USING HIGH-RESOLUTION NIGHTTIME REMOTE SENSING DATA TO IDENTIFY LIGHT SOURCES IN HONG KONG

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ABSTRACT

Although artificial light at night (ALAN) is essential for nighttime activities, any unregulated and abusive usage can lead to severe degradation in quality of life. In this study, we used high-resolution nighttime remote sensing data of 1-meter spatial resolution to investigate light sources in an urban area of Hong Kong with one million residents. We classified ALAN sources into three categories based on their origins: *Building*, *Park*, and *Street*. We found that 42% of light was from *Building*, a large fraction of which was unnecessary decorative lighting such as signboards. Lighting from *Street* accounted for 41%, whereas an unexpectedly high proportion was associated with *Park* (17%), with sport facilities-related lighting being the dominant contributor. We also detailed one case study which shows the disruptive effects of unregulated usage of LED signboards to the neighboring residential apartments.

***Index Terms*—** Artificial light at night, light pollution, commercial lighting, sports lighting, remote sensing, Hong Kong

1. INTRODUCTION

Artificial light at night (ALAN) is a form of anthropogenic phenomenon [1]. Although it is essential for human activities, unregulated and abusive usage of ALAN leads to environmental degradation, bringing adverse effects on vegetation, animals, and humans [2, 3, 4]. In existing literature using remote sensing imagery to study ALAN, satellite sources such as the widely available images from VIIRS with 742 m ground sampling distance are among the most popular [5]. However, while light sources are often a small physical point source or a board the size of a shopfront, their impact may reach as far as 100 meters – still far more granular than the resolution of these satellite data though.

There exist a few studies using high-resolution imagery to identify light sources. For example, Levin et al. (2014) [6] introduced the EROS-B commercial satellite imagery (1-meter resolution) to identify light sources in Brisbane (Australia) and found arterial roads and commercial areas to be the brightest lit areas. Zheng et al. (2018) [7] introduced the Jilin satellite imagery (1-meter resolution) and classified the light sources into two types of electric lamps (high pressure sodium [HPS], light-emitting diode lamps [LED]). Yet, the analysis of using high-resolution imagery to identify light sources is still limited.

Effects of the observation angle with respect to the ground of nighttime imagery cannot be ignored even with the coarse spatial resolution of the VIIRS images [8]. Unlike its daytime counterpart, nighttime satellite imagery captures active light sources that are highly angle-dependent. In an urban landscape dominated by high-rise such as Hong Kong, light sources from a particular building wall can be visible from one viewing angle but invisible from another. The impact of observation angle is even more important in high-resolution satellite imagery because individual light sources, with their different angular lumen characteristics, can often be resolved. This observation angle effect brings challenges and opportunities. While it makes analysis difficult, it allows us to account for decorative lighting on building walls that are otherwise not visible from a strictly-overhead image [9].

In our study, using a high-resolution image of 1-meter spatial resolution taken by the Jilin 1-03 satellite, we investigated ALAN and its distribution in 67 subdistricts (officially District Council Constituency Areas, DCCAs) in an urban area of Hong Kong – one of the brightest or most light-polluted cities in the world [10]. The study area is approximately 60 km^2 land and water area, covering one million residents, 14% of the city's population. We classified the light sources into three categories based on their origins: *Building*, *Park*, and *Street*. To account for the observation angle, we used a high-resolution building dataset with the building

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height information (1-meter resolution) and reconstructed the building height at the time when the image was taken. We further identified the ultra-bright area and conducted field works to find out the light sources and analyzed how they may affect the urban environment. We demonstrated one case study showing how a signboard with unregulated lighting has created light trespass and affected the nearby residential apartments.

2. DATA AND METHOD

The nighttime image was captured by the Jilin 1-03 satellite at 22:45:48 local time (UTC+8) on 28 June 2017 (Figure 1). The image has a spatial resolution of 0.92 meters and three RGB channels. The image was taken off-nadir, with an elevation angle of 64.75 degrees and an azimuth of 234.38 degrees, roughly equivalent to observing from southwest to northeast. In this setting, lighting from southwest walls of buildings was captured, but from the northeast walls was blocked. We resampled the image to 1-meter spatial resolution using a bilinear interpolation algorithm while georeferencing the image.

