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RESEARCH ARTICLE

Map of Sky Brightness over Greater Bandung and the Prospect of Astro - Tourism

Rhorom Priyatikanto[1] , Agustinus Gunawan Admiranto[2], Gerhana Puannandra Putri[3], Elyyani[4], Siti Maryam[5] and Nana Suryana[6]
[12456]Space Science Center, National Institute of Aeronautics and Space (LAPAN), Bandung, Indonesia
[3]Space and Atmosphere Observing Station, National Institute of Aeronautics and Space (LAPAN), Sumedang, Indonesia

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Corespondent Email:
rhorom.priyatikanto@lapan.go.id

Abstract In this paper, results of moving campaigns of night sky brightness measurement over Greater Bandung area are reported as a part of the first step to mitigate the level of light pollution in the area and its multidimensional impact. Though the campaigns were not commenced in ideal condition in terms of cloud cover and moon light contamination, some statistical treatment and moonlight correction were performed to improve the quality of the data. The obtained value of sky brightness range from ~17 mpsas at downtown region to ~20 mpsas at Haurgombong, Sumedang which is more than 30 km away from the city center. It is in agreement with months-length stationary measurements of sky brightness over Bandung, Lembang, and Sumedang. R-square (R^2) between this in-situ measurement and the average nighttime radiance map from Visible Infrared Imaging Radiometer Suite Day/Night Band (VIIRS-DNB) was found such that empirical relation between the two variables can be utilized to create the map of sky brightness over Greater Bandung area. From this map, it was found that majority (~90%) of the existing tourism destinations, hotels, and resorts in the region belong to the third class of astro-tourism site where only bright celestial objects are observable. Better locations (class 2) can be found in Ciwidey, Cikole-Ciater, and Padalarang regions.

1.Introduction

Light pollution which is defined as inappropriate or excessive use of artificial lighting becomes another form of pollution produced by modern human civilization. This can either be glare, skyglow, light trespass or clutter with various negative impacts on different aspects of life in biosphere, ranging from human health to wildlife, from waste of energy to decrease of stellar visibility (Isobe and Hamamura, 2000; Chepesiuk, 2009; Gallaway et al., 2010; Falchi et al., 2011; Lunn et al., 2017). In some literatures, light pollution can also be categorized into astronomical, ecological, and polarized light pollution depends on the perspective used and the impacted aspect of life (Longcore and Rich, 2004; Horvath et al., 2009). The first category refers to the excessive light directed, reflected, or scattered to the night sky that degrade human view to the starry night sky. The ecological light pollution can be regarded as the alteration of natural pattern of light and dark that affects ecosystem, including human. Some fraction of the light pollution can be linearly polarized by human-made objects or by the atmosphere and rise a threat to the animals sensitive to the polarized light.

From the perspective of culture, light pollution snatches away valuable opportunity of the modern society to perceive the beauty of starry night sky which inspires so many forms of art and sciences (the light pollution here and then refers to the astronomical light pollution, unless explicitly stated). Enjoyment of the beauty of night sky can also be regarded as passive pleasure which is fundamental to human welfare and recreation of the society (Gallaway, 2010). As the level of light pollution increases from time to time, dark sky becomes scarce commodity for urban community such that a novel concept of astro-tourism (Iwaniszewski, 2015) find its place in sustainable ecotourism while preservation of dark sky as natural heritage becomes necessary. With increasing global human population and habitat, dark sky preservation seems to be possible if the society are aware of the consequences negative consequences caused by astronomical and ecological light pollution and take action on it. This awareness needs to be raised through education and promotion that can be wrapped in astro-tourism.

In order to identify the potency of astro-tourism that market the starry night sky in Indonesia, proper mapping of light pollution level over this country is required. Quantitative information on how pristine the night sky over particular area will be combined with the existing conventional tourism map to determine whether that tourist area can be upgraded to offer astro-tourism. Spatial information on light pollution or sky brightness is also demanded by the governing authority for establishment of dark sky sanctuary, reserve, or park as a policy-based way to preserve the beauty of night sky as outlined by the International Dark-Sky Association (IDA). The ideal way to determine the area of dark sky reserve or the area for further development in astro-tourism requires multi-dimensional consideration. This process is almost similar to the selection of astronomical observatory that consider climatological, geological, geographical, and also infrastructure access. Those variables need to be considered in order to find the area or site with the best visibility to the night sky (Hidayat et al., 2012; Koc-San et al., 2013). Geographical and anthropogenic data, especially the map of light pollution or sky brightness has the central role in this context.

