017) propose a new method for estimating ArT. He used multiple linear regression considering LST, NDVI, and elevation as predictors (Huang et al., 2017). However, Zhang et al., (2018) used simple linear regression between LST and ArT to generate high-resolution spatial ArT. Moreover, Good (2015), used a dynamic multiple linear regression model to generate high-resolution spatial ArT for Europe.

Bangladesh was declared as the lower-middle income country by the World Bank in 2014 and is currently working on achieving the middle-income status by 2021 (The World Bank, 2016). It is a small country with a large population and 36.5% of them live in urban areas making these urban centers one of the most densely populated areas of the world. Urban population is still increasing at more than 3.3% per annum (*ibid*). Moreover, 62.4% of its total population has access to electricity.

Evidently, light pollution occurs in areas with higher population density, LC type with a higher percentage of impervious surface and higher LST. Moreover, ArT is related to the LC type and LST. Therefore, there might be a significant relationship exists between night light or light pollution and air temperature. As no prior research has been done regarding this issue, this paper aims to investigate how LP is affecting the ArT in Bangladesh.

Materials and Method

Data and Study Area

This research is on Bangladesh. However, as LP does not occur all over the country, only the light polluted areas of Bangladesh until 2013 is considered in this research. Moreover, 2003 and 2013 is selected as the study period for this research to observe the change.

Night light data is acquired from the Defense Meteorological Satellite Programs' Operational Lines can System (DMSP-OLS) sensor. This data provides a yearly average cloud-free night light data globally. Data from F14, F15, and F18 satellites are collected. For night light data of 2003, an average of F14 and F15 is computed and for 2013 data, only F18 data is used. After acquiring data, it is processed for further analysis. This includes projection, clipping, and demarcation of light polluted area. Where pixels of DMSP-OLS night light image containing positive value is identified as a light polluted area. Moreover, combining both years of data, the light polluted area was identified (Figure 1 B).

ArT is estimated using MODIS MOD11A1 daily Land Surface Temperature (LST) and MOD13A3 monthly vegetation indices data product of Terra constellation and ArT data from 34 weather stations of Bangladesh Meteorological Department (BMD) (Figure 1 A).

Multiple linear regression model is used in this research to estimate air temperature (***eq. 1***), where LST and NDVI are considered as the explanatory variable and air temperature as a dependent variable.

$$\boldsymbol{T_a = \alpha + \beta_1 * LST + \beta_2 * NDVI + \varepsilon} \dots\dots\dots\dots\dots\dots (\mathbf{1})$$

Where, T_a = Air Temperature, LST = Land Surface Temperature, $NDVI$ = Normalized Difference Vegetation Index, α = Intercept, β_1 & β_2 = Regression coefficients and ε= Random error.

Using data collected from weather stations, LST and NDVI data and the regression parameters β_1, β_2 α & ε are calculated. Applying the parameters to the satellite image, annual average continuous air temperature of 2003 and 2013 is calculated.

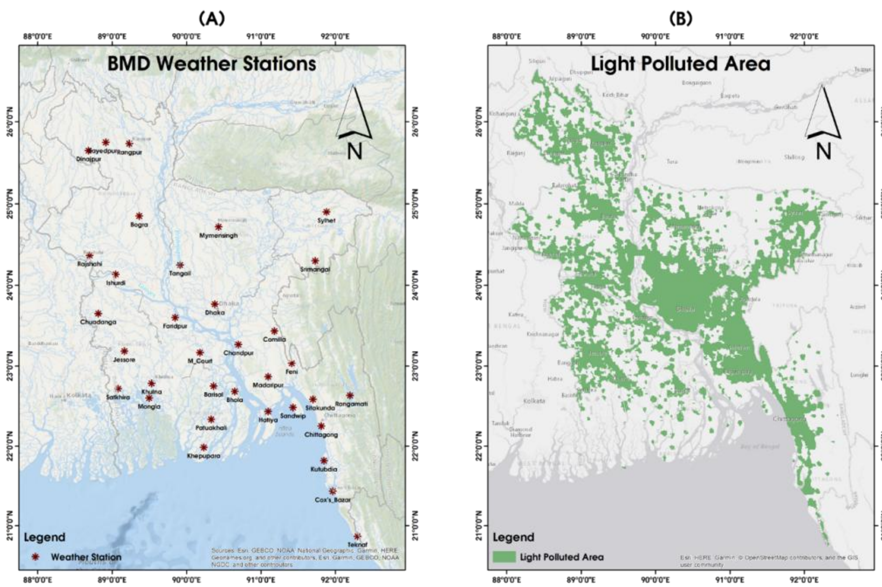

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Figure 1: Locations of BMD Weather Stations (A) and Light Polluted Area (B).