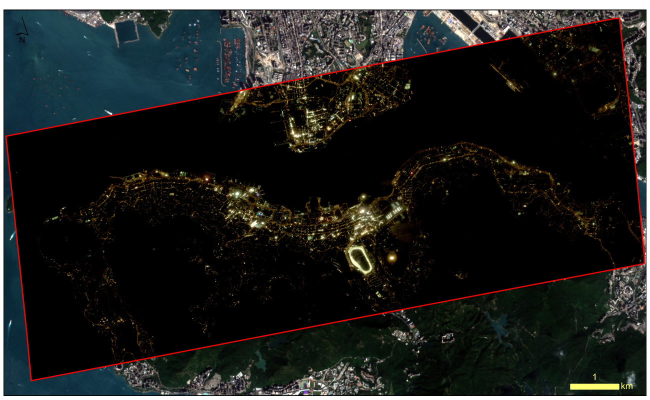

Fig. 1. The nighttime image covering one million residents.

We used the official formula obtained from the data header to calibrate the image, converting the raw digital number (DN) to energy unit (L):

$$L = a \times DN + b \quad (Wm^{-2}sr^{-1}um^{-1}). \tag{1}$$

The coefficients a and b are 0.000809 and 0.003825 for the red channel, 0.001538 and 0.005694 for the green channel, and 0.003539 and 0.015821 for the blue channel, respectively.

To determine the building areas in the off-nadir image, we reconstructed their heights at the time when the satellite captured the image. Denote the elevation angle as ϕ and the azimuth angle as α. In this off-nadir image, they are 64.75 degrees and 234.38 degrees, respectively. For a pixel (x, y, h) in the 3-D building footprint mask, where x, y are along the direction of longitude and latitude, respectively, and h is the height of the building, its observation at this off-nadir image will be offset to northeast by a length of its height projection h_p:

$$h_p = \frac{h \cdot cos\phi}{sin\phi}. \tag{2}$$

The offset direction is affected by azimuth α:

$$(\delta x, \delta y) = (h_p \cdot \sin\alpha, h_p \cdot \cos\alpha)\,. \tag{3}$$

The Lorenz curve and Gini coefficient are used to describe the imbalanced distribution of artificial light. In our study, the perfect equality is a 45-degree line where the $X\%$ areas corresponds to $X\%$ lighting $F(X)$. The Gini coefficient is the area enclosed by the perfect equality and Lorenz curve, which can be calculated as

$$G = 1 - 2\int_0^1 F\,(X)\,dX. \tag{4}$$

In our study, the x-axis is the subdistricts, and the y-axis is lighting. A higher Gini coefficient indicates a higher inequality of the distribution of light emissions. We argue that if a high inequality occurs, it is due to the overusage of ALAN in the extra-bright regions, which is the main cause of light pollution.

3. RESULTS AND ANALYSIS

The analysis was conducted at two levels. On a macro level, We used the Gini index to demonstrate the unequal distribution of ALAN. Within each district, we analyzed the composition of the three types of light sources. On a micro level, individual light sources were identified. We used a case study to demonstrate the potential of using high-resolution satellite imagery to identify light sources that have significant impacts on the urban environment.

Overall, the light emission was dominated by blue light (44%), as compared to the green (35%) and red (21%) colors. Geographically speaking, a highly disproportionate distribution was found. We measured a Gini index of 0.756 in the studied area of 67 subdistricts in blue light, which was 0.146 higher than the expected value had the ALAN was equally distributed (Figure 2). This is consistent with the finding that almost half of the light emission from the entire metropolis came from the districts of Central (19%) and Tsim Sha Tsui (TST, 16%), characterized by the bustling commercial activities, and the Happy Valley district (12%), dominated by the horse track facility.

Light emission from buildings accounted for 42%, compared to parks or sports facilities-related (17%) and streets (41%). For each subdistrict, the distribution of three light sources varies, as shown in Figure 3. Figure 3 is ordered by the percentage of light emission from buildings. Subdistricts with a high percentage of light emission are mainly from two categories: major residential areas (Nam Fung, Whampoa West, Aldrich Bay, Centre Street) or major commercial areas (TST Central, Causeway Bay, Chung Wan).