Global map of artificial sky brightness was first constructed in early 2000s (Cinzano et al., 2001) based on nighttime satellite imagery acquired by DMSP-OLS (Defense Meteorological Satellite Program Operational Linescan System) and light propagation model (Cinzano et al., 2000). This global map was updated by Falchi et al. (2016) using more recent nighttime observation by Visible Infrared Imaging Radiometer Suite Day/Night Band (VIIRS-DNB). With higher resolution and dynamic range, VIIRS-DNB imagery enabled the team to create more accurate map of sky brightness with spatial resolution up to 750 m. The resulted map was tuned and validated using in-situ measurements conducted in number of places, mostly in Europe and North America regions. Those measurements were done using Sky Quality Meters (SQMs) which produce the values of sky brightness expressed in magnitude per square arcsecond (mpsas). The root mean square error between in-situ measurements and satellite-based model is around 0.3 mpsas. The systematic error of the model or the map may rise following the local atmospheric characteristics that deviate from the global average (Falchi et al., 2016).

More in depth mapping of sky brightness with relatively smaller scope were also performed and reported by some authors. Biggs et al. (2012) performed kriging to SQM data obtained at various locations to construct 30 km-radius sky brightness map over Perth, Western Australia. Zamorano et al. (2016) constructed high resolution map of sky brightness over Madrid, Spain, based on moving observing campaigns covering area of about 200×200 km^2. They emphasized that single source model is not sufficient to produce the observed sky brightness over the area, even though Madrid as the biggest city becomes the dominant source of light pollution. Small scope mapping can also be performed using stationary measurements at several closely located points as conducted by Tahar et al. (2017) at Langkawi Island. Using data gathered from 16 points, they produced sky brightness map covering area of approximately 30×30 km^2. Those studies pointed out that empirical models based on in-situ measurement still have important position in the mapping of sky brightness and artificial light pollution.

This paper aims to create a map of sky brightness over Greater Bandung area (Bandung, Cimahi, and Sumedang), based on the measurement campaigns conducted in 2018. Empirical model that combine the in-situ measurements and satellite nighttime imagery was used for this objective. and also to analyze the prospect of astro-tourism to be developed in the area by considering current situations. Greater Bandung area becomes the scope of study since this area hosts several sites with astronomical values such as Bosscha Observatory in Lembang and Puspa IPTEK (The Sundial) in Padalarang.

2.The Methods

Measurement Campaigns

Measurement campaigns were conducted on 19-20 July and 11-12 October 2018 with different routes which basically started from Space Science Center LAPAN on the west part of Bandung City, went eastward to Sumedang, and back to the initial point. Data acquisitions were conducted along the routes, with relatively even sampling distance. The routes were selected based on some considerations. Firstly, they need to cover the brightest region of the city, peri-urban, and also rural area with low expectation of light pollution such that the measurements cover the wide range of condition. Secondly, roads with minimum glare (from street light or billboard) and clear view to the sky are preferred such that measurement noise are avoided. However, such ideal condition cannot be achieved every time such that median filtering was implemented to the data.

On the first campaign, the Moon was in first quarter phase such that it was ~ 60° high on the western part of the night sky when the campaign commenced at 20.00 local time (UT+7). Analytical model of scattered moonlight by Krisciunas and Schaefer (1991) was used to correct sky brightening due to moonlight. The numerical correction to the magnitude of sky brightness is less than 2 magnitude, depend on the zenith distance of the Moon and its illumination. After such correction, measured values more resemble the night sky brightness without moon. The weather at that time was relatively clear as indicated by sky brightness profile obtained at Sumedang Station on the same night (see Figure 1). On the second campaign, the Moon was at early phase and located below the horizon such that it did not influence the observed night sky brightness. However, the cloud cover at this time was higher resulting scattered data.

For the campaigns, measurement devices were attached on top of the car which moved at rather low speed to get closely spaced sampling locations. Unihedron Sky Quality Meter (SQM) and smartphone navigation system were two essential instruments for this campaign. SQM-L is a diode-based photometer