Change Detection

Discriminant function is used to identify the change of LP and ArT data between 2003 and 2013. This function provides a probability of change of DN value between two different periods for each pixel. The output value of the discriminant function ranges from 0 to 1, where a value close to 0 means a lesser probability of change and vice-versa. Among three types of changes, combined change function is used, which provides the probability of change (increase or decrease) of value over the change of time.

Results and Discussion

Light Pollution

DMSP-OLS night-light data shows that Bangladesh has experienced a rapid increase in light pollution between the year 2013 and 2003 (Figure 2). Applying the threshold value to declare light pollution (Butt, 2012), it is found that in 2003 only 7.1 percent of the total area of Bangladesh was light polluted, and in 2013, the amount of area dramatically increased to 25.4 percent (Table 1).

Table 1: Percentage of the light polluted area in 2003 and 2013.

Year	2003	2013
Not Polluted	92.9	74.6
Polluted	7.1	25.4
Low	5.1	21.1
Moderate	1.2	2.7
High	0.4	1.0
Extreme	0.3	0.6

Furthermore, using the natural breaks method, light polluted areas are categorized into three categories (low, moderate, high, and extreme). Majority of the light polluted area fall into low pollution category. However, in 2013 the area under this category increased more than four-fold compared to 2003. Remaining categories doubled in size by 2013.

Dhaka is the most affected urban area followed by Chittagong, Khulna, Sylhet, Rajshahi, Jessore, Rangpur, and other urban centers. In 2003, only urban centers were featured with light pollution. Nonetheless, in 2013 light pollution spread out into the suburban areas, indicating significant development of the human activity in these areas.

