Chapter

Light Pollution Observations in Indonesia

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Abstract

Light pollution is a growing concern in the world. It affects many walk of lives, including human health, the degradation of nocturnal animal habitat, and the inability of the astronomers to observe dimmer objects. We in Space Science Center of LAPAN (Indonesian National Institute of Aeronautics and Space) try to mitigate this through a coordinated observation of light pollution using Sky Quality Meter equipments which are located in several LAPAN's stations [Agam (West Sumatra), Pontianak (West Kalimantan), Sumedang (West Java), Garut (West Java), Pasuruan (East Java), Kupang (East Nusa Tenggara), and Biak (Papua)]. The observations has been conducted since 2018 in stationary and moving modes, and the results are then sent to a central database which is located in Space Science Center in Bandung (West Java). The results showed that there are some variations of light pollution across Indonesia. In this respect most of the stations have moderate pollution as can be seen from the values of Biak, Agam, Sumedang, and Pontianak (20.0, 19.5, 19.6, and 17.7 mpsas respectively). On the other hand, the stations which are located near or in cities have high light pollution (Bandung and Pasuruan with 17.1 and 18.0 mpsas, respectively). A particular station (Garut) has low light pollution (20.6 mpsas). The data of these observations are presented in a website to be accessed by interested parties.

Keywords: light pollution, coordinated observations, Sky Quality Meter, moving observations, website

1. Introduction

Light pollution is a growing concern all over the world. It affects all ways of life, human and animals alike. People are more and more affected by light pollution, and some are getting health problems like lack of sleep, obesity, and breast cancer. Other problems are that people cannot see the beauty of night sky, the disruption of the circadian rhythm in human and animals, and the efficiency of energy in street lamps in cities.

Falchi et al. [1] analyzed light pollution all over the world. They made an atlas of light pollution in Europe, Asia, and North America.. They observed that more than 80% of the world and more than 99% of the U.S. and European populations live under light-polluted skies.. They concluded that this pose humanity with problems of unprecedented magnitude. Cinzano et al. [2] discussed the same problem and observed that this problem also affect many regions like Central Africa and Central Asia which was previously thought were free from this problem.

Light pollution is related with the sky quality, in which the better the sky quality means that the light pollution is the lesser. A good sky quality means that one can see much of the objects of the sky, including dimmer objects. The sky quality can be measured using Sky Quality Meter device which records the light emitted by the sky and calculates the incident radiation. Spoelstra [3] measured the sky quality of Arnhem, Holland using an SQM which equipped with a filter wheel. The observations conducted in blue, green, red, and infra red wavelengths. His results indicated that the level of light pollution in a certain location depends on the dominant wavelength of the sky brightness of the location.

In their effort to quantify light pollution, Cinzano and Falchi [4] reviewed indicators of light pollution and products available with recent observational and modeling techniques. They used LPTRAN (Light Pollution radiative TRANsfer) software package to predict the distribution of the night sky in any visible wavelength. This software can be applied in various atmospheric conditions and geographical differences of local conditions (cloud cover) and ground surfaces. The calculations were then applied to the cities of Verona, Vicenza, Padova and Venezia in Italy. They found that the condition of the atmosphere can contribute significantly to the light poluution and they are able to do this quantitavely.

Light pollution have been mapped based on satellite data. Cinzano et al. [5] created the first world map of artificial light of the world using data obtained by Defense Meteorological Satellite Program (DMSP). The conclusion of their analysis is that light pollution of the night sky appears to be a global-scale problem affecting nearly every country of the World. The problem is more severe in the United States, Europe and Japan, as expected. However the night sky appears more seriously endangered than commonly believed.

Light pollution had been observed locally also. Using operation line scan (OLS) data of DMSP satellite, Tavoosi et al. [6] analyzed the light pollution of Teheran in 1993, 1998, and 2003 and mapped the changes of light pollution in those years. They concluded that the changes of light pollution in Teheran did not evenly occurred and this information can be used to project the development of the city in the future. Bruehlmann [7] observed the light pollution in the city of Winterthur, Switzerland using a luxmeter. These observations were compared with the results of DSLR observations obtained in International Space Station, and it was concluded that the map obtained from lux meter observations is more accurate than obtained using DSLR observation, but there is a good correlation between this two observations, so DSLR observation can be use to determine local light pollution map if there are no observations using lux meter.

Analysis of the light pollution map was carried out by Butt [8] who examined light pollution maps in urban and rural areas of Pakistan using data captured by the Defense Meteorological Satellite Program (DMSP) satellite using the Operational Linescan System (OLS) equipment on the satellite. The areas covered by this study include several provinces in Pakistan, namely Punjab, Sindh, Khyber Pukhtoonkhwa, and Baluchistan. In this case, the data were collected twice a day in the period 2004–2009. This data is taken from an altitude of 830 km from the Earth's surface with a spatial resolution of 2.7 km. The data obtained by Butt [8] is then processed using Geographical Informational System (GIS) software. Light pollution parameters used are light that comes directly from urban areas and sky glow caused by these urban areas. Furthermore, other data used is cartographic data (road networks, topography, land surface coverage, and river networks). Using the data obtained over a period of 6 years (2004–2009) they can finally obtain a map of light pollution during that period. They concluded that there are some areas that experience changes in light pollution levels drastically, but there are also areas that have relatively little change in light pollution. Other researchers, namely Chalkias et al. [9] conducted an analysis of the observational data for the Athens and surrounding areas in Greece etc. during the period 1995–2000 using the same data used by Butt [8] above, namely using the DMSP satellite and OLS data contained in that satellite. They tried to calculate the change in light pollution intensity during the 5 years period. They concluded that there are areas around Athens that have experienced a drastic increase in light pollution, but there are also those that are not experiencing too much light pollution.

