RAA 2017 Vol. **17** No. **4**, 37 (10pp) doi: 10.1088/1674–4527/17/4/37

http://www.raa-journal.org *http://iopscience.iop.org/raa*

Research in Astronomy and Astrophysics

Spatial Model of Sky Brightness Magnitude in Langkawi Island, Malaysia

Mohammad Redzuan Tahar[1], Farahana Kamarudin[1], Roslan Umar[2], Mohd Khairul Amri Kamarudin[2], Nor Hazmin Sabri[3], Karzaman Ahmad[1], Sobri Abdul Rahim[1] and Mohd Sharul Aikal Baharim[4]

[1] Langkawi National Observatory, Space Science Research Unit, National Space Agency, Empangan Bukit Malut, 07000, Langkawi, Kedah, Malaysia; *roslan@unisza.edu.my*

[2] East Coast Environmental Research Institute (ESERI), Universiti Sultan Zainal Abidin, Gong Badak Campus, 21300 Kuala Terengganu, Terengganu, Malaysia

[3] School of Fundamental Science, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

[4] Department of Surveying Science and Geomatic, Faculty of Architecture, Planning and Surveying, Universiti Teknologi Mara, 02600 Arau, Perlis, Malaysia

Received 2016 June 2; accepted 2017 January 4

Abstract Sky brightness is an essential topic in the field of astronomy, especially for optical astronomical observations that need very clear and dark sky conditions. This study presents the spatial model of sky brightness magnitude in Langkawi Island, Malaysia. Two types of Sky Quality Meter (SQM) manufactured by Unihedron are used to measure the sky brightness on a moonless night (or when the Moon is below the horizon), when the sky is cloudless and the locations are at least 100 m from the nearest light source. The selected locations are marked by their GPS coordinates. The sky brightness data obtained in this study were interpolated and analyzed using a Geographic Information System (GIS), thus producing a spatial model of sky brightness that clearly shows the dark and bright sky areas in Langkawi Island. Surprisingly, our results show the existence of a few dark sites nearby areas of high human activity. The sky brightness of 21.45 mag arcsec^{-2} in the Johnson-Cousins V-band, as the average of sky brightness equivalent to 2.8 $\times 10^{-4}$cd m^{-2} over the entire island, is an indication that the island is, overall, still relatively dark. However, the amount of development taking place might reduce the number in the near future as the island is famous as a holiday destination.

Key words: light pollution — atlases — site testing — methods: data analysis

1 INTRODUCTION

In some parts of the world, aggressive efforts are taking place to map sky brightness in areas where dark sky should be preserved for the sake of astronomy. The International Dark-Sky Association (IDA), founded in 1988, is dedicated to protecting night skies from light pollution. Several countries have developed initiatives to create Dark Sky Reserve Areas, and as of 2015, 17 new Dark Sky Places have been nominated[1]. IDA, in cooperation with the Illuminating Engineering Society (IES) of North America, has also developed a Model Lighting Ordinance (MLO)[2] in its effort to overcome light pollution issues.

Recently, as reported by The Star Online, a local newspaper, the National Space Agency (ANGKASA) in Malaysia is considering the implementation of a Light Pollution Act to provide regulations on the spillover of light caused by urban development[3]. Langkawi National Observatory (LNO) is an observatory located on an island where its main economy is based on tourism. What was long ago a pristine sky now creeps slowly into a category no longer suitable for optical astronomy research.

[1] *http://darksky.org/wp-content/uploads/2016/03/IDA_2015_Annual-Report_low_res3.pdf*

[2] *http://www.ies.org/PDF/MLO/MLO_FINAL_June2011.pdf*

[3] *http://www.thestar.com.my/news/nation/2016/08/23/move-to-decrease-light-pollution-around-observatory/*

It is only appropriate that a sky brightness map of this island be made for future reference, to support and justify the reason why Langkawi was chosen to host the nation's first national observatory. The objective or goal of this research is to create a sky brightness map for the island of Langkawi as of 2013, where LNO is located. This map will serve as a historical document or record of how the surrounding sky brightness affects the observatory.

Brighter sky is always a big disadvantage to any observatory as this reduces the number of objects that are able to be observed. This also limits its potential to conduct optical astronomy related research, especially for LNO, as this is the only facility dedicated to this purpose in this country. This study presents the spatial model of sky brightness magnitude in Langkawi Island, Malaysia. Two types of handheld portable Sky Quality Meter (SQM) manufactured by Unihedron were used to measure the sky brightness in this project. The selected locations are marked by their GPS coordinates. The sky brightness data obtained in this study were interpolated and analyzed by using a Geographic Information System (GIS), thus producing a spatial model of sky brightness that clearly shows the dark and bright sky areas in Langkawi Island.