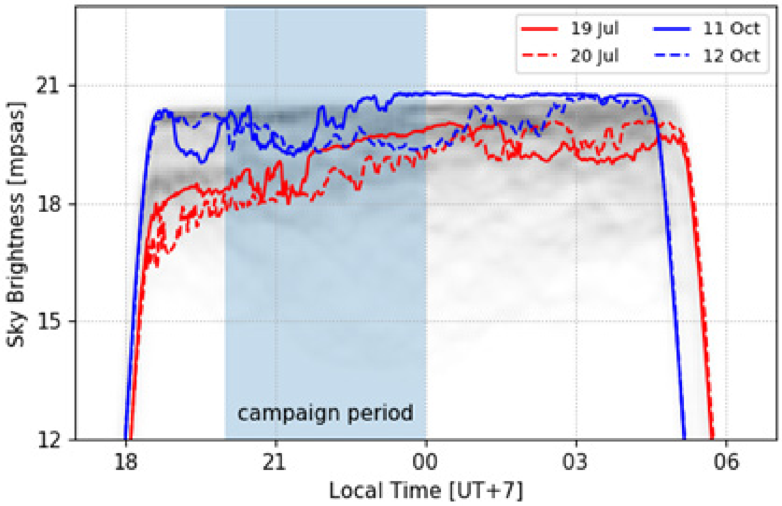

Figure 1. Sky brightness over Sumedang measured on 19/20 July (red) and 11/12 October (blue) plotted over the whole year measurements (grays). The data is not corrected for moonlight. Flat top of the sky brightness curve over time means clear sky without Moon appearance.

which works at ultraviolet (300 nm) to infrared bands (1000 nm) with maximum efficiency reaches 60% while the effective field of view is about 20° (Cinzano, 2005). In recent years, this instrument becomes popular choice for sky brightness measurement and research as it is reliable, inexpensive and also viable for measurement on moving platform (Hänel et al., 2018). SQM yields sky brightness in terms of magnitude per square arc second (mpsas) and its precision is 0.01 mpsas. This scale is proportional to the logarithm of measured intensity and smaller value means brighter sky.

Two types of SQM were used in this study, namely SQM-L (handheld) which manually operated by pressing hard button on it and SQM-LU DL which is complemented with data logger to enable automatic reading and recording with certain interval. Manual measurements using SQM-L were done along the routes for every 500 m at certain location away from glare and free from tree canopy. In parallel, SQM-LU DL continuously measured and recorded the data for every 10 seconds (corresponds to ~100 meters distance). To reduce stray light or glare during measurement, we put 20 cm baffle in front of the SQM-LU DL. Median filtering with window 25 data was also applied to clean the data from localized brightening.

Positional data was acquired with smartphone navigation system with actual median accuracy of 28 m if it was network-based and 14 m if it was based on Global Positioning Satellites (GPS). These accuracy and other important parameters were recorded with the help of GPSLogger application for Android (https://gpslogger.app/). Positional data was then combined with SQM data based on the time stamps, of-course with prior time synchronization of those devices.

In total, 2030 sky brightness data acquired automatically on 19/20 July and 117 data manually sampled along the same route. On the second campaign (11/12 Oct), 66 data was obtained and recorded manually using handheld SQM.

VIIRS-DNB Composites

VIIRS-DNB onboard SUOMI National Polar Project (NPP) Satellite covers regions between latitude of −65° south and +75° north and produce versatile nighttime images after decommissioned DMSP-OLS (Elvidge et al., 2017). Monthly composites of those images, processed by the National Centers for Environmental Information, National Oceanic and Atmospheric Administration (NCEI NOAA), were used in this study. These 16-bit images have spatial resolution of 15 arcsecond, equivalent to approximately 0.5 km on the equator. Each month, NCEI NOAA provides two different composites which are composite with .cf_cvg and .avg_rade9 extension. The first composite summarizes the integer count of cloud-free coverage, while the second one stores the average cloud-free radiance expressed in radiance expressed in nanowatt//cm^2/sr. For this study, monthly composites of epoch July to November 2018 were downloaded from NCEI and cropped to the study area. Four month composites were then averaged to get more robust radiance map.

Sky Brightness Model

Sky brightness is the accumulation of celestial lights (stars, moonlight, and zodiacal light), natural atmospheric lights (sky glow) and scattered artificial lights propagate from Earth surface (Garstang, 1986). Artificial lights have the largest contribution to the sky brightness above inhabited regions such that the amount of artificial light produced or even the population density is proportional to the sky brightness (Netzel and Netzel, 2016). Nighttime satellite images