Albers and Doriscoe [10] made a model of light pollution and discuss its implications for the many dark sky parks in the United States. They made a map of the brightness of the sky in the zenith direction and based on the assumption that the brightness of the sky has a linear relationship with population density in a particular area and is inversely proportional to the power of 2.5.

This map is then compared with satellite data obtained from the Defense Meteorological Satellite Program (DMAP) satellite. Next they made use of the scale of the sky's brightness expressed in the limiting magnitude in the zenith direction proposed by Schaaf [11] and then compared the model they obtained with the observational data they collected from each location they chose.

The results of their comparison showed that the observational data matched what they got from the model, except for certain places such as very dark areas and brighter areas. In dark regions the observer cannot observe the weakest stars as predicted by the model, while for bright regions the observer can still observe stars that are weaker than predicted by the model.

Related to light pollution which occurred in a certain location, this depends on the process of light arriving to that location. Bara and Lima [12] conducted an analysis of the arrival of light pollution in one place, by calculating the weight of each light pollution emission from various light sources arriving at that point.

In this case they do the sum of the radiation emission that comes at one point from various sources by taking into account the absorption and refraction processes of various types of aerosols through which the light emission passes before reaching the specified point.

Here, the data used is data from the Suomi-NPP satellite which appears in the form of a map of the distribution of light irradiation in a particular area where the area being the subject is covered in that area. Furthermore, the area under review is converted into a light pollution transfer matrix and from this the contribution made by each matrix component is calculated at the point that is the subject of this analysis. In this case, Bara and Lima [12] take the case of the A Veiga area in the Galicia region, and then calculate the light pollution experienced by the Xares area which is part of the A Veiga region.

Furthermore, a more detailed satellite map is made of the light pollution received by each point from the A Veiga area. From the calculations they did for each point on the map they made, finally a map was created showing the light pollution coming from A Veiga that was experienced by each surrounding area. This analysis conducted by Bara and Lima [12] can be applied to the case described by Albers and Doriscoe [10] above to calculate how far a point experiences light pollution from surrounding points, and how far each point contributes on light pollution experienced as a whole.

Light pollution observations had also been conducted in Indonesia, but those mainly were conducted sporadically mainly in an island (Java) and not in an extended period of time [13–15]. In this respect, we need observations of light pollution which conducted in extended period of time and in an extended area. As an archipelagic nation which covers vast area of sea and land, Indonesia need night sky brightness observations which conducted in regions outside Java so the comprehensive map of light pollution in Indonesia can be obtained.

This article is a summary of works related to the night sky brightness observations in Indonesia after its installation in 2018. The purpose of this article is to present the current understanding of light pollution in Indonesia using observations in several locations in Indonesia. Preliminary reports and analyzes of these works can be seen at Admiranto et al. [16, 17]. Section 2 describes the equipment, data, and methodology of obtaining the data. Section 3 describes the data analysis, and results of this data analysis. Section 4 describes the web presentation of the observations, and Section 5 describes discussion and conclusions of this analysis.

2. Data and methodology

Indonesian National Institute of Aeronautics and Space (LAPAN) has several stations across Indonesia which are used to observe night sky brightness. These stations are: Agam (West Sumatra), Pontianak (West Kalimantan), Bandung (West Java), Sumedang (West Java), Garut (West Java), Pasuruan (East Java), and Biak (Papua) (**Figure 1**). Locations of these stations can be seen in **Table 1**.

In each station we put Sky Quality Meter manufactured by Unihedron Company to observe the night sky brightness. The Unihedron Sky Quality Meter are SQM-LU types which can make night sky observations continuously during the night. These equipments are of photodiode-based instruments which has effective field of view of ~20° and produce sky brightness data in mag/arcsec^2. All SQM record sky brightness magnitude in zenith direction from 5 pm to 7 am with sampling rate of one minute. **Figure 2** shows the equipment we use to record the sky quality.

We made observations of night sky brightness (NSB) continuously since 2018 (the observations were not started simultaneously for each station). These data were obtained under different sky conditions, during dark and full Moon, low and high cloud cover, and clear and overcast conditions. Because the NSB are different between moonlit sky and otherwise, we then classify the nights depend on the phases of the Moon. The data then sent to a server in Bandung and organized according to data sources (7 stations) through Virtual Private Network (VPN) to the server in Space Science Center in Bandung through this address https://bima-sakti.sains.lapan.go.id/. The organization of this data transfer process can be seen in **Figure 3**.

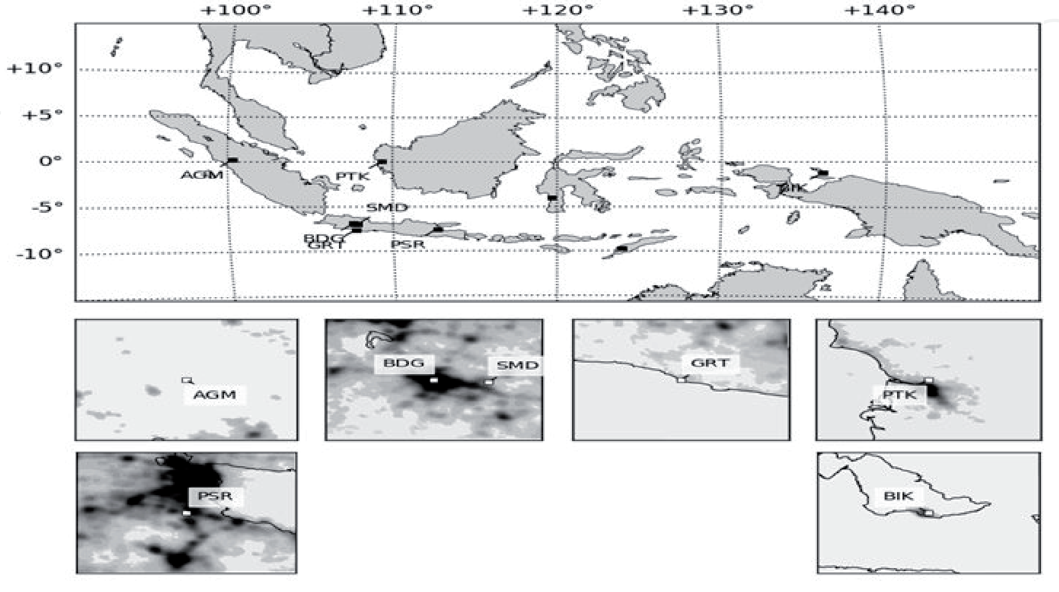

Figure 1.
Locations of sky quality observations in Indonesia.