The increasing prevalence of exposure to light at night also has significant social, ecological, behavioral and health consequences that are only now becoming apparent (Navara & Nelson 2007). Other significant impacts of light pollution are related to road safety and public safety, high energy consumption (the excessive use of fossil fuels and greenhouse gasses, Davies et al. 2014), loss of desert basins and other areas, and also possible health risk due to manipulation of mercury vapor lamps (Schwarz 2002). Intelligent illumination systems can help by reducing sky light pollution by preserving the dark quality of the sky for astronomy research. Site selection for astronomy observations depends on population density (Umar et al. 2014). According to Falchi et al. (2016) and Abidin et al. (2013), a location situated nearby human activity such as industrial and residential areas will affect optical astronomical observations. Proper design of luminaries can be done such that they provide optimum illumination while minimizing energy consumption and providing adequate road and public safety. Also, limiting illumination to inhabited areas can help minimize detrimental impacts on the natural day/night cycle of all species in the natural environment and ecosystems.

There are many benefits to a nation once their society becomes concerned about sky brightness. For example, it will connect diverse groups that share these interests and goals (for example a group of professionals in lighting and astronomy), who can develop educational materials (e.g. exhibitions and posters). This societal need or awareness will then give birth to a new field of expertise to assist and advise the governing body on good practice in external lighting. This growth will then drive industry to develop more efficient lighting methods and at the same time meet new national and international lighting standards.

Today, GIS is becoming more popular among users, especially decision makers due to enabling them to quickly refer to GIS outputs which assist them in solving problems and making equitable decisions (Alvarado et al. 2016). GIS is playing a very important role in helping users to collect, analyze and display spatial data in different forms tailored to their individual needs (Kamarudin et al. 2015b; Mustafa et al. 2015; Yusri et al. 2009). Site selection studies are essential for decision makers to propose where to build an astronomical observatory with the highest efficiency (Sabri et al. 2015; Umar et al. 2015). So, in this study, application of GIS will be used to generate the spatial model of sky brightness in Langkawi Island, Malaysia. This spatial model of sky brightness concentration is important for indicating darker and brighter locations that can be used to evaluate the level of light pollution in Langkawi Island, Malaysia.

2 METHODOLOGY

2.1 Study Areas

Langkawi Island is used in this study primarily because it hosts LNO which began operation back in early 2006 and offers users on-site observing facilities for optical astronomy related research. The site was preferred due to accessibility and consistent climate for this area with lesser cloud coverage than regular tropical climate elsewhere in Peninsular Malaysia. This project will serve as a record for the future of what the island was like in terms of sky brightness if actions to control light pollution are not taken soon.

The island was first divided into grids of 15 squares. Locations where readings were to be taken were then roughly selected based on road accessibility for each grid (see Fig. 1). When the plans are set, data collection was executed based on three requirements: (i) moonless night or when the Moon is below the horizon, (ii) cloudless conditions, and (iii) minimum of 100 m from the nearest light source. These are important to ensure that the readings taken are as accurate as possible and represent the true sky brightness for each location.

Langkawi contains of a set of 99 gorgeous islands along the west coast of Peninsular Malaysia. It is about 30 km from Kuala Perlis jetty and 51 km from Kuala Kedah jetty. The main island is known as Pulau Langkawi. These islands have a legacy of interesting myths and legends, such as the history of a giant and an eagle, and a warrior and princess of the sky, which involves war and romance.

2.2 Equipment

Readings are taken with two versions of Unihedron SQM, and a lens equipped version denoted as SQM-L. The older version of the SQM has a wider aperture with a field-of-view diameter of 84°. However, it averages readings based on a weighted angular response of the device with an acceptance area of 55° in diameter (Cinzano 2005). Meanwhile, the SQM-L version of the device provides a more concentrated field-of-view by using a small lens that better represents the brightness of a small area. The SQM-L restricts the opening to a 20° diameter based on its Full Width at Half Maximum (FWHM) response (Cinzano 2007; Patat 2003). Consequently, this improvement provides a more accurate result for sky brightness at zenith and is used in this paper.

The purpose of using the two different devices is due to the fact that we are interested in seeing how much difference will be produced in the overall reading and also the spatial analysis. As both devices incorporate similar detectors, they both have a similar spectral response that is best for the Johnson-Cousin's V band, with responsivity peaking at a wavelength of 550 nm (Cinzano et al. 2001).

Three SQMs and another three SQM-L devices were used to take readings at each site by applying each device five times. This approach avoids any bias (or error) that might arise from device or handling. However, the readings did not vary much between devices throughout the entire data collection process. The ambient temperature varied between 21°–25° Celsius at the time the readings were taken and all of the readings pointed toward zenith.

Both SQMs produce readings in the unit of Magnitude per Square Arcsecond (mag arcsec^{-2}). This is a commonly used unit in astronomy that refers to the brightness of observed objects. For reference, a sky with a higher magnitude (e.g. 22) refers to a darker site than a lower magnitude (e.g. 19). Dark sites with SQM reading of 21 mag arcsec^{-2} to 22 mag arcsec^{-2} (equivalent to $1.7 \times 10^{-4}\ \mathrm{cd\ m^{-2}}$) are places where it is easy to see the Summer Milky Way with the unaided eye. However, sites with 19 mag arcsec^{-2} brightness start to mask the Summer Milky Way due to a brighter sky background.

