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The estimation of the Skyglow by using the nighttime light satellite imagery in Northern Thailand

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ABSTRACT

The skyglow is scattering from natural light sources and non-natural light, which maximizes night sky brightness, resulting in visual impairment and star visualization loss. This phenomenon leads to an impoverished environment and surroundings. SNPP - VIIRS Day/Night Band (DNB) is a source for monitoring skyglow phenomena and Nighttime Light (NTL) spatial expansion trend in northern Thailand. A scatter plot model was applied to the data. The sky brightness and radiance from SNPP-VIIRS exhibited R2 values of 0.9488. And the correlation of sky brightness in summer and winter had a value of 0.888. During summer, the Aerosol Optical Depth (AOD) value increased by 2.3-times and the natural sky rose to 1 times magnitude brighter than winter. In contrast, the amount of brightness in the city area decreased, resulting from the NTL released skyward by luminaires with aerosol particles, generating a luminous background. This research estimates and illustrating the skyglow map for a more straightforward astronomical interpretation. Consequently, Bortle's map and the skyglow profile are crucial research tools for monitoring light pollution and understanding the skyglow characteristics of skyglow which varies upon the specific AOD value, a substantial amount of aerosol and intensity of light directed upward.

1. INTRODUCTION

Interestingly, less than 10 decades ago, the human could see a spectacular starry night sky with the naked eye. Nowadays, people around the world have never seen the Milky Way from their residences, especially in the big city. The massive amount of artificial light leads to visual impairment of seeing the starry night. Furthermore, there are substantial impacts on the environment.

Light pollution was a significant factor for astronomical observation in the second half of the 20 century when finding new locations for the astronomical observatories. The astronomers have addressed and concerned about the skyglow because it can limit human visual acuity to see the celestial objects. Also, the skyglow can brighten up the dark sky areas, which decreases the contrast of stars or other celestial objects against the dark sky background.

This concept demonstration study uses the Visible/Infrared Imager/Radiometer Suite (VIIRS) Day/Night Band (DNB) observations on the Suomi National Polar-orbiting Partnership (SNPP) satellite data. The method is applied for retrieving Aerosol Optical Depth (AOD)(τ) (Johnson, Zhang et al. 2013), utilizing the contrast among designated areas and artificial surface light data of the NTL satellite over the north of Thailand. Due to the summer situation, open biomass burning, including forest, bush and field fires, caused air pollution in northern Thailand. Most Northern Thailand was severely affected by smoke-haze pollution episodes caused by the emissions of forest and crop fires (Supasri, Itsubo et al. 2020)

Therefore, this research emphasizes estimating and illustrating the skyglow map from NTL satellite imagery and determining the correlation between the radiance values of the VIIRS DNB image and sky brightness in the magnitude unit. This study expresses the differences in the sky brightness in summer and winter by means of the Bortle's scale and skyglow profile.

2. METHOD

2.1 Study Area

In northern Thailand, the growth of urban areas of Chiang Mai, Chiang Rai, Lampang, etc. were selected to

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be the study area. Satellite imagery products from 2014 to 2019 were analyzed. By focusing on Chiang Mai, were recognized as a capital city of Northern Thailand

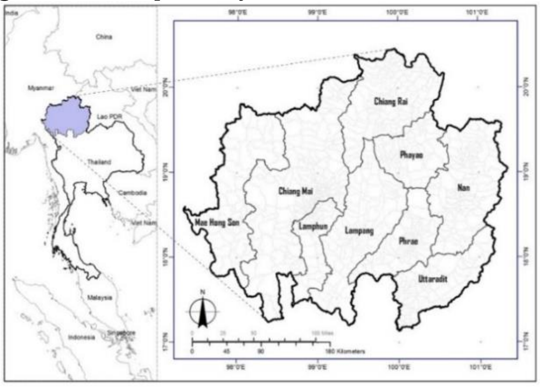


Figure 1. Map of studying area in Northern Thailand

2.2 Data collection step

Data collecting and data preprocessing are study methods for diagnosing information and supporting this research. The correction data were obtained from the NOAA and NASA Comprehensive Large Array-Data Google Earth Engine (GEE) site. The datasets were used to study the skyglow and dark sky. The SNPP/ VIIRS datasets were also downloaded and preprocessed in GEE by means of filling gap correction, mosaic image, re-projection, resampling, and co-registration to parallels with The NTL from VIIRS DNB and MODIS AOD product. Data from 2014 to 2019 were downloaded to analyze the relationship between the NTL radiance and AOD at 500 m resolution(Wang, Mu et al. 2020).