Stations	Longitude	Latitude	Condition
Agam (AGM)	100 19′ 10.00″ E	0 13′ 48.00” S	Rural
Pontianak (PTK)	109 20′ 23.00″ E	0 02′ 48.00” N	Peri urban
Bandung (BDG)	107 40′ 40.21″ E	6 55′ 32.03” S	Urban
Sumedang (SMD)	107 50′ 13.97″ E	6 54′ 47.08” S	Rural
Garut (GRT)	107 41′ 31.97″ E	7 39′ 00.22” S	Rural
Pasuruan (PSR)	112 40′ 00.00″ E	7 34′ 00.00” S	Peri urban
Biak (BIK)	136 01′ 00.00″ E	1 17′ 00.00” S	Urban

Table 1.
Locations and conditions of 7 observation stations.

Figure 2.
Unihedron SQM LU-DL equipments.

The summary of the observations can be seen in **Tables 2–4**. The observations were not started simultaneously so there are some stations which were late in starting the observations. There are some occasions that the data was not obtained

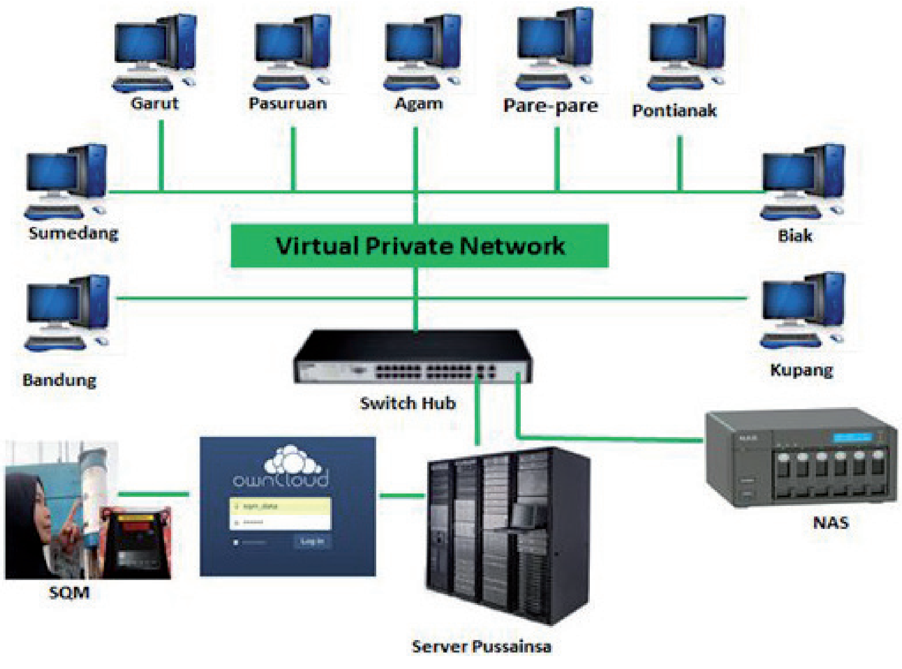

Figure 3.
Architecture of sky quality meter data management system in Space Science Center.

Location	2018											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agam	X	X	X	X	X	X	V	V	V	V	V	V
Biak	X	X	X	V	V	V	V	V	V	V	V	V
Kupang	X	X	X	X	X	X	X	X	X	X	X	V
Garut	V	V	X	V	V	V	V	X	V	V	V	V
Pasuruan	V	V	V	V	V	V	V	V	V	X	X	X
Pontianak	X	X	X	V	V	V	V	V	V	V	V	V
Sumedang	X	X	X	X	X	X	X	V	V	V	V	V

Table 2.
SQM data in 2018.

Location	2019											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agam	V	V	V	V	V	V	V	V	V	V	V	V
Biak	V	V	V	V	V	V	V	V	V	V	V	V
Kupang	V	V	V	V	V	V	V	V	V	V	V	V
Garut	V	V	V	V	V	V	V	V	V	V	V	V
Pasuruan	V	V	V	V	V	V	V	V	V	V	V	V
Pontianak	V	V	V	V	V	V	V	V	V	V	V	V
Sumedang	V	V	V	V	V	V	V	V	V	V	V	V

Table 3.
SQM data in 2019.

Location	2020											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Agam	V	V	V	V	V	V	X	X	X	X	X	X
Biak	V	V	V	V	V	X	X	X	X	X	X	X
Kupang	V	V	V	V	V	X	X	X	X	X	X	X
Garut	V	V	V	V	V	X	X	X	X	X	X	X
Pasuruan	V	V	V	V	V	V	X	X	X	X	X	X
Pontianak	X	V	V	V	V	X	X	X	X	X	X	X
Sumedang	V	V	V	V	V	X	X	X	X	X	X	X

Note: V: available data, X: data is not available.

Table 4.
SQM data in 2020.

continuously, and this is caused sometimes by the equipment which was not working and we need to wait for the replacement from the vendor. Available data are designated by V, and unavailable data are designated by X.

