Journal of Quantitative Spectroscopy & Radiative Transfer 139 (2014) 90–108

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

Contributions of artificial lighting sources on light pollution in Hong Kong measured through a night sky brightness monitoring network

Chun Shing Jason Pun, Chu Wing So*, Wai Yan Leung, Chung Fai Wong

Department of Physics, The University of Hong Kong, Pokfulam, Hong Kong

ARTICLE INFO

Article history:
Received 19 August 2013
Received in revised form
9 December 2013
Accepted 14 December 2013
Available online 28 December 2013

Keywords:
Light pollution
Night sky brightness
Skyglow
Moon radiation
Urban lighting

ABSTRACT

Light pollution is a form of environmental degradation in which excessive artificial outdoor lighting, such as street lamps, neon signs, and illuminated signboards, affects the natural environment and the ecosystem. Poorly designed outdoor lighting not only wastes energy, money, and valuable Earth resources, but also robs us of our beautiful night sky. Effects of light pollution on the night sky can be evaluated by the skyglow caused by these artificial lighting sources, through measurements of the night sky brightness (NSB). The *Hong Kong Night Sky Brightness Monitoring Network* (NSN) was established to monitor in detail the conditions of light pollution in Hong Kong. Monitoring stations were set up throughout the city covering a wide range of urban and rural settings to continuously measure the variations of the NSB. Over 4.6 million night sky measurements were collected from 18 distinct locations between May 2010 and March 2013. This huge dataset, over two thousand times larger than our previous survey [1], forms the backbone for studies of the temporal and geographical variations of this environmental parameter and its correlation with various natural and artificial factors. The concepts and methodology of the NSN were presented here, together with an analysis of the overall night sky conditions in Hong Kong. The average NSB in Hong Kong, excluding data affected by the Moon, was 16.8 mag arcsec^{-2}, or 82 times brighter than the dark site standard established by the International Astronomical Union (IAU) [2]. The urban night sky was on average 15 times brighter than that in a rural location, firmly establishing the effects of artificial lighting sources on the night sky.

1. Introduction

Outdoor lighting is an indispensable element of modern civilized societies for safety, recreation, and decorating purposes. However, poorly designed outdoor lighting systems and excessive illumination levels can lead to light pollution [3,4]. The scattering of artificial light by cloud, aerosol, and pollutants such as suspended particulates in the atmosphere spread the effects to distances beyond the position of the lighting source and can brighten the entire night sky [5]. Light pollution is a form of environmental degradation in which excessive artificial outdoor lighting affect the natural environment and the ecosystem. It not only represents a waste of energy, money, and valuable Earth resources, but also indirectly contributes to the global environmental problems. Last but not least, the skyglow due to these artificial lighting sources leads to the degradation of the quality of night sky and reduces the number of observable stars, robbing us the beautiful night sky on dark nights when it would otherwise be visible.

The energy wasted by artificial lighting sources can be directly monitored by night-time images of the Earth. Satellite imagery taken from the US Air Force Defence Meteorological Satellite Program (DMSP) Operational

* Corresponding author. Tel.: 852 2859 2360; fax: 852 2559 9152.
E-mail address: socw@hku.hk (C.W. So).

0022-4073/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jqsrt.2013.12.014

Linescan System (OLS)[1] sampled large areas of landmass at a moderate spatial resolution (~1 km), making studies of the extent and degree of night time radiation over a metropolis or even globally possible [6–9]. The night-time photographs taken by astronauts onboard the International Space Station (ISS)[2] provided even higher spatial resolution (at ~6 m per pixel) for selected locations on Earth. While the light intensity on the ISS photograph of Hong Kong was found to be positively correlated with population density in general [10], the scarcity of these photographs was insufficient for studies of nightly variations of light pollution in the city.