2.3 Spatial Model Analysis

ArcGIS is a software program that is used to create, display and analyze geospatial data. This software is often applied in GIS software (Bennie et al. 2014; Kamarudin et al. 2015a). Basically, this software was implemented to visualize, create, manage and analyze geographic data in our study. ArcGIS is also applied to explore geographic data which include categorizing, representing and labeling map features to improve visualization and interpretation of a mapping (Bernhardsen 1999; Abdullah et al. 2013). Map production is the last step after all other processes are completed. ArcGIS specializes in spatial analysis and map production.

In this study, the method used for spatial model analysis was the interpolation method. Interpolation is a mathematical technique that enables estimating the values of a curve at any position between known points. The field measurements required conversion into a continuous space before mapping and spatial analysis can take place. For this study, Inverse Distance Weighting (IDW) techniques were employed to interpolate the datasets.

IDW implements an algorithm that effectively deals with highly variable data during interpolation. This technique computes the value at each assigned grid node by considering the surrounding data points which are between the user-defined radius. All the data points can be included in the interpolation process and this grid node value is obtained by means of the weighted sum of all the points. The IDW interpolator ascertains that all the input points have a local influence which reduces with distance. It first weights the points that are closer to the processing cell higher than those far away from it. The output values of each location are always determined from the points within the specified radius (Fathian et al. 2016; Haque et al. 2016).

Using natural neighbor interpolation, both the interpolation and extrapolation techniques can be used with clustered scattered points. Weighted-average techniques are the basic equation that will be used in natural neighbor interpolation, which is similar to the one used in the

IDW interpolation technique. This method is proficient in handling a large amount of input data. The Natural Neighbor Inverse Distance Weighted (NNIDW) method is a geometric approximation method which uses natural neighborhood areas created around an individual point within the data set. Furthermore, IDW is based on approximations and assumptions about a given value at the unsampled points within several predefined distances or from a given set of numbers. Weight factor is related to the distance (Haque et al. 2016; Kazemi et al. 2016) through the equation

$$\lambda_i = \frac{D_i^{-\alpha}}{\sum_{i=1}^{n} D_i^{-\alpha}},$$

where λ_i, D_i, i and α are the weight of a point, the distance between points, the unknown point and the power ten of weight, respectively (Kazemi et al. 2016; Alvarado et al. 2016; Ngetich et al. 2014; Mahdian et al. 2001). In a nutshell, Figure 2 shows the framework of the sky brightness concentration spatial model in Langkawi Island, Malaysia.

3 RESULTS AND ANALYSIS

Based on this study, magnitude is the main parameter that has been collected from the sampling method that uses in-situ measurements. During the sampling, 16 stations were used to collect data on sky brightness. The data on sky brightness were collected at night from 10:30 p.m. until 4.00 a.m. in different locations. The collected data show that the darkest magnitude of sky brightness is 21.47–21.65 mag arcsec^{-2} in the Johnson-Cousins V-band (Garstang 1989) ($2.8 \times 10^{-4} - 2.4 \times 10^{-4}$ cd m^{-2}). The brightest magnitude of sky brightness in Langkawi was at Stations 1, 9 and 14, which are 20.40-20.75 mag arcsec^{-2}, equivalent to ($7.5 \times 10^{-4} - 5.4 \times 10^{-4}$ cd m^{-2}) (refer to Table 3). The map of the night sky brightness magnitude obtained by SQMs is as shown in Figure 3. However, to ensure that readings are highly accurate, an average of SQM and SQM-L data will be used in this study. Note that the higher the magnitude is, the darker the sky is, which means lower light intensity.

A total of 16 locations, that were coordinated over the entire island which satisfy all the requirements as mentioned previously, was collected on two consecutive nights in the first week of August 2013. The time of data collection, which only started after midnight, takes into consideration that some business related external lightings are turned off afterwards, which would otherwise provide less consistent findings. Data collection ended around 4.30 a.m. in the morning on both days to avoid any inconsistency due to zodiacal light.

The brightest spot in the map is Gunung Raya (mountain), where most of the big transmission towers are located with a reading of 20.4 mag arcsec^{-2} (7.5×10^{-4} cd m^{-2}) on the SQM and 20.9 mag arcsec^{-2} (4.7×10^{-4} cd m^{-2}) on the SQM-L. They are heavily lit for safety with bright high pressure sodium spotlights and are always turned on between sunset and sunrise. Here, the sky brightness readings are the lowest (the brightest) which might be because of the number of light posts, even though the reading was made 150 m away from the area. After a quick drive down the mountain, the sky brightness at the foot of the mountain drops significantly to 21.47 mag arcsec^{-2} (2.8×10^{-4} cd m^{-2}) on the SQM and 21.29 mag arcsec^{-2} (3.3×10^{-4} cd m^{-2}) on the SQM-L, around 1 magnitude difference within just a short distance, but lower elevation.

The southern and southeastern part of the island shows a higher reading which is consistent with development and also popular destinations on the island. Pantai Tengah, right next to the most popular beach in Langkawi, Pantai Chenang, is where almost all tourists concentrate, with many hotels and other night activities, leading to the SQM reading here of 20.97 mag arcsec^{-2} (4.4×10^{-4} cd m^{-2}) and SQM-L of 21.03 mag arcsec^{-2} (4.2×10^{-4} cd m^{-2}). This could have been worse if the readings were taken during squid fishing month where hundreds of fishing boats equipped with very bright spotlights surround the entire island.