Each station has its unique surroundings which make each has different light pollution characteristics. A station which is located near an urban concentration has high light pollution. We took satellite images of the stations from the site https://www.lightpollutionmap.info to verify the observations from below using the Sky Quality Meter. We can see that the sky conditions in Indonesia depend upon the proximities of those various locations to the source of night sky. There are places which are very dark, especially in Sumedang and Garut, but there are some places that are very bright like in Bandung and Pasuruan which are urban and peri urban in nature, respectively.

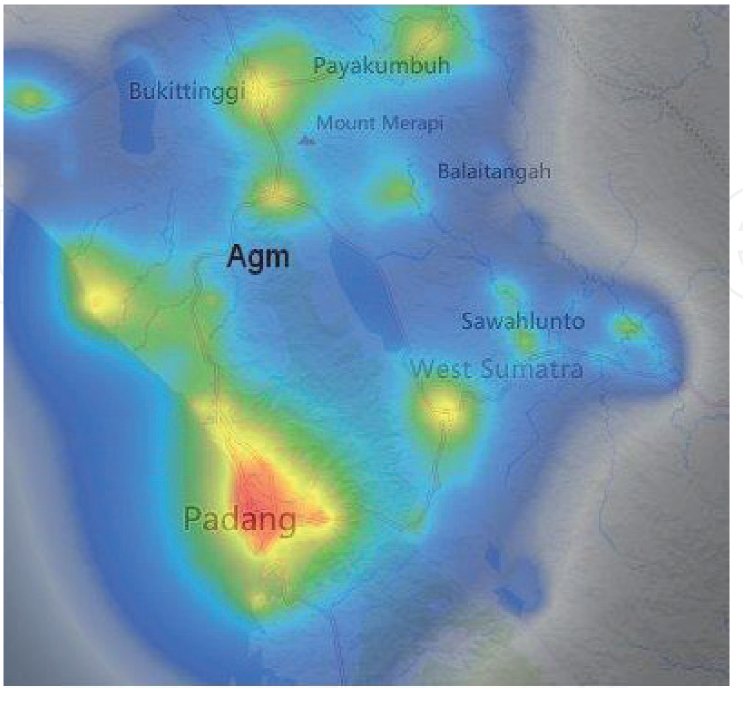

Figure 4.
Light pollution at Agam station.

2.1. Agam station

This station is located in some hilly region with height about 865 m above sea level, and the nearest city is about 20 km from the station. This explains the relatively low light pollution in this station at the value of 19.5 mag/arc sec^2. **Figure 4** is the light pollution of Agam and its surroundings. According to the satellite reading, the sky quality value observed from this station is 21.99 mag/arc sec^2.

2.2. Pontianak station

Pontianak station is located near the city of Pontianak (the capital of West Kalimantan), so the light pollution in this location is rather high as can be seen in the **Figure 5** below with the value of 17.7 mag/arc sec^2.. The satellite reading of this station is 19.93 mag/arc sec^2.

2.3. Bandung station

Bandung is the capital of West Java at which is located about 750 m above sea level. so the light pollution here is a bit high as can be seen in **Figure 6** below with the value of 17.1 mag/arc sec^2. The satellite reading of this station is 19.55 mag/arc sec^2.

2.4. Sumedang station

Sumedang station which is about 800 m above sea level is a rural observation station, and the value of the sky quality is 19.6 mag/arc sec^2. Meanwhile, the satellite reading of this station is 21.00 mag/arc sec^2 (**Figure 7**).

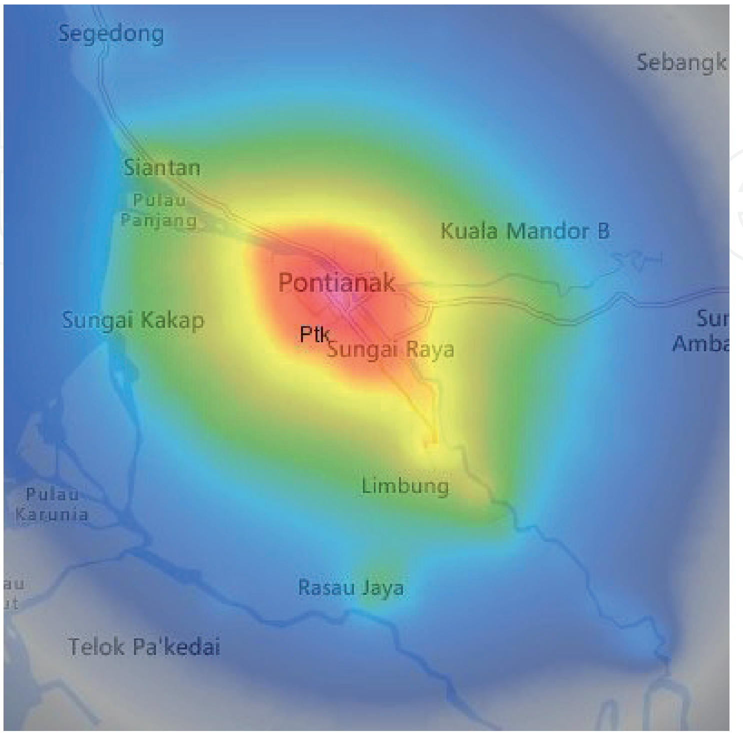

Figure 5.
Light pollution at Pontianak station.