Table 1. Satellite imagery information

Imagery	Platform	Instrument	Image Resolution	Sensor Resolution
DNB	SNPP	VIIRS	500 m	750 m
AOD (550nm)	SNPP	VIIRS	500 m	750 m

2.3 Converting The VIIRS-DNB Image Data to Estimated Astronomical Units

The correspondence between VIIRS-DNB and SQM (de Miguel, Kyba et al. 2020) is quite essential to estimate the sky brightness. Typically, nW / cm^2 * sr is a SI radiometry unit for radiance. Radiance is radiant flux emitted, reflected, transmitted and received by a surface per unit solid, angle per unit projected area for satellite imagery data. Radiance can compare the raster of data from the sky's brightness measurement using the Sky Quality Meter (SQM) device to calculate it in units of mag/arcsec^2. The SQM is a device to measure the light of the incident sky on the CCD sensor and measure the number of photons against the standard value. Collecting the brightness quality data of the observed celestial area is helpful in studying the changes in the brightness of the sky. That makes the instrumentation accurate in international system units of astronomy.

The VIIRS DNB image's radiance values are relationships to brightness values using the following Alejandro Sanchez de Miguel's equation.

$$S = 20.0 - (1.9 * Log (VIIRS\ DNB)) \quad (1)$$

S is sky brightness in the magnitude unit. To convert the pixel value of VIIRS-DNB image data to mag/arcsec^2 in the astronomical unit for the analysis of the data in NTL satellite imagery.

2.4 Spatial Distribution

The spatial structure and variability of NTL were analyzed using geostatistical methods. Geostatistics analysis uses the 6-year mean values of the sky brightness were computed across the study area to analyze the spatial patterns (Suepa, Qi et al. 2016) of the spatio-temporal trends of NTL. In this research, NTL data were analyzed the brightness mean deviation by raster calculation of NTL monthly data using QGIS software to reduce the data between 2014 and 2019.

2.5 Bortle's scale

The Bortle's Scale, a nine-class numerical scale, is acknowledged as a technique used to estimate the surface sky brightness from the observation ground point during the night. Astronomically, it measures the observational capabilities of celestial objects and the intervention that occurred by light pollution. John E. Bortle (Bortle 2001) built the scale and published it in 2001. The scale clearly classifies from level 1, as the darkest sky in the world, up to level 9, the brightest sky in the city center. In the current study, the Bortle's Scale was criticized for the reliable results and the usefulness for classifying a separate map of the sky's brightness levels. The chart below shows Bortle's descriptive explanation of each level. Every single level differs from the one beside it, such as in Figure 2.

Figure 2. The Bortle's show the night sky's brightness by compared with the observational area of the constellations

2.6 Scatter Plots with Regression Model

The scatter plot model was used to evaluate the brightness's correlation in modelling the skyglow between the winter sky brightness data and the summer sky brightness data. This model also performed a regression analysis for quantifying the relationship between the two-period data (Li, Xu et al. 2013).

3. RESULTS

3.1 Skyglow Map

This experiment's results revealed the converting of the radiance from the VIIRS DNB satellite imagery to the universal astronomical sky brightness (mag/ arcsec^2) show in Figure 3.

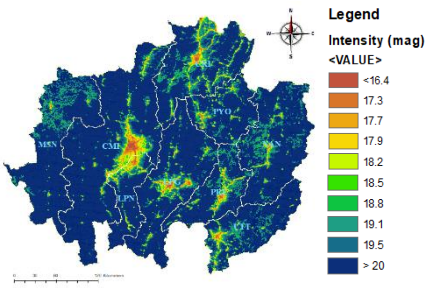


Figure 3. Optimized the nighttime light map for estimating the skyglow over northern Thailand. on December 11, 2019

The map shows the brightness (mag/arcsec ^{2}) of the night sky in northern Thailand. The sky in urban areas of Northern Thailand, specifically Chiang Mai, Chiang Rai, Lampang, Phrae, Uttaradit Phayao etc., was most brilliantly lit, approximately 16 mag/arcsec^2. In contrast, the night sky brightness in rural and forest areas was about 18 mag/arcsec^2 and more than 20 mag/arcsec^2, respectively.