The main town on Langkawi, Kuah, is located south of Kedah, but after midnight, almost all activities there close and the town is moderately lit. The location of LNO is east of the Pantai Tengah point, not too far from the sea. Pinned between Pantai Chenang and Kuah town, LNO's sky is also starting to see a difference when doing observations. Dimmer objects are beginning to become harder to observe and detect compared to 5 years ago.

The western part of the island is where development is slightly slower and population is less dense. This provides darker skies up to 21.65 mag arcsec^{-2} (2.4×10^{-4} cd m^{-2}) on the SQM and 21.31 mag arcsec^{-2} (3.2×10^{-4} cd m^{-2}) on the SQM-L. Most of the land here is either state owned or privately owned with very exclusive hotels. We do not entirely understand why the reading was brighter for the zenith SQM-L as com-

Fig. 1 Areas studied in Langkawi Island, Malaysia.

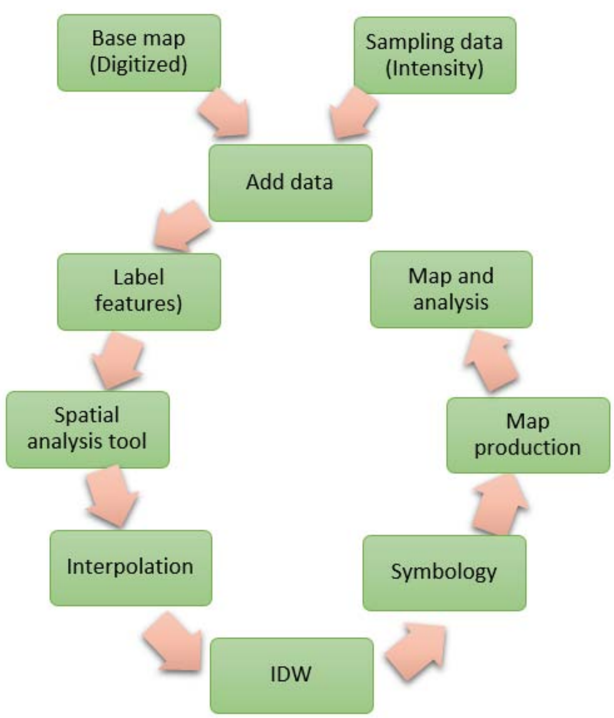

Fig. 2 Framework of sky brightness concentration spatial model in Langkawi Island, Malaysia.

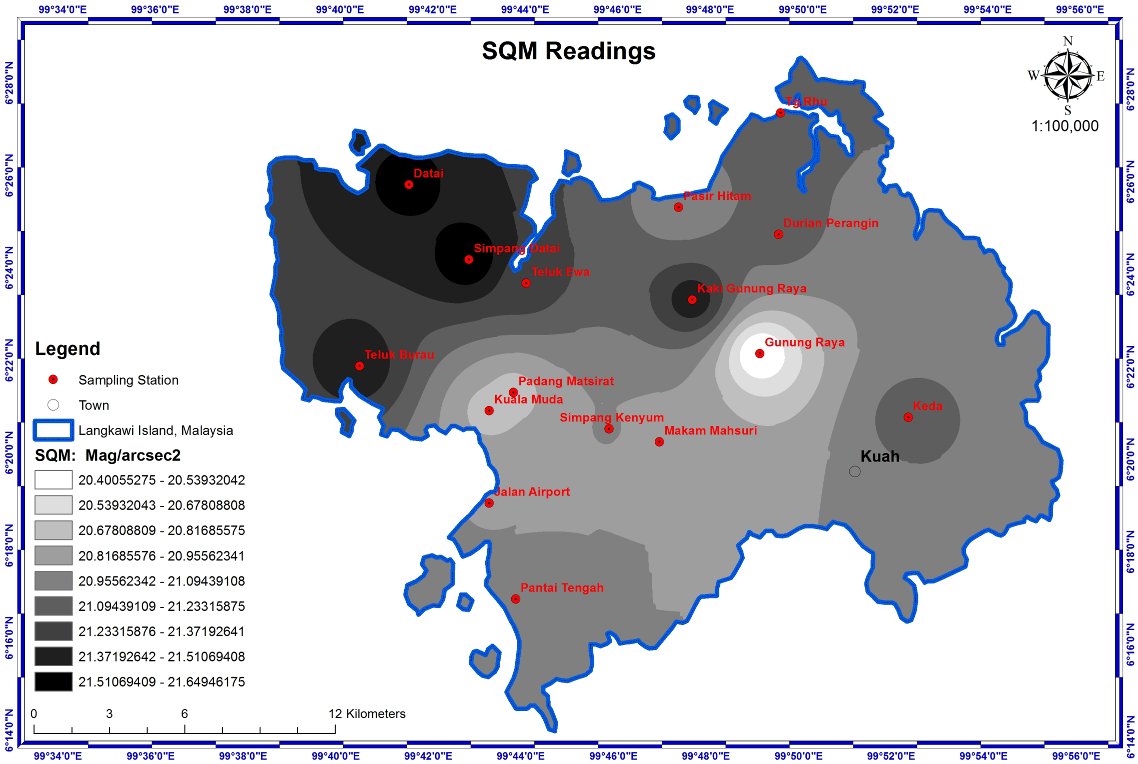

Fig. 3 Sky brightness map of Langkawi Island using SQM.