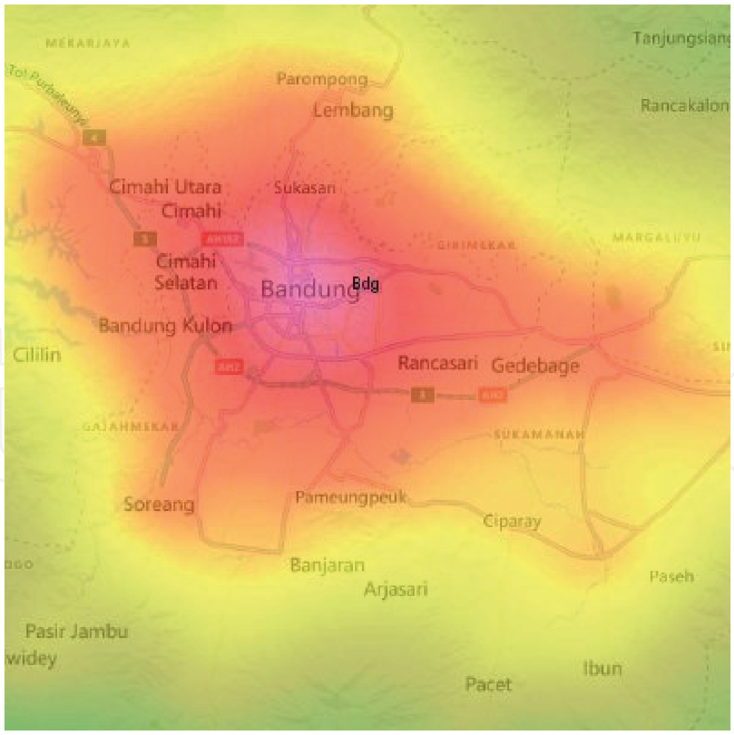

Figure 6.
Light pollution at Bandung station.

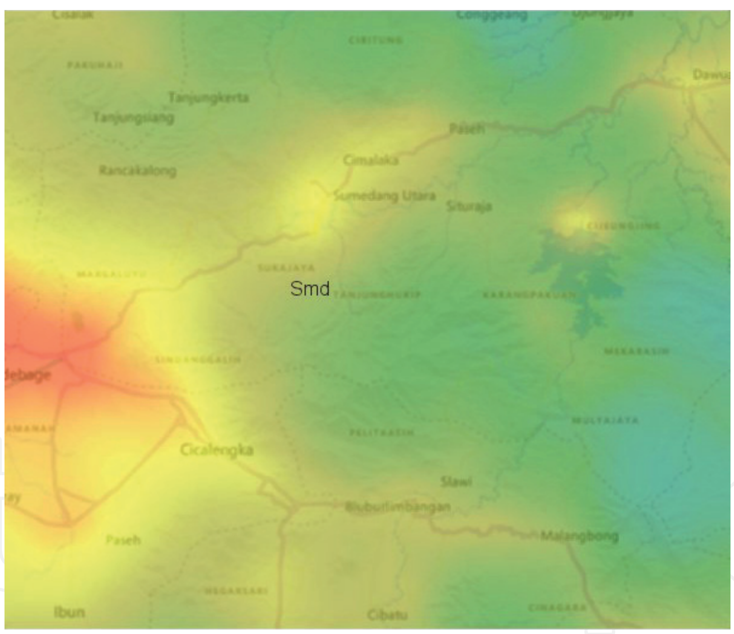

Figure 7.
Light pollution at Sumedang station.

2.5. Garut station

This station is located southern West Java coastal area. The value of the sky quality is 20.6 mag/arc sec^2, and the satellite reading of this station is 21.95 mag/arc sec^2 (**Figure 8**).

2.6. Pasuruan station

This station is located near a big city (Surabaya) and a busy highway. The value of the sky quality is 18 mag/arc sec^2, and the satellite reading of the sky quality is

Figure 8.
Light pollution at Garut station.

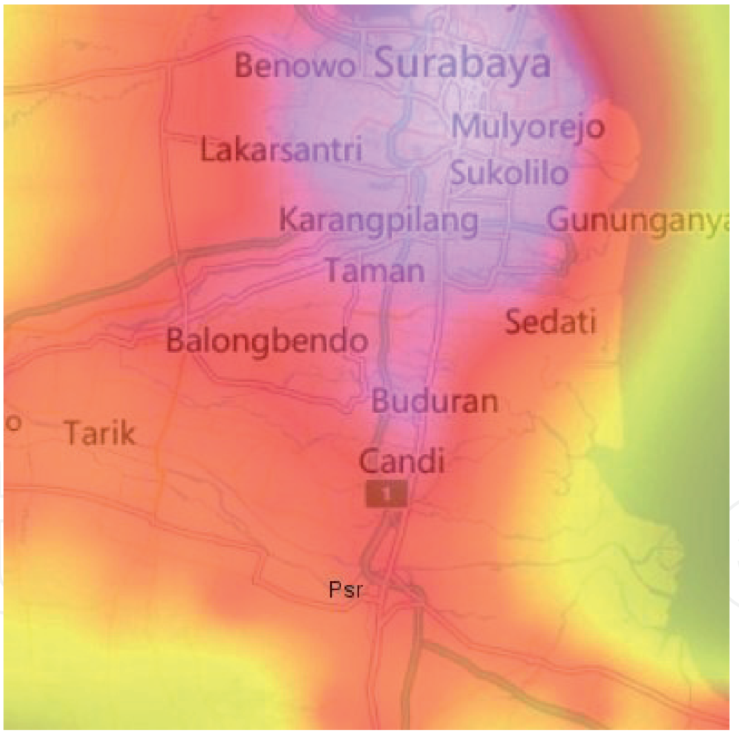

Figure 9.
Light pollution at Pasuruan station.

20.44 mag/arc sec^2. One can see in the **Figure 9** that the light pollution at this location is a bit high.

2.7. Biak station

This station is also located in a coastal area near the city of Biak, and the value of the sky quality is mag/arc sec^2. Meanwhile, the satellite reading of this station is 20.98 mag/arc sec^2 (**Figure 10**).