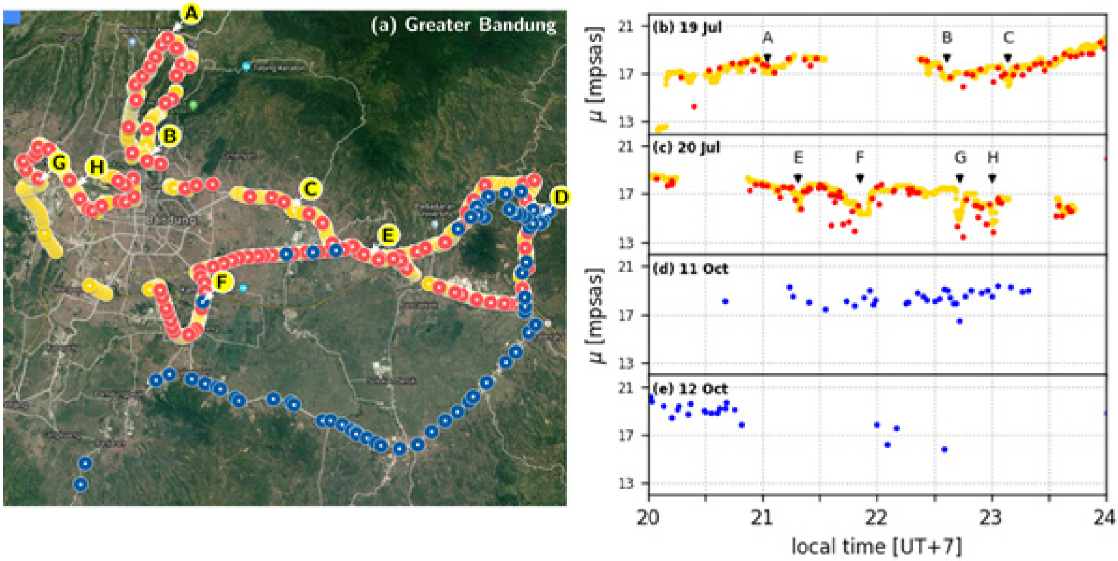

Figure 2. (a) Campaign routes covering area of Greater Bandung, about 40×30 km2. Colors used to distinguish data from different instruments and campaign dates (red: SQM-L 19/20 July, yellow: SQM-LU 19/20 July, blue: SQM-L 11/12 Oct). Locations with relatively higher light pollution are marked with letters (A-H). Point of origin (0,0) corresponds to the initial point of campaign routes, while the letter D marks Observing Station at Sumedang as the end point. (b-e) Temporal plot of the sky brightness (μ in mpsas) measured along the routes.

that portray the amount of artificial light emitted from the surface can be stuffed to light propagation model, which also account a couple atmospheric and topographic parameters, to calculate the sky brightness above the region (Cinzano et al., 2000; Cinzano et al., 2001; Falchi et al., 2016). Another simpler altirenative is to use empirical correlation between radiance map (stored in the VIIRS-DNB composite images) and the magnitude from SQM to construct the sky brightness map. Since the magnitude is a logarithmic scale of perceived brightness, then the logarithm of nighttime radiance needs to be calculated prior to the correlation. Simple least-square fitting with proper statistical weighting was employed to get linear relation between the variables. Similar approach was also presented by Zamorano et al. (2016) for high resolution map of sky brightness over Madrid and its proximity based on measurement campaigns in 2010-2011 which is comparable to 2011 DMSP/OLS composite image. This simple approach makes escalation of the model, to encompass the whole region of Indonesia, becomes possible. It is advantageous compared to the kriging or spatial interpolation method (e.g. Tahar et al. 2017) that produces map which is limited only on the region with densely distributed data points.

3.Result and Discussion

Measured Sky Brightness

Figure 2 displays the spatial coverage of the measurement campaigns conducted twice in 2018. The campaigns encompass approximately 150 km routes and about 40×30 km2 area of Greater Bandung which includes five distinguished administrative territories (Bandung City, Cimahi City, Bandung Regency, West Bandung Regency, and Sumedang). Area with various level of light pollution were passed during the campaigns, among which Lembang (northern part) with growing ecological and agricultural themed tourism. However, the central part of Bandung City, where numerous shopping malls can be found, was not covered in these campaigns. Decorating lights, billboards, and videotrons are likely to be dominant source of light pollution in the city center. During the passage through area with higher socio-economic activities, increase of sky brightness were observed as depressions upto 4 magnitude (40 times brighter).

It is noteworthy that the sky brightness measured using SQM-LU was quite noisy due to street lights, billboards or even tree canopies which hinder the view to the sky. On the highway or toll road, the noise becomes minimum as the densities of street lighting and other sources of glare are lower. Median filtering did its job to reduce such noise as indicated by the convergence between the data recorded automatically using SQM-LU (after filtering) and the data obtained manually using SQM-L. The residue or differences between initial and filtered value has right skewed distribution with median of 0.3 mpsas. Compared to the data obtained using SQM-L, which is manually controlled, the filtered data from SQM-LU seems to well behaved. The correlation coefficient between the two measurements is R^2=0.66. At the brighter section (μ ≤16 mpsas), SQM-LU tends to produce higher value compared to SQM-L.