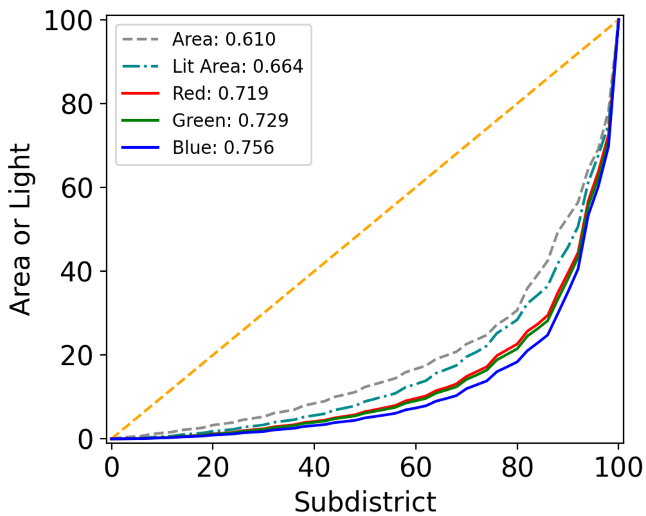

Fig. 2. Gini indexes. If equal distribution: 0.610. If equal distribution across lit areas: 0.664. Actual distribution of red light: 0.719. Actual distribution of green light: 0.729. Actual distribution of blue light: 0.756.

Passive light sources are light reflected by walls because of an overbright urban environment. For residential areas, the high percentage of light emissions from buildings is a result of a lack of other commercial light sources (relatively dark areas). For commercial areas, the high percentage of light emissions from buildings is a result of decorative lighting from building walls. In the later setting, light emission from buildings includes two parts, either from active light sources or passive ones. Active light sources include LED signboards for decorative purposes and interior lighting emitted from windows.

Figure 4 shows a case study of a high-rise residential building (named Kwan Yick Building, hereafter called the Building) in a residential area. The light source from another residential building lit up the walls of the Building, making the building visible from nighttime satellite imagery. In this case, the passive light source, the Building, was like the Moon, and the other building with the light source was like the Sun – both contributing to increased ALAN. From the photo taken inside the residential building, we can see how the LED signboards affected the building environment.

4. CONCLUSIONS

This study advanced artificial light at night (ALAN) research by using very high-resolution (1 m) imagery that can capture specific light sources in complex high-density urban areas dominated by high-rise. Results show a highly unequal distribution, with almost half of the light emission came from only 3 out of the 67 districts surveyed. Buildings and sports-related lighting contributed the most to light emission – and