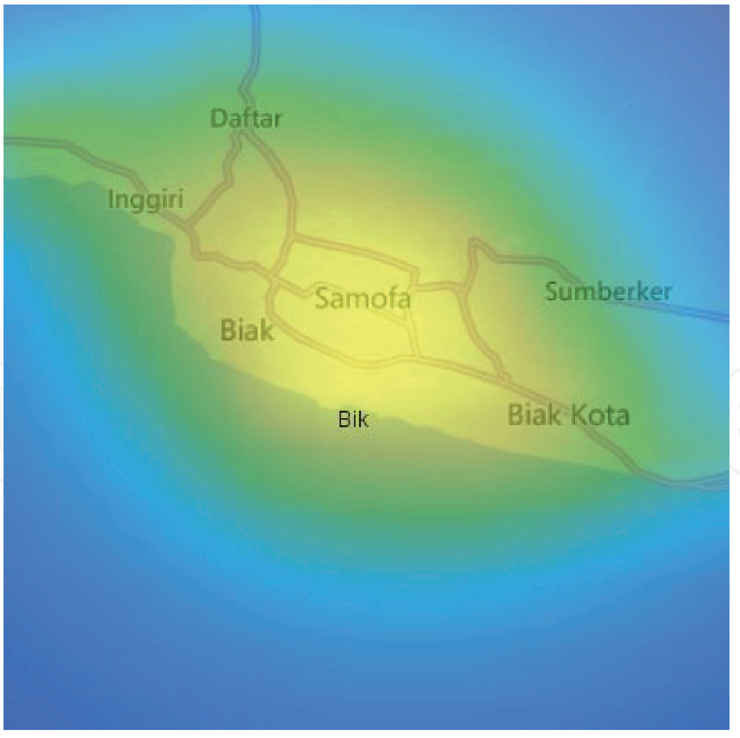

Figure 10.
Light pollution at Biak station.

S.No.	Station	S Q M (mag/arc sec^2)	Bortle Scale	Satellite (mag/arc sec^2)	Bortle Scale
1.	Agam	19.5	5	21.99	3
2.	Bandung	17.1	8	19.93	6
	Sumedang	19.6	5	21.00	4
	Garut	20.6	2	21.95	2
	Pontianak	17.7	8	19.93	6
	Pasuruan	18	6	20.44	5
	Biak	20	5	20.98	4

Table 5.
Comparison of sky quality observations using sky quality meter with reading from the satellite observations complemented with its Bortle scale.

Table 5 depicts the SQM observations and satellite reading of these stations. One can see that the value of the satellite reading of the sky quality is systematically higher than the value of the sky quality observed from below. Priyatikanto [18] stipulated that this discrepancies are caused by atmospheric extinction and scattering.

3. Moving observations

Apart of conducting stationary observations, we conduct observations in moving mode also. These mobile campaigns were conducted to measure the sky brightness using moving vehicles through various conditions, ranging from cities to villages, highlands to lowlands. The observations were conducted by six different team which observe the night sky brightness at the same night on June 24–26,

S.No.	Areas	Designation	Distance covered	Remarks
1.	Pasuruan-Probolinggo- Jember-Blitar -Mojokerto-Pasuruan	PSR	590 km	Mainly urban
2.	Surabaya-Lamongan-Bojonegoro-Ponorogo-Nganjuk-Pasuruan	SBY	532 km	Mainly urban
3.	Bandung-Cirebon-Semarang-Kudus- Ngawi -Salatiga-Kebumen	BDG	987 km	Mainly urban
4.	Agam-Bukittinggi-Batusangkar-Sawahlunto – Solok-Padang-Pariaman-Padang Panjang	AGM	292 km	Mainly rural
5.	Sumedang	SMD	94 km	Mainly urban
6.	Oelnasi-Kupang-Kuanheun	KOE	80 km	Mainly rural

Table 6.
Routes and distances covered in moving observations.

2019 during which the weather was relatively good (no rain or overcast) and the moonlight does not much contaminated the sky. During that period, the moon age was 20 to 23 days and the fraction of illumination was 63–45%.

In this campaign we use also the Unihedron SQM-LU (Sky Quality Meter with data logger attached through a USB port). The SQM was equipped with a battery charger and inserted into a tube that can be placed outside the vehicle. The Unihedron Device Manager application is also installed on a computer which connected to Shared GPS application on Android to see which location has such and such night sky brightness. Data were sampled all along the trip with 10 second intervals, and data recorded are location and time of observation, and sky brightness in unit of magnitude per square arcsecond (mag/arc sec^2), among others. The summary of observations are presented in **Table 6**.

In general, trips in **Table 6** which occurred in Java Island (1, 2, 3, and 5) were considered urban trips areas and the roads covered are in the northern part of Java which has more economic activities compared with the southern part of Java. On the other hand, trips in Sumatra and Timor (4 and 6) are considered mainly rural trips (**Figure 11**).

There are variations of night sky brightness among locations covered in the journey. The all journey which path of 2870 km length covered big cities with high sky brightness of 10 mag/arc sec^2 to the suburban and rural areas with low sky brightness of 21–22 mag/arc sec^2. The values of much of the data are in the 17–21 mag/arc sec^2 range.

Some of the data are contaminated by the glare of external light which made the sky brighter than it should be, but on the other hand some trees sometimes cover the equipment so the sky appear darker than it should be. This circumstances should be taken into account using some kind of data filtering to get the real sky brightness.

One of the purpose of moving observations of night sky brightness is to establish a preliminary sky brightness map. Night sky brightness data from VIIRS (Visible Infrared Imaging Radiometer Suite) satellite can be compared with SQM data to obtain an empirical model, in which the correlation can be used to obtain the night sky brightness over a greater area. **Figure 12** shows correlation between two kinds of data above. Density plots are shown to represent two dimensional data distribution in which darker color represent regions with higher density.