As displayed in Figure 2 panel a, the first campaign (19/20 July) covered the northern and middle part of Greater Bandung, while the second one covered the southern region with relatively dark sky. According to this campaign, Bandung City has typical sky brightness of around 17 magnitude per square arcsecond. This figure is similar to the value obtained in stationary measurements for more than two months conducted at the Space Science Center (Admiranto et al. 2019). The sky brightness over the southern Bandung reaches 19 mpsas, while the darkest value of μ ~ 20 mpsas was obtained around Sumedang Station at Haurgombong which is in agreement with Admiranto et al. (2019). Around this site, the Milky Way is still visible during the dry season.

Temporal plots of measured sky brightness along the routes (depressions in Figure 2 b-e) show local brightening over several locations. Those locations correspond to several nodes of economic activities such as markets and commercial regions. Above these locations, the sky brightness could reach 14 mpsas or equivalent to the sky brightness during full moon. With light pollution at this level, it is impossible to observe the beauty of starry night sky.

Along the route passed, there is indication of increasing sky darkness from the central part of Bandung to the northern part where letter A marks the location of Lembang Market. Before the market or the Lembang square, the observed sky brightness reach 18 mpsas which corresponds to the typical value of brightness for transition area between urban and suburban. Based on Bortle (2001) who defined dark-sky scale of 1 for pristine sky and 9 for severely polluted sky over urban region, then Lembang region has moderate scale of 6 or 7. At this region, the white band of the Milky Way galaxy is hardly visible and the sky within 35° from the horizon glows grayish white. This also emphasizes that the existence of Bosscha Astronomical Observatory, which is less than 2 km from the market, is threatened by the light pollution. Away from the market, the sky becomes darker and reaches 18 mpsas around Punclut where numerous restaurants can be found offering the unique scenery of Bandung Basin seen from the ridge as the complement. The campaign took a break for about an hour at Punclut before went down to brighter region of Ciumbuleuit (letter B) where the artificial light pollution engulfs the sky and sets the sky brightness back to 17 mpsas. This area is relatively dense with artificial lighting. One private university can be considered as the attracting force of modern development as indicated by establishment of several high-rise apartments, market places, and cafes that contribute to light pollution.

Between Punclut and Ciumbuleuit, several steep road segments (upto 70% slope) were passed. At these segments, the SQM-LU with platform fixed to the car was certainly not directed to zenith but to zenith distance of 35° or less. At this direction the measured sky brightness could be 0.5 magnitude brighter than the zenithal value (Zamorano et al., 2016). Utilization of specially designed gimbal mount, similar to the one used by Ges et al. (2018), is expected to reduce the error caused by measurements over sloped tracks.

Close to the city center, the sky brightness fluctuates around 17 mpsas. It gradually declines (or rises in terms of magnitude) as the campaign went away from the urban area (started from letter C, Cicaheum). At Haurngombong, Sumedang (letter D) where the population density declines and agriculture dominates the land use, the sky brightness is about 20 mpsas. This declining trend is in agreement compared to the one obtained by Zamorano et al. (2016). At approximately 30 km from the city center, the sky brightness could reach 20 mpsas. It is important to note that Bandung with approximate population of 2.5 million is comparable to Madrid, the city surveyed by Zamorano et al. (2016).

In the second campaign, it was revealed the the southern part of Greater Bandung area is relatively dark. The sky brightness fluctuates around 19 mpsas while local brightening around Majalaya was observed. The obtained value of sky brightness could be brighter than it use to be since the second campaign was conducted during cloudy weather.

Map of Sky Brightness

A comparison between in-situ data and satellite imagery is performed to evaluate the quality of the result obtained in the campaigns. Figure 3 shows the relation between the average radiance from VIIRS-DNB composite image between July to November 2018 and the sky brightness measured in the campaigns. Those variables have correlation coefficient of R^2=0.821, which is considerably good. The empirical relation between the two variables is:

$$□ = 20.595 - 3.090 \log E \qquad (1)$$

where E represents the average radiance from VIIRS-DNB composites. This simple relation can be utilized to create the map of sky brightness based on the nighttime satellite imagery. However, there are several caveats regarding this model.

First, the area surveyed is considerably narrow and limited to the radius of ~30 km from city center. At this area, the darkest sky is only 20 mpsas while the natural dark sky away from the Milky Way and zodiacal light could reach 22 mpsas. Expansion of the surveyed area, especially where the sky is pristine dark, is needed such that the empirical relation obtained will be more robust. The second problem is addressed to the saturation level and the non-linearity of photometer used in VIIRS-DNB. As indicated by the rightmost data in Figure 3, some regions captured by VIIRS-DNB with radiance above 20 nW/cm2/sr have sky brightness with more scattered values, from 17 to 14 mpsas.