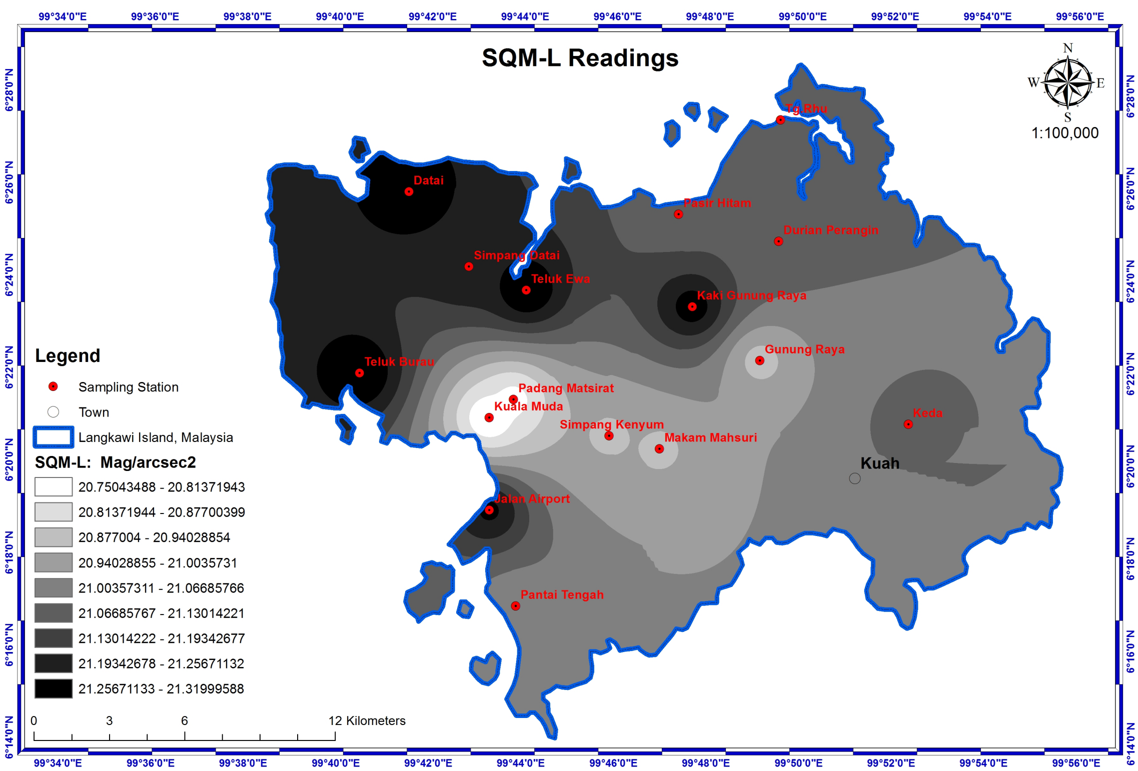

Fig. 4 Sky brightness map of Langkawi Island using SQM-L.

Table 1 SQM and SQM-L Average Readings at Each Point

	Sites	Latitude	Longitude	SQM (mag arcsec^{-2})		SQM-L (mag arcsec^{-2})		Average SQM and SQM-L	
				Magnitude	Std dev	Magnitude	Std dev	Magnitude	Std dev
1	Gunung Raya	6.3701972	99.817406	20.40	0.24	20.92	0.03	20.66	0.14
2	Kaki Gunung Raya	6.389497	99.792862	21.47	0.10	21.29	0.03	21.38	0.07
3	Tg. Rhu	6.456944	99.824317	21.14	0.07	21.10	0.03	21.12	0.05
4	Pasir Hitam	6.422722	99.792862	21.01	0.18	21.10	0.07	21.06	0.13
5	Teluk Ewa	6.395044	99.733058	21.31	0.13	21.32	0.04	21.32	0.09
6	Simpang Datai	6.403496	99.712349	21.65	0.13	21.25	0.04	21.45	0.09
7	Datai	6.430379	99.690582	21.56	0.09	21.31	0.06	21.44	0.08
8	Teluk Burau	6.364907	99.673164	21.47	0.04	21.32	0.07	21.40	0.06
9	Kuala Muda	6.349042	99.720047	20.75	0.08	20.75	0.06	20.75	0.07
10	Jalan Airport	6.315681	99.717201	20.95	0.12	21.27	0.15	21.11	0.14
11	Pantai Tengah	6.281226	99.729935	20.97	0.16	21.03	0.05	21.00	0.11
12	Makam Mahsuri	6.338233	99.781425	20.90	0.07	20.93	0.05	20.92	0.06
13	Simpang Kenyum	6.342761	99.763199	20.96	0.07	20.93	0.03	20.95	0.05
14	Pdg Matsirat	6.355681	99.728699	20.75	0.05	20.79	0.03	20.77	0.04
15	Durian Perangin	6.413231	99.823921	21.14	0.05	21.09	0.02	21.12	0.04
16	Keda	6.347536	99.870972	21.14	0.05	21.08	0.04	21.11	0.05