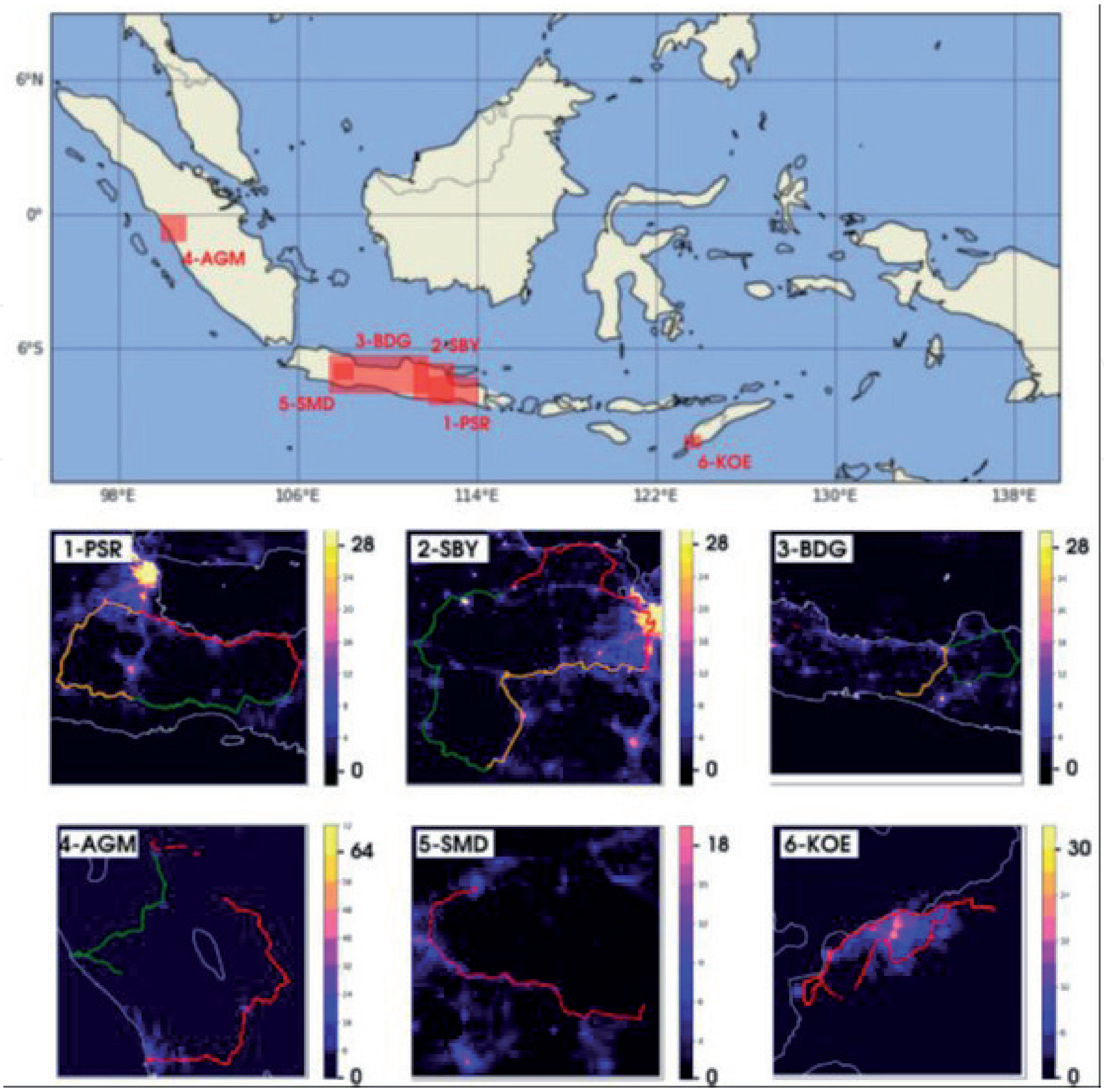

Figure 11.
Upper panel depicts regions covered in the campaigns. Lower panels show the routes taken by each team. Different colors (red, green, orange) represent different night of observation. This map is superposed with radiance map of VIIRS (in nW/m2/sr).

From the plots one can see a trend of increasing sky brightness with the increase of surface radiance measured by VIIRS. Nevertheless, this correlation is weak which caused by some contamination from unwanted light sources like light from transportation, street light, and buildings. Anoher problem is that the sky was not completely clear so some clouds scatter back the light some incoming radiation from the Earth's surface. We need very clear night condition to make observations with accurate results.

Priyatikanto et al. [19] obtained an empirical model in which the logarithm of VIIRS radiance and the value of night sky brightness in mag/arc sec^2 follow a linear function:

$$\mathrm{SQM} = 20.595 - 3.090 \log \mathrm{RADIANCE} \tag{1}$$

We can use the Eq. (1) to obtain the value of night sky brightness expressed in mag/arc sec^2 provided the value of VIIRS magnitude which should be expressed logarithmically.