The map constructed from VIIRS-DNB radiance map using Equation 1 is displayed in Figure 4 while the Bortle scale version is provided in Figure 5. This map can be used as a considerant in the context of dark sky preservation and the discussion of potentiality of astro-tourism in Greater Bandung and further development

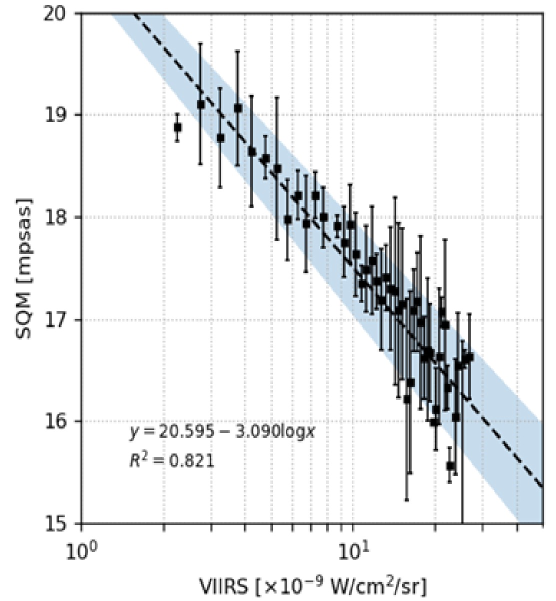

Figure 3. Empirical relation between the average radiance from VIIRS-DNB composite image and the sky brightness obtained from the campaigns. Every point and its error bar represent the average and standard deviation of sky brightness associated with certain value of the radiance. Dashed line is the least square fit to the data with 1σ uncertainty represented by shaded area.

and planning. In Figure 4 and Figure 5, the location of tourist attractions and accommodations compiled from the Office of Tourism of West Java Province and TripAdvisor are overplotted to get a general picture of astro-tourism prospect based on the existing conditions or facilities. It is clearly seen that most of the points are concentrated in the city center, within the boundary of 19 mpsas (Bortle scale 6 to 9 for peri-urban and city regions).

Prospect for Astro-Tourism

As reviewed by Collison & Poe (2013), astro-tourism was initially associated with the visit to ancient sites connected to past astronomical activities or phenomena, such as Stonehenge in the United Kingdom or the Great Pyramid of Giza in Egypt. Nowadays, several form of activities can be considered as astro-tourism, including visitation to observatories, polar regions with aurora displays, national parks with starry dark skies, planetarium and the center of amateur astronomers, and other miscellaneous activities. In other words, astro-tourism has a very broad spectrum. In the end of the spectrum, it can be related to the beauty of starry night sky over pristine regions such as Brecon Beacons National Park in Australia. In the other end of the spectrum, general hotels or resorts with limited viewing can also serve astro-tourism. Annually occurring astronomical phenomena such as meteor showers, Milky Way passage, or occasional lunar eclipse become the attractions from the night sky. Similar to the Christmas Eve, New Year's Eve, or Ramadhan that become a good moments for the hotel manager to release special packages, astronomical events can also be exploited for additional value of staying at the hotel. How far the 'exploitation' could be is related to the quality of night sky at the site.

Based on the visibility of celestial objects or phenomena, certain site can be classified into three major classes. The first class has the Bortle scale of 1-2 such that the Milky Way and zodiacal light are clearly visible and the observation of deep sky objects (clusters, galaxies, and nebulae) is possible in a good weather. The second class has the Bortle scale of 3-4 where some features of the Milky Way are observable at sites with this class. Annual meteor showers can still be observed, but with a rate that depends on the local condition and observer's sensitivity. The third class is for locations with Bortle scale of 5 or higher at which Milky Way is unseen, but bright planets and the Moon (or lunar phenomena) can still be celestial attraction.