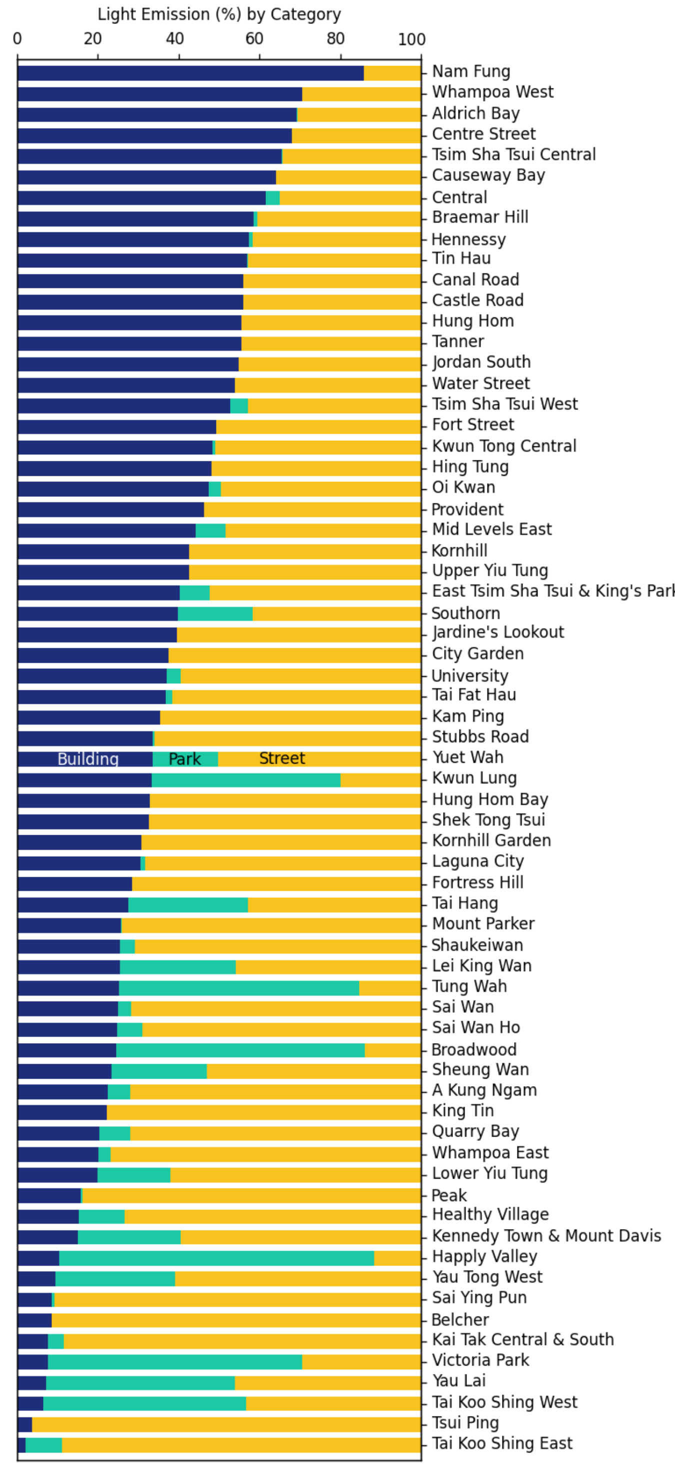

Fig. 3. Breakdown of light emissions. Blue: buildings; green: parks; yellow: streets.

since most were for non-essential purposes – policies and regulations should be implemented to reduce the unnecessary light emission to the night sky. Actionable regulations include adding shielding, reducing unnecessary decorative