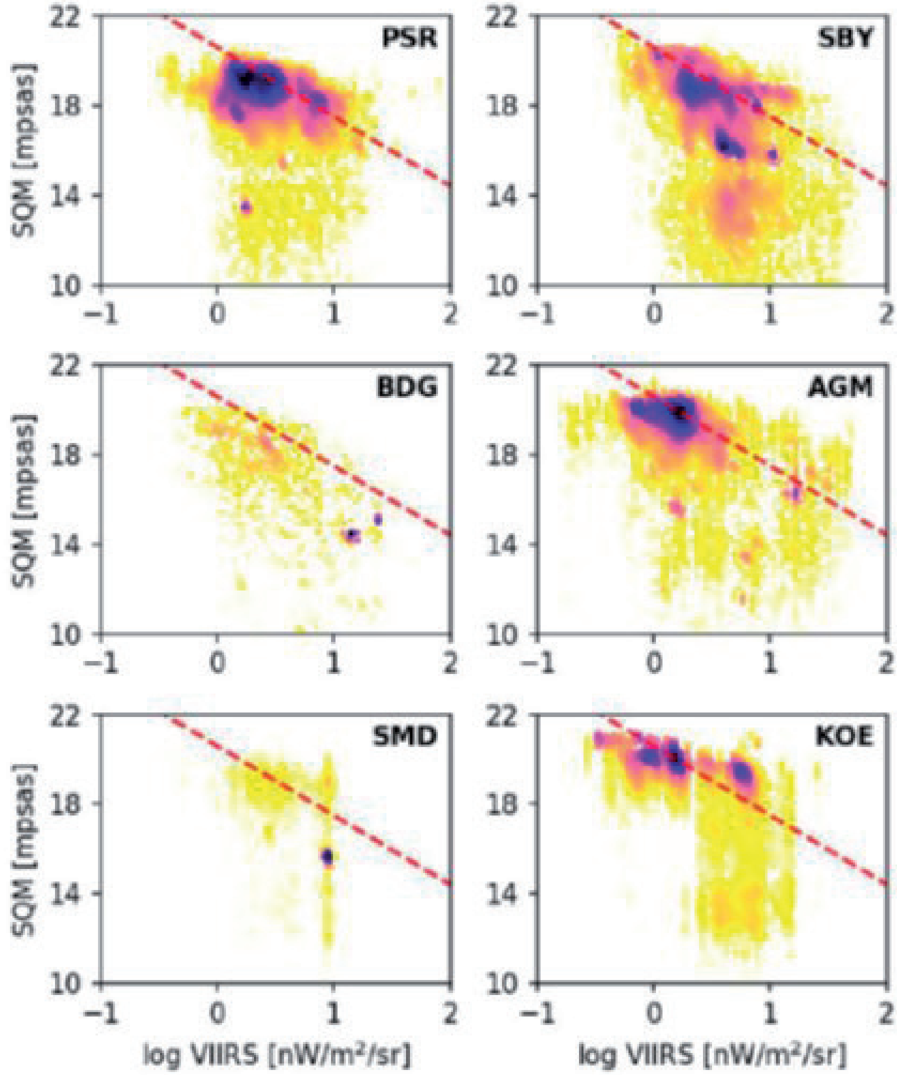

Figure 12.
Density plot of SQM data obtained during the trip by each team correlated with map from VIIRS which put in logarithmic scale. Dashed line represents empirical model from [14].

4. Website presentation

To disseminate the results of night sky brightness measurements, Space Science Center maintains a Sky Quality Observation (SQO) website which can be accessed at the address *sqm.sains.lapan.go.id*. This website is aimed for the general public where the information displayed uses simple language so that it can be easily understood even though they do not have an astronomical background.

The information displayed on the SQO Website includes understanding to readers regarding the explanation of the brightness of the night sky and light pollution. This information about the introduction of the brightness of the night sky is expected to arouse public awareness to protect the night sky in order to minimize light pollution. In addition, there is information to determine the brightness of the night sky using the Bortle Scale. The Bortle scale is a numerical scale to measure the brightness of the night sky. This scale starts from class 1 which is the darkest sky scale to class 9 which is the brightest sky which usually found in urban areas. This website also displays a glimpse of information about the Java-Bali light pollution map made based on the 2013 DMSP-OLS composite image combined with measurements of the Earth's surface as well as several location points for measurements of the brightness of the night sky carried out by the Space Science Center in Indonesia (**Figure 13**).

Figure 13.
Website representation about information of sky quality and its pollutions and of sky quality observations conducted by Space Science Center and LAPAN's stations.

There is a Request Our Data feature on the SQO Website, to facilitate ones which need night sky brightness data which had been carried out by the Space Science Center and the LAPAN's stations. To make a data request, one needs to fill personal information such as full name, telephone number, email address, and affiliation. After that, fill in the detail requested SQO data such as where the data from (Agam, Garut, Kupang, Pasuruan, Pontianak, and Sumedang) and the month-year of the data. And finally, fill in the reason for requesting SQO data.

Apart from providing information about the brightness of the night sky, the SQM website also has an SQO Map feature. This feature is presented digitally to make it easier for users to access by selecting data for the desired month and year. The information displayed in this feature is based on the average measurement of the SQO value each month, which is differentiated when calculating the average for the new moon and at the time of the full moon at points according to the location of the night sky brightness recorder and the point of observation location. Users can also zoom and scroll on the digital map to see the location of the night sky's brightness more easily.

Lastly, the SQO Website has a Backend or Admin Menu page that is used to manage content on the Front end of the Website such as Data Requests, Contact Pages, Homepage Info, Space and Atmospheric Observation Center locations, and SQO maps.

5. Discussions and conclusion

The coordinated observations of light pollution in Indonesia reveal some interesting insights, namely there are some regions in Indonesia with very low light pollution, and there are some sites which have very high light pollution. These observations are linearly correlated with satellite observations, namely which use VIIRS data channels.

The light pollution observations conducted by Space Science Center of LAPAN is the first coordinated light pollution observations in Indonesia. There are many works that should be done to improve the results, especially in the process of building of light pollution map across Indonesia. This can be done by installing more Sky Quality Meter equipments, especially near the locations with high pace of development to mitigate the adverse effects of light pollution.

On the other hand, light pollution observations should be conducted also in strategic locations, especially in some dark places which are suitable for astrotourism, and this strategy can be used to preserve the environment and can be used to make star party events to give some education in astronomy.

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