pared with the wider field-of-view of SQM. However, this place remains the darkest site available on the island. Another unique site which we found interesting was the airport runway which was a little darker than the surrounding areas at 20.95 mag arcsec^{-2} (4.5×10^{-4} cd m^{-2}) on the SQM and 21.27 mag arcsec^{-2} (3.4×10^{-4} cd m^{-2}) on the SQM-L. We believe this is due to the vastness of the airport and also how lighting on the runways is concentrated (directional) and not emitted except parallel to the runway. Still, five spotlight towers bath the terminal about 3 kilometers away from where the reading was taken, which affected the SQM readings more. Overall, following the three conditions of (i) moonless night; (ii) cloudless and; (iii) minimum of 100 m away from any external light source, the SQM results were pretty close to those of the SQM-L. Figure 4 illustrates the map of sky brightness reading using SQM-L.

Figure 5 shows the magnitude of sky brightness in Langkawi Island based on the average of SQM and SQM-L readings. The sky brightness level fluctuates with a difference of less than 1 magnitude over the entire island. Based on Figure 5, the darkest magnitude of sky background at Langkawi Island was found at Station 6, which is 21.45 mag arcsec^{-2} (2.8×10^{-4} cd m^{-2}) at Simpang Datai. Then, the lowest magnitude in Langkawi Island was at Station 1, 20.66 mag arcsec^{-2} (5.9×10^{-4} cd m^{-2}) in Gunung Raya. For Gunung Raya, the heavily lighted transmission towers are a requirement for safety at this facility. Usually, the factor that influenced the highest and lowest magnitude of sky brightness depends on the usage of light for industry, sky glow or any artificial light.

Overall, they can be seen to be divided into three different categories. The brightest category is represented by Stations 1, 9 and 14 (atop Gunung Raya, Kuala Muda and Padang Mat Sirat respectively) with an overall brightness of about 20.7 mag arcsec^{-2}. For Kuala Muda and Padang Mat Sirat, there is a higher concentration of villages and their presence also is impacted by the number of street lights within this area. The next category of overall brightness is around 21.04 mag arcsec^{-2} which is comprised of Stations 3, 4, 10, 11, 12, 13, 15 and 16. These areas have lesser population density and some of them are quite remote. While for areas closer to the airport, it seems external lightings are not allowed surrounding the runways, which helps to make it quite dark. The darkest areas in Langkawi can be put into one category together which is made up of five stations. Stations 2, 5, 6, 7 and 8 represent the darkest sites on the island and are situated on the most remote parts of the island where population density is very low. However, there is a very secluded upscale hotel at Datai which promotes nature as part of its specialty.

From this data set, a spatial distribution model has been developed to visualize sky brightness concentrations in Langkawi Island. By using the interpolation method, the distribution of sky brightness can be seen

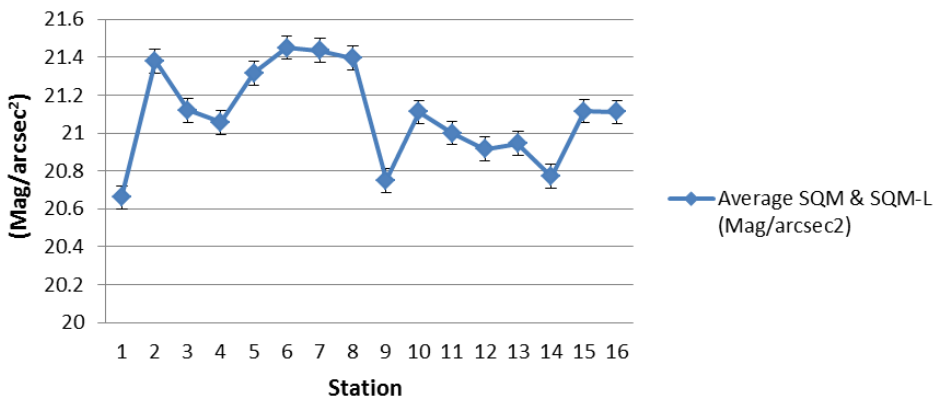

Fig. 5 Average magnitude of sky brightness for all sites in Langkawi Island.