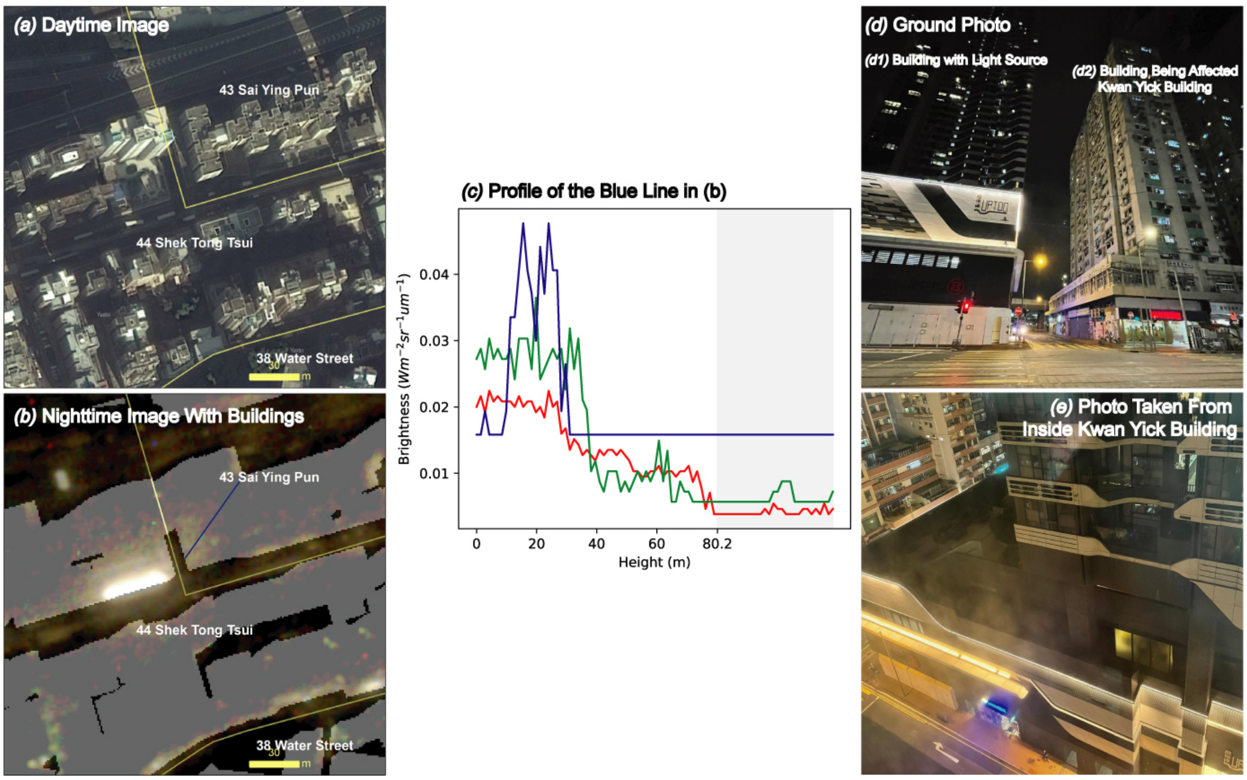

Fig. 4. Case study of the lighting environment of the residential high-rise Kwan Yick Building (hereafter referred to as the Building). *(a)* daytime satellite imagery for reference. *(b)* nighttime satellite image, overlapped with 3-D building structures. The blue line marks the vertical direction from ground floor to the rooftop of the Building. Note there is a single major light source on the left, which was a series of signboards shown in (d). *(c)* Light profiles along the vertical line; reached maximum at around 20 meters, 5th-6th floor. *(d)* The Building (right) and the nearby signboards (left). Even without active light sources, the walls of the Building reflected the light of environment and appeared to be bright in satellite imagery shown in (b). *(e)* Photo taken through a window of a residential apartment inside the Building to highlight the impact by the nearby LED signboards.

lighting, and building more indoor sports facilities. The off-nadir nighttime images bring challenges in processing the data and yet provide opportunities that can detect lighting from the side walls of buildings. These off-nadir images and multi-angle observations will benefit future ALAN research [9].

5. REFERENCES

[1] Knop et al., "Artificial light at night as a new threat to pollination," *Nature*, vol. 548, no. 7666, pp. 206–209, 2017.

[2] Meng et al., "Artificial light at night: an under-appreciated effect on phenology of deciduous woody plants," *PNAS Nexus*, 2022.

[3] Van Doren et al., "High-intensity urban light installation dramatically alters nocturnal bird migration," *Proc. Natl. Acad. Sci. U.S.A.*, vol. 114, no. 42, pp. 11175–11180, 2017.

[4] Holzhauer et al., "Out of the dark: establishing a large-scale field experiment to assess the effects of artificial light at night on species and food webs," *Sustainability*, vol. 7, no. 11, pp. 15593–15616, 2015.

[5] Liu et al., "Analyzing long-term artificial light at night using VIIRS monthly product with land use data: Preliminary result of Hong Kong," in *IGARSS 2021*. IEEE, 2021, pp. 6821–6824.

[6] Levin et al., "A new source for high spatial resolution night time images—the EROS-B commercial satellite," *Remote Sens. Environ.*, vol. 149, pp. 1–12, 2014.

[7] Zheng et al., "A new source of multi-spectral high spatial resolution night-time light imagery—JL1-3B," *Remote Sens. Environ.*, vol. 215, pp. 300–312, 2018.

[8] Li et al., "Anisotropic characteristic of artificial light at night–systematic investigation with VIIRS DNB multi-temporal observations," *Remote Sens. Environ.*, vol. 233, pp. 111357, 2019.

[9] Kyba et al., "Multiple angle observations would benefit visible band remote sensing using night lights," *J. Geophys. Res. Atmos.*, vol. 127, no. 12, pp. e2021JD036382, 2022.

[10] Chun Shing Jason Pun and Chu Wing So, "Night-sky brightness monitoring in Hong Kong," *Environ. Monit. Assess.*, vol. 184, no. 4, pp. 2537–2557, 2012.