3.2 Trend Analysis of NTL

The diagram in Figure 4 showed the Spatial Distribution NTL lighting. It presented the trends between 2014 and 2019, with bright tones representing the NTL change in more brilliant. In contrast, Dark tones show a dimmed light area. By the trend of changes since 2014, the spatial area has changed a lot. The urban area is much brighter than other areas. Chiang Mai Province tends to have the most changes in the northern provinces of Thailand.

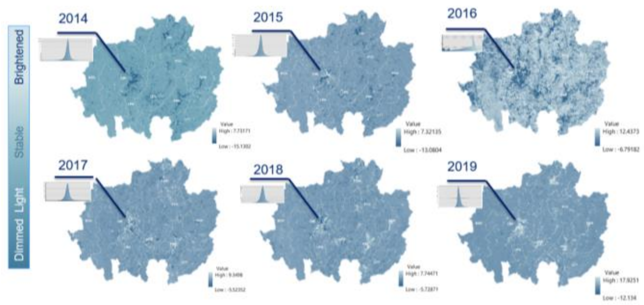


Figure 4. Nighttime light spatial distribution of brightness mean deviation from 2014 to 2019

3.3 Bortle's scale Map

The Bortle's Scale map presented a nine-scale numerical scale used to measure the night sky brightness and classify the light pollution levels, with each colour shade clearly identifying the different level of the sky brightness.

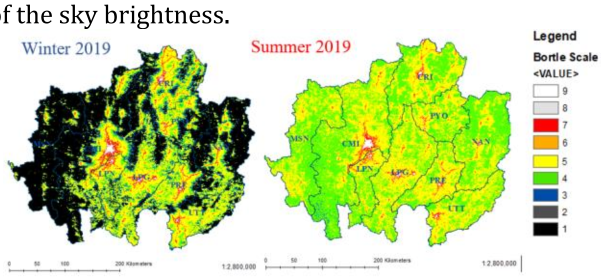


Figure 5. Skyglow map in 2019 to show light pollution in northern Thailand classified by using Bortle's scale model of light pollution between winter and summer.

Level 1(Black), considered the darkest is the light pollution-free zones, including the province's border. level 9(White) in the city of Chiang Mai regarded as the brightest, is the highest light pollution zone; meanwhile, level 7 (red) covered the other city center of each province. Maps in figure 5 revealed that light pollution in summer is distinctively more than in winter. The level 1 areas in winter became to level 4 in summer.

3.4 The Scatter Diagram of the Correlation

The graph (Figure 6 A.) shows empirical data and plots the correlation between the radiance (nW /cm^2 * sr) and brightness (mag/ arcsec^2) that occurred significantly as a nonlinear correlation. This can be explained by the nonlinear regression coefficient of determination known as R^2 value of 0.9488, which was considered as a higher correlation.

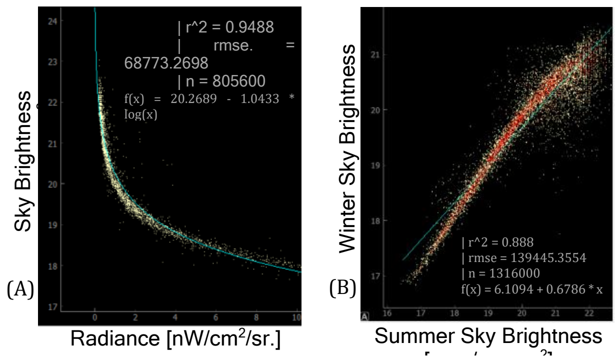
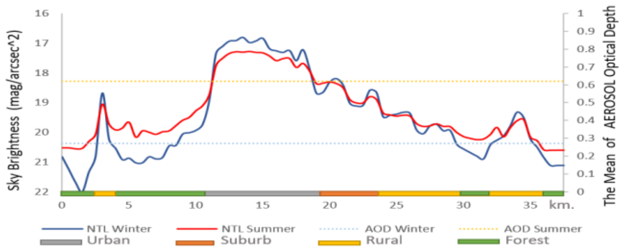


Figure 6. (A) A scatter plot of the relationship between radiance and sky brightness. **(B)** Correlation between the sky brightness model during winter and summer in Chiang Mai

Figure 6 (B) shows that R2 of the sky brightness between winter and summer in Chiang Mai is 0.888, which is perfectly correlated in 17 – 19.5 mag/arcsec^2 (Brighten) and dispersed about 19.5 – 22 mag/arcsec^2 .