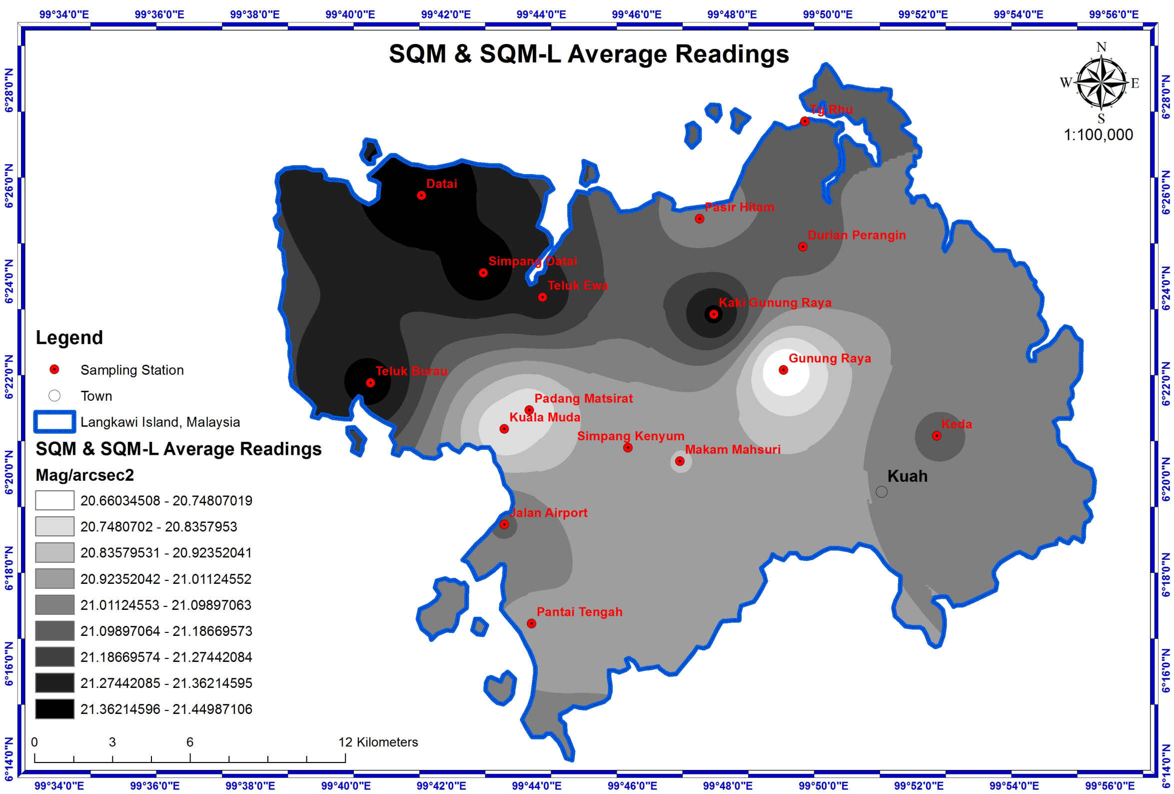

Fig. 6 Spatial distribution model for average value of SQM and SQM-L magnitude of sky brightness intensity in Langkawi Island.

clearly as illustrated in Figure 6. Darker color on the map indicates higher magnitude and the magnitude decreases as the color becomes brighter (which indicates greater light pollution).

Based on Figure 6, the highest range of magnitude is 21.36–21.45 mag arcsec^{-2}, equivalent to $(3.1 \times 10^{-4}\ \mathrm{cd\,m^{-2}} - 2.8 \times 10^{-4}\ \mathrm{cd\,m^{-2}})$. Then, the lowest magnitude of sky brightness in Langkawi Island is 20.66–20.75 mag arcsec^{-2}, equivalent to $(5.9 \times 10^{-4}\ \mathrm{cd\,m^{-2}} - 5.4 \times 10^{-4}\ \mathrm{cd\,m^{-2}})$. We found that Station 6 at Simpang Datai is the best place which has the highest value of magnitude with the least exposure to light pollution in Langkawi Island. This may result from the fact that data were collected after midnight, and Station 6 is also located far from the city center. Data were collected on a night when the sky was cloudless without the Moon. All of these criteria play a big part in the accuracy of the magnitude values. We can conclude that this area is free from any artificial light or anything that can contribute light pollution to the sky observer. This area is suitable for optical astronomy observation since we knew the ideal area for such activities needs to be in an unpopulated area and free from any artificial light (Serveny 2010). Station 4 at Pasir Hitam has middle values of intensity among all the areas in Langkawi Island because it has been affected by some small amount of light pollution. Even though it can be considered dark, it was slightly brighter and affected by light pollution from the town nearby.

The preservation of the area with the least light pollution will not only benefit astronomers in their sky observation, but also helps to sustain the wildlife including amphibians, birds, mammals, insects and plants. Scientific evidence suggests that artificial light has negative effects on the environment and ecology (Rich & Longcore 2013). The considered brightest site in Langkawi Island is in Station 1 or Gunung Raya. This is due to many sources that contribute artificial light to the surroundings, for example lamp posts, factories, buildings, parking lots and vehicles. Gunung Raya is one of the main attractions in Langkawi Island for visitors.