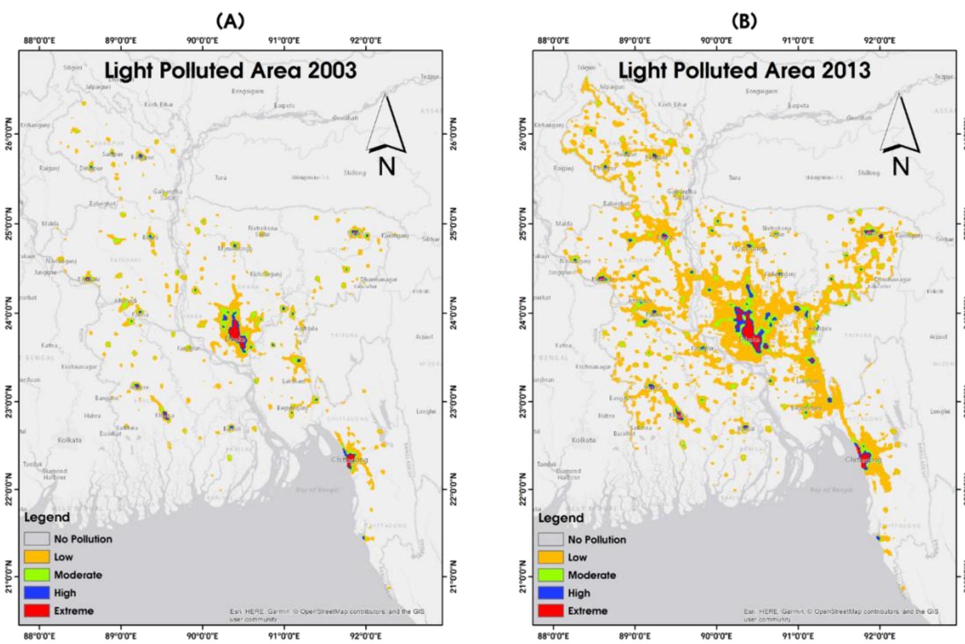

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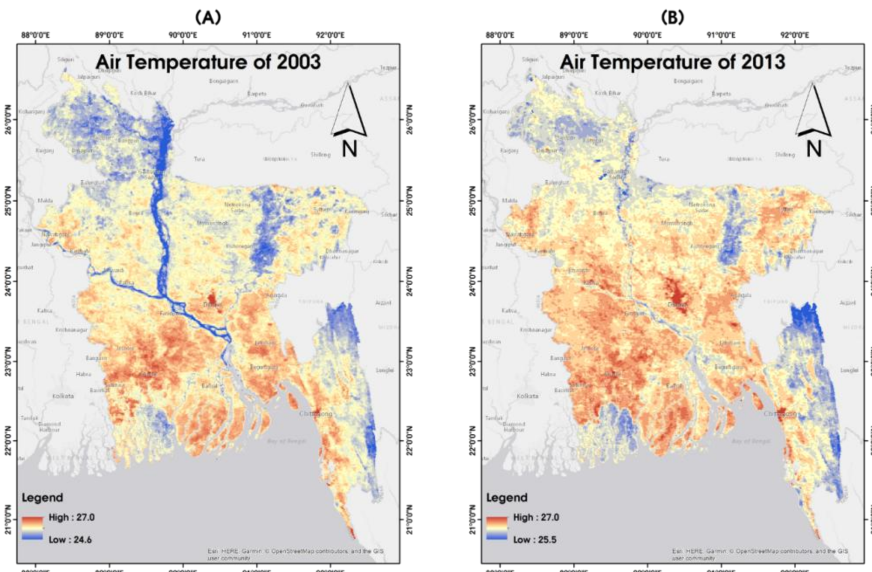
Figure 2: Light polluted areas of Bangladesh in 2003 and 2013.

Air Temperature

Air temperature maps are generated using equation 1 (Figure 3). GWR is not an option in this case as the number of data points (34 weather stations) available for this regression is not suitable for GWR. According to which, in 2013 the minimum annual average temperature increased up to 25.5°C compared to 24.6°C in 2003. However, the maximum annual average temperature remained the same (27°C). Evidently, the temperature in Rajshahi Division, river, haaor and hill tracks areas are less than the rest of the country. However, hotspots are found in both maps which are mainly the urban areas having the highest estimated temperature. Hotspots can be easily identified in the 2003 map for Dhaka and Chittagong. However, in 2013 the number of hotspots increased compared to 2003 whereas, the hotspots of 2003 increased in size. In 2013, the suburbs of Dhaka featured increased temperature compared to the surrounding rural areas. This phenomenon confirms that the urban areas, where natural land cover is less are prone to have a higher temperature (Islam and Islam, 2013).



Source: Author

Figure 3: Air temperature of Bangladesh in 2003 and 2013.

Nexus between Air Temperature and Night Light

Earlier studies characterized urban areas as light polluted areas (Butt, 2012; Elvidge et al., 1997; Khorram et al., 2014). Other studies also characterized them as warmer areas (Dontree, 2010; Sidiqui et al., 2016; Zhou and Wang, 2011). In Bangladesh, areas that have experienced an increase in LP in 2013 compared to 2003 also experienced an increase in ArT. To identify the nexus between ArT and LP, estimated discriminant function of combined change is used in the following analysis. Table 2 suggests that data of both variables are significantly clustered as depicted by positive Z-score and significant p-value. Following this result, cluster and outlier analysis is performed on both data sets.

The analysis shows that clusters exist in urban areas in both data sets. The cluster in Dhaka is significantly visible than other urban areas (Figure 4).

Table 2: Global Moran's I Summary

	Air Temperature	Night Light
Moran's Index:	0.4	0.1
z-score:	1399.8	489.8
p-value:	0	0

However, to understand the relationship between ArT and NL, both (ordinary least square regression) OLS and geographically weighted regression (GWR) is used, where the ArT is considered as the dependent variable and LP as an explanatory variable. The result shows that GWR outperforms OLS. AICc for GWR is considerably lower compared to OLS while Adjusted R^2 also shows significant improvement for GWR. Thus, the authors preferred GWR to explain the relationship between the variables. Moreover, the database contains 67,000 data points which are comparatively more suitable for GWR.