3.5 The Skyglow Profile

In comparison, the AOD value of sky brightness in winter was 0.2725, but the summer value was relatively high 0.6254. The skyglow profile (Figure 7 A) showed the spotlight areas in winter had a high brightness value, whereas the dark areas had a low brightness value. In contrast, in summer, the brightness value was inversely proportional to winter. The brightness value of the Spotlight areas decreased. Particularly, the dark areas in summer, the background brightness had higher than in winter.



(A)

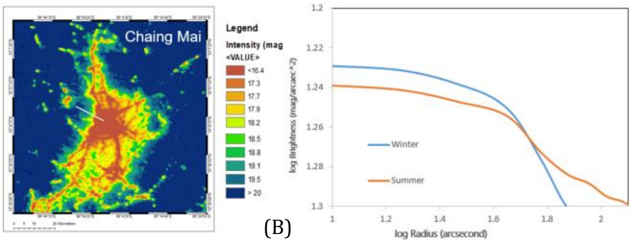


Figure 7. (A) The skyglow profile graph compares Chiang Mai's brightness during winter and summer and **(B)** Sérsic Skyglow Profile Model

4. DISCUSSION

In physics, the equation converter radiance (nW / cm² * sr) to brightness (mag / arcsec²) was not found. This research reviewed and examined the conversion from correlation, based on the research of Alejandro Sanchez de Miguel and his team, in a study of the nature of the diffuse light near cities and the correlation between the sky brightness at the zenith (The UCM sky brightness survey) and VIIRS imagery which were found to strongly correlated from the observational data(de Miguel, Kyba et al. 2020). Therefore, it is possible to convert the value by using the above equation.

The scatters plot model performed as a regression analysis to describe the relationship for quantifying the relationship between the two-period data (Li, Xu et al. 2013) as well as other NTL regression model. The scatters plot model could build the simple fit graph linear and nonlinear regression.

The Bortle's Scale map can be applied to identify and specify the degree of sky brightness and the area affecting light pollution by the colour differentiation. In observing the areas affected by light pollution, figures 5, 6 and 7 present interactions with forest fire dust expressed through AOD. The impact of the skyglow was severe. Remarkably, not only the amount of brightness in rural and national park areas increased but also the amount of brightness in the city area decreased. Significantly. This led to very little chance of seeing starlight with the naked eye in the affected area. Outstandingly, the dark sky during the winter season and the light pollution with the highest skyglow effect rate in the summer season were associated with changes in radiances over artificial light sources between aerosol-free and high aerosol loading (and cloud-free) nights(Zhang, Jaker et al. 2019).

5. CONCLUSION

This research exhibited the correspondence between radiance VIIRS-DNB imagery convert to sky brightness unit and then analyzed the Nighttime light spatial distribution of brightness mean deviation from 2014 to 2019. The trend of changing, mainly Chiang Mai city center, has the most change to brighten and the city center of each province also brighten too.

The Bortle's scale map to compare light pollution severity was accounted for the heart of estimating the attribute of skyglow in night time from satellite imagery. The Bortle's scale colour shades were efficiently implemented to compare the brightness maps and describe the sky brightness differences in winter and summer. The imagery was also interpreted more clearly.

Furthermore, the skyglow cross-section profile provided a noticeable ratio of the brightness range of the sky. A typical urban night sky usually is 5 times magnitude brighter at the zenith than the natural sky. In summer, the zenith of the natural sky rose up to 1 times brighter than winter. While the AOD value increased by 2.3-times in the summer, the effect of the sky brightness in the city center and the typical natural sky were inversely proportional to winter.

In addition, Sérsic Skyglow Profile Model was described when the nighttime light has been affected by aerosols in summer, then the intensity of the skyglow will be decreased but the radius of the skyglow will be expanded.

Eventually, this research was carried out towards achieving all of the objectives.

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