The extent of light pollution can also be monitored by studying the night sky brightness (referred to as NSB hereafter). The NSB is a combination of the natural sky glow due to celestial objects (Sun, Moon, planets, stars, Milky Way, galaxies, etc.), and the sky glow due to direct or reflected light from artificial lighting sources. Apart from the effects of the Sun and the Moon, the chief contributor to the NSB for a highly populated metropolitan city is the artificial lighting source. The level of the NSB had mostly been studied at professional astronomical observatories using the traditional astronomical technique of photometry — the amount of light detected in star-free regions on the CCD images was extracted to estimate the NSB at different wavelength bands [11–17]. This kind of observation helped astronomers to reveal potential light pollution threats to the observatory and aid in their search for a new potential dark observing location. These observations would normally require skilled personnels using delicate experimental setup (telescope/lens/camera/mounting). The geographical and temporal coverages of those studies were usually limited (limited to a single site, and only a relatively few observations per night).

Large-scale surveys of the sky conditions had also been carried out by campaigns which recruited ordinary people to conduct visual studies of the night sky following simple procedures with minimal technical expertise required, such as the *GLOBE at Night*[3] and the *Great World Wide Star Count*[4] projects. Without the need for specialized or expensive equipment, this kind of citizen-science project encouraged a large number of people from around the world to take part in studies of light pollution, yielding results with broad geographical coverage and high spatial resolution if the number of observers were large enough. Furthermore, many observations were conducted near places where the participants lived, such as city centers or suburban regions, or at places that they could gain access to, such as country parks. Recent comparison of a subset of the *GLOBE at Night* results with the night-time satellite images illustrated that this kind of study has huge potential for global scale studies of the night sky [6].

Hong Kong is a populous metropolitan city (mid-2012 population 7,154,600 [18]) with a high population density (6620 per km^2), known for its spectacular night lights. The mountainous city has a complex geographical landscape, leading to a short supply of habitable land. A photograph taken from the ISS in March 2003 (Fig. 1) revealed the huge amount of upward shooting light at night. As seen in the figure, there were substantial variations in the level of night-time emission from the city, mostly due to differences in population and land utilization. It seems obvious that the degree of light pollution in Hong Kong should be strongly dependent on human activity, in particular, how and where people use external lighting.

The availability of low-cost light sensors originally targeted for the astronomical community allowed for detailed and comprehensive studies of the NSB. Between 2007 and 2009, we conducted a citizen-science survey of light pollution in Hong Kong by inviting students, astronomy enthusiasts, and campsite employers to measure the NSB using one such device, the Sky Quality Meter (SQM) [1]. Compared to projects such as *GLOBE at Night*, the use of a standard measuring device in this study reduced the uncertainties in night sky measurements due to variations in observers′ eyesight and experience. From the over 2000 measurements taken at almost 200 locations by over 170 volunteers, it was concluded that light pollution in Hong Kong is severe, with large brightness contrast between the observed urban versus rural locations. Moreover, later night skies (at 23:30, local time (UTC+8) hereafter) were generally darker than at an earlier times (at 21:30), which could be attributed to some public and commercial light sources being turned off late at night.

This survey not only provided the first glimpse of the light pollution situation in Hong Kong, but also spread the message of dark sky conservation and energy saving among students and the general public through participations in the hands-on sky brightness measurements and first-hand observations of the environmental consequences of light pollution. However, the dataset collected was limited by its geographic distribution (volunteers made measurements usually within or near urban population areas), temporal resolution (a majority of volunteers made measurements usually once or twice every several nights), a short monitoring time (volunteers were swapped every few months to allow for more participation), and possible human-related errors (volunteers might make mistakes during measurements and/or data reporting).

We launched the succeeding project *Hong Kong Night Sky Brightness Monitoring Network* (referred to as NSN hereafter) in 2010 to comprehensively study the properties of the NSB in Hong Kong and its dependence on time, location, and various atmospheric and meteorological conditions with the support of the Environment and Conservation Fund of the Hong Kong SAR government. The range, depth, and accuracy of data collection were optimized by setting up automatic NSB measurement stations in 18 distinct urban and rural locations around Hong Kong. All these stations were designed so that on-site NSB monitoring for over a year was possible after securing long-term commitments from our collaborating partners (refer to acknowledgment section for the full list). The temporal resolution of data collection was vastly improved and human errors were eliminated through the use of the ethernet version of the SQM. In Section 2,

[1] http://ngdc.noaa.gov/eog/
[2] http://eol.jsc.nasa.gov/
[3] http://www.globeatnight.org/
[4] http://www.windows2universe.org/citizen_science/starcount/