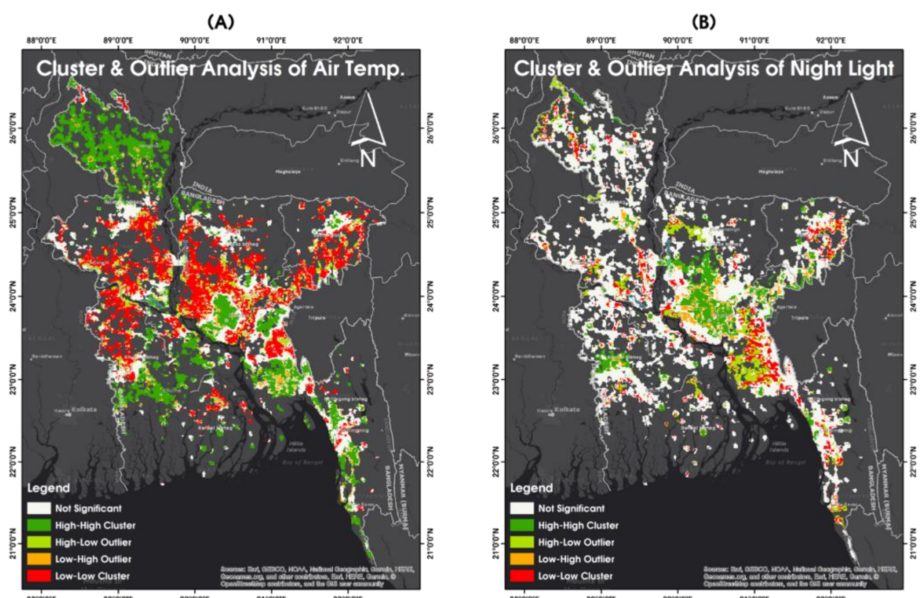


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Figure 4: Cluster and outlier analysis maps.

GWR was run using adaptive kernel. However, the model summary reveals that only 50 percent of air temperature change can be explained by the change in light pollution. The spatial variation of the relationship between ArT and NL (the coefficient of explanatory variable) is shown in Figure 5. The dark green areas on the map suggest that the relation between NL and ArT is relatively higher compared to the brown areas. Meaning, in green areas any change in NL will incur higher impact on ArT and vice versa.

Interestingly, the concentration of higher coefficients is observed mainly in urban areas. In other words, the more LP occurs in an urban area, the warmer the area is.

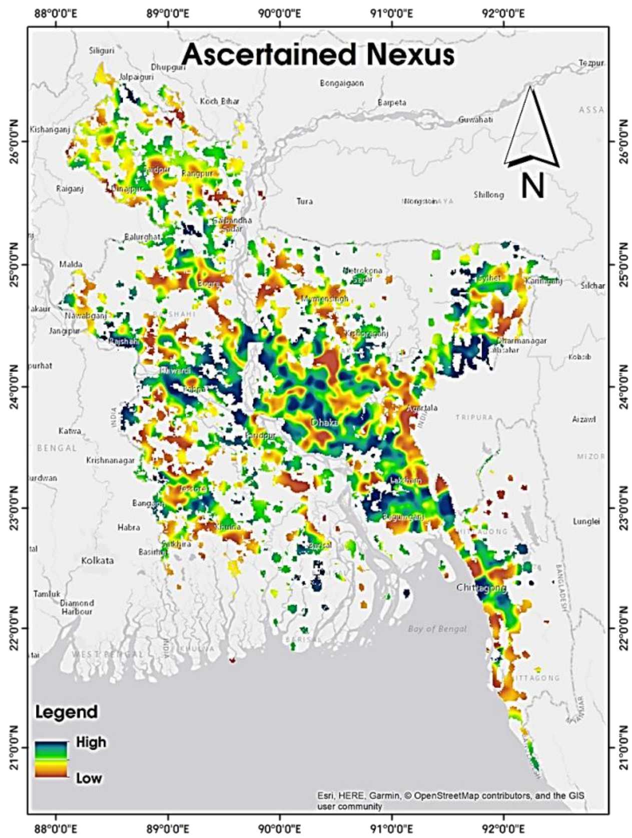

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Figure 5: Spatial variation in the relationship between the change of light pollution and the change of air temperature.

Conclusion

As lights generate heat, it is most likely to feel warmer where light pollution is higher. Moreover, light pollution also indicates the concentration of impervious surface, man-made objects, and higher human activity. As vegetation is less or absent in impervious surface, these areas are warmer than its surroundings. Therefore, increasing population density in urban areas will result in the brighter night sky and warmer temperature. However, light pollution alone cannot explain the total change in air temperature. Other factors such as land cover type, wind, humidity, solar radiation might have their own impact on it. As there is a lack of availability of high-resolution climatic data, they were not considered in this research. Moreover, land cover classification of large areas (e.g. entire Bangladesh) using remotely sensed data products (e.g. Landsat) is quite challenging for many reasons. Though machine-learning algorithms have proven to be competent in image classification with higher accuracy, they have their own limitations too. However, this research has successfully achieved its purpose in identifying the nexus between light pollution and air temperature, which is quite significant and considering the rate at which light pollution is increasing in Bangladesh, we should now consider it with due importance. The planning community and the researchers should work together to devise measures to limit light pollution in our country before it is too late. Countries like USA, UK, Canada, Italy, Germany, Chez Republic, and Singapore have taken planning interventions to reduce light pollution in their countries. And we should not fall behind.

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