In the scope of Greater Bandung region, astro-tourism is regularly offered by Bosscha Observatory in Lembang in the form of educational visit during the day and public night when the Moon is at first quarter phase. Based on the empirical model mentioned before, the zenithal sky brightness above Bosscha Observatory is about 18.2 mpsas, which is higher than the average value (\mu = 17.75) reported by Herdiwijaya (2018), but it is still below the value obtained in the darkest night of 2013 (19.68 mpsas) reported by Herdiwijaya (2015). If the observatory only offers Moon and planets observation as its main menu of night astro-tourism, then the inundation of light pollution over this area is not a big problem. However, further exploration of the beauty of starry night sky becomes more difficult. Milky Way is harder to see while Andromeda Galaxy and Magellanic Clouds which are situated at altitude of less than 45° is almost unseen by the naked eye due to sky glow near the horizon. With this condition, Bosscha Observatory could lose its role as research observatory and its potentiality for expansion of astro-tourism and stay at the third class of astro-tourism site as defined before.

The other existing site currently offering astro-tourism menu is Pusat Peraga IPTEK Sundial (Puspitek). Located in the proximity of Downtown Padalarang, this site has relatively bright night sky (17.7 mpsas) with limited opportunity for deep sky observation, though some incidental event such as star camp often held by the Puspitek. Natural park with pristine dark skies is needed to organize such event.

Astro-tourism can also be offered by existing hotels and resorts, although the majority (~90%) of the hotels in Greater Bandung are situated very close to the central region where the light pollution is severe (Bortle scale 6 or above) such that celestial attractions are limited. Such hotels can be categorized in the third class of astro-tourism site. Citizens or tourist need to get away

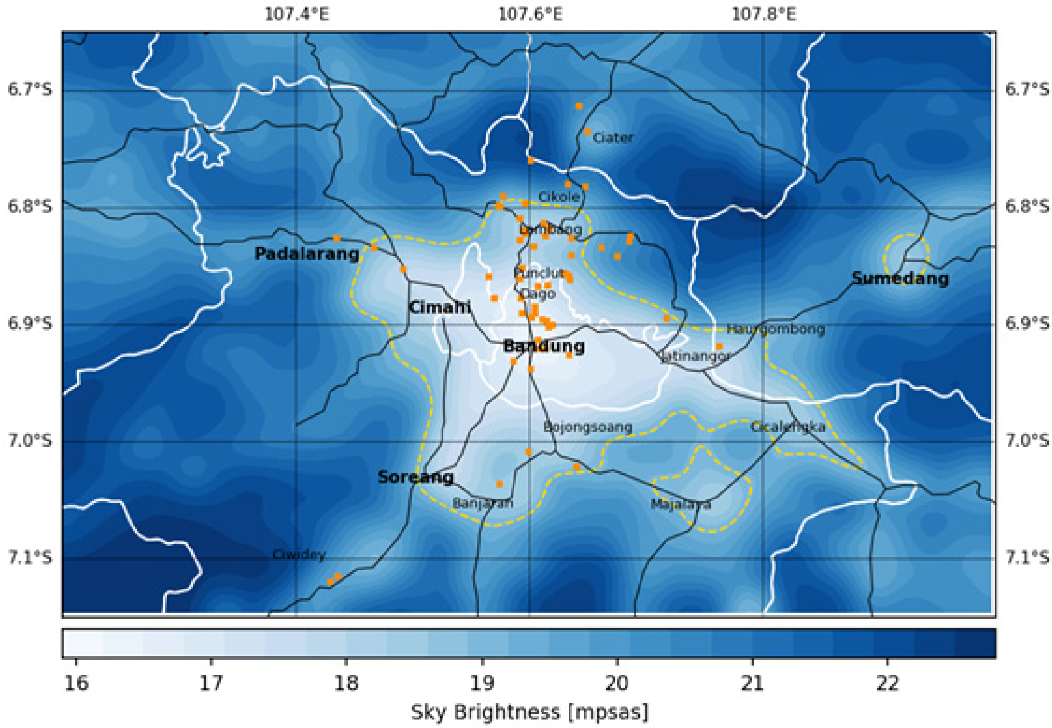

Figure 4. Map of sky brightness over Bandung and its proximity. Bold white lines mark administrative boundaries of the cities and regencies, while dashed lines enclose the area with sky brightness less than 19 mpsas. Black lines mark the main roads, while orange points mark the locations of hotels and tourist attractions.

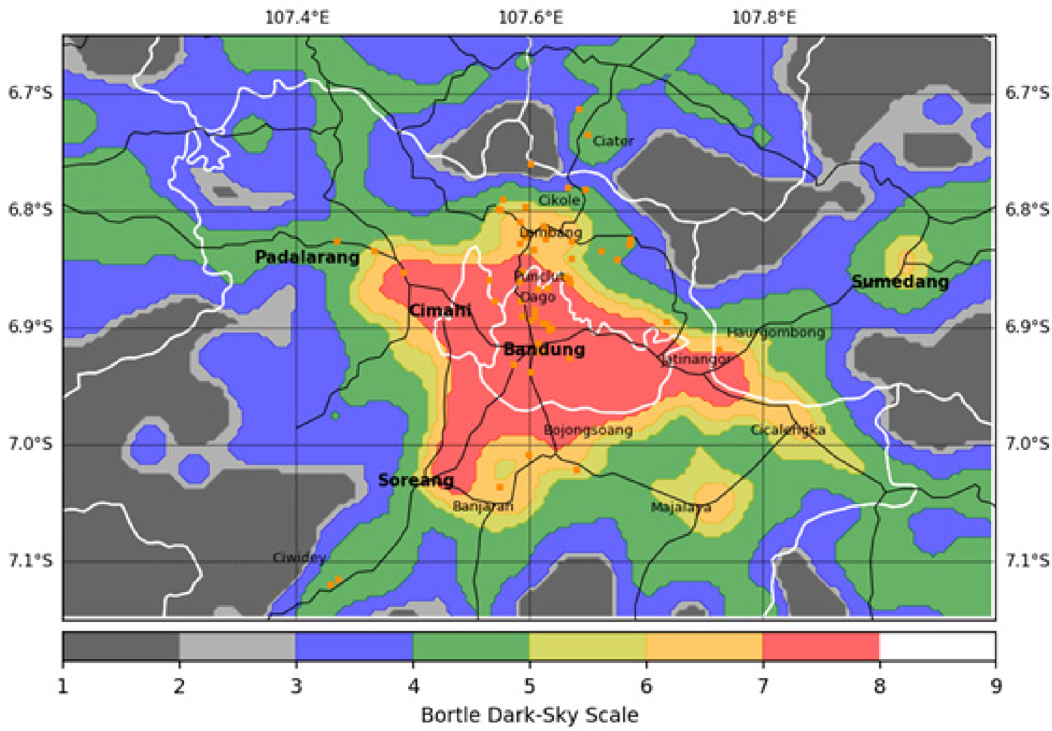

Figure 5. Same as Figure 4, but the sky brightness is expressed in Bortle scale.

approximately 10 km from the downtown in order to have a better view of the starry sky.

Ideally, climatological factors are taken into consideration in alayzing and determining which regions have a good night sky visibility (e.g. Koc-San et al., 2013). Ideally, the analyzes and determination of regions with good night sky visibility require climatological considerant (e.g. Koc-San et al., 2013). Hidayat et al. (2016) obtained average clearness fraction of night sky of about 45% (165 clear nights a year) for Lembang and its proximity. The local variation within Greater Bandung region is likely to be insignificant. Dry season during which Milky Way hangs high in the sky becomes ideal season for stargazing and astro-tourism.

With the same criteria, Ciwidey region (two existing tourist attractions plotted in Figure 5) becomes the second potential region, situated south of the Bandung City. The other region is around Stone Garden Geopark in Padalarang which has already served natural attraction during the day. Similar to that of established dark sky reserves around the world (see astrotourism. com), natural landscapes become significant additional value to the beauty of starry night sky experienced by tourists. This region can also be plotted as Urban Night Sky Park following the guidance of the International Dark Sky Association. Of course, further focused study is required to evaluate the eligibility of the region.

4.Conclusion

Preservation of starry dark sky is an important step to take in the context of unstoppable modern development of human civilization within the complex ecosystem. Light pollution needs to be mitigated and managed wisely and systematic mapping of sky brightness and light pollution become the starting point of the mitigation. Measurement campaigns using Sky Quality Meter and smartphone navigation system were conducted on 19/20 July and 11/12 October 2018 under partially cloudy sky. The campaigns cover 30 × 40 km^2 of Greater Bandung area with sky brightness range from ~17 mag/arcsec^2 (mpsas) at the downtown region to ~20 mpsas at Haurngombong, Sumedang which is ~30 km from the city center. The obtained values are comparable to the one acquired stationary at Bandung, Lembang, and Sumedang. The in-situ measurements correlate well (correlation coefficient of 0.821) with the average radiance map obtained by VIIRS-DNB. Employing the established empirical relation between the two variables, map of sky brightness over the Greater Bandung can be constructed.

In the context of astro-tourism, majority (~90%) of the existing tourist attractions and hotels are situated in the region with severe light pollution (brighter than 19 mpsas, Bortle scale 6-9) such that offering deep sky objects as astro-tourism attraction becomes unlikely. However, Ciwidey region in the south, Cikole-Ciater region in the north and Padalarang region in the west still have relatively dark skies with Milky Way appearance such that further development of astro-tourism can be expected in these regions.

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