4 DISCUSSION AND CONCLUSIONS

Based on this study, the spatial distribution model for sky brightness magnitude in Langkawi Island showed a clear distribution where dark sites are located on the island as of September 2013. This study is very important for finding the best location and whether the area at this location is still acceptable for building an astronomical observatory or not. In this study, the darkest locations in Langkawi Island are at Simpang Datai, Datai, Teluk Burau and Kaki Gunung Raya. These locations are the best and still acceptable for building an astronomical observatory because the value is still within acceptable tolerances needed to build one. However, from this data set, the government can also take further action in this area to reduce light pollution, for example, enacting new regulations to reduce community usage of artificial light because it will have a big effect on the natural environment in the future.

This study is very important to record and identify the overall sky brightness condition of the island where LNO was built in 2005. Overall, the average sky brightness is still reasonably dark at 21.09 mag arcsec^{-2} (4.0×10^{-4} cd m^{-2}) considering the island is an international tourist destination. However, it is starting to increase, particularly at the most popular attractions like Pantai Chenang and Kuah town. Plans to build a theme park in the coming years nearby Teluk Burau are also expected to further increase the sky brightness there, limiting the number of dark sites on the island even further. It is hoped, this finding will help the local governing body on Langkawi better plan future developments on the island to preserve the night sky, considering that the island is also recognized as a UNESCO Geopark.

Acknowledgements The authors would like to thank Langkawi National Observatory, Space Science Research Unit, National Space Agency and East Coast Environmental Research Institute (ESERI), Universiti Sultan Zainal Abidin under university grant (RACE/F1/ST1/UNISZA/15-RR118).

References

Abdullah, N. M., Toriman, M. E., & Din, H. M. 2013, Malaysian Journal of Analytical Sciences, 17, 11

Abidin, Z. Z., Umar, R., Ibrahim, Z. A., et al. 2013, PASA, 30, e047

Alvarado, A., Esteller, M., Quentin, E., & Expósito, J. 2016, Water Resources Management, 30, 1549

Bennie, J., Davies, T. W., Inger, R., & Gaston, K. J. 2014, Methods in Ecology and Evolution, 5, 534

Bernhardsen, T. 1999. Geographic Information Systems: an Introduction (New York: John Wiley & Sons)

Cinzano, P., Falchi, F., & Elvidge, C. D. 2001, Monthly Notices of the Royal Astronomical Society, 328, 689

Cinzano, P., 2005, Night Sky Photometry with Sky Quality Meter, ISTIL; Technical Report 9. v1.4 (*www.lightpollution.it/download/sqmreport.pdf*)

Cinzano, P., 2007, Report on Sky Quality Meter, Version L. ISTIL; Technical Report 9. (*http://unihedron.com/projects/sqm-l/sqmreport2.pdf*)

Davies, T. W., Duffy, J. P., Bennie, J., & Gaston, K. J. 2014, Frontiers in Ecology and the Environment, 12, 347

Falchi, F., Cinzano, P., Duriscoe, D., et al. 2016, Science Advances, 2, e1600377

Fathian, F., Aliyari, H., Kahya, E., & Dehghan, Z. 2016, International Journal of Hydrology Science and Technology, 6, 62

Garstang, R. 1989, Publications of the Astronomical Society of the Pacific, 101, 306

Haque, M. N., Shahid, S., Keramat, M., & Mohsenipour, M. 2016, Water Resources, 43, 283

Kamarudin, M. K. A., Toriman, M. E., Rosli, M. H., et al. 2015a, Mitigation and Adaptation Strategies for Global Change, 20, 1319

Kamarudin, M. K. A., Toriman, M. E., Juahir, H., et al. 2015b, Jurnal Teknologi, 76, 31

Kazemi, H., Sadeghi, S., & Akinci, H. 2016, Ecological Indicators, 63, 37

Mahdian, M. H., Hosseini, E., & Matin, M. 2001, Investigation of Spatial Interpolation Methods to Determine the Minimum Error of Estimation: Case Study, Temperature and Evaporation, in Proc. 6th Int. Conf. GeoComputation, Citeseer, 24

Mustafa, A. D., Azid, A., Juahir, H., et al. 2015, Malaysian Journal of Analytical Sciences, 19, 1318

Navara, K. J., & Nelson, R. J. 2007, Journal of Pineal Research, 43, 215

Ngetich, K., Mucheru-Muna, M., Mugwe, J., et al. 2014, Agricultural and Forest Meteorology, 188, 24

Patat, F. 2003, A&A, 400, 1183

Rich, C., & Longcore, T. 2013, Ecological Consequences of Artificial Night Lighting (Island Press)

Sabri, N. H., Umar, R., Mokhtar, W. Z. A. W., et al. 2015, Jurnal Teknologi, 75, 313

Schwarz, H. E. 2002, Light Pollution: The Global View. LA Serena, 284 (Chile: Kluwer Academic)

Serveny, A. B. 2010, The Measurement of Sky Brightness. Lunar Science Institute

Umar, R., Zainal Abidin, Z., Abidin Ibrahim, Z., Rosli, Z., & Noorazlan, N. 2014, RAA (Research in Astronomy and Astrophysics), 14, 241

Umar, R., Hazmin, S. N., Abidin, Z. Z., & Ibrahim, Z. A. 2015, Publications of The Korean Astronomical Society, 30, 691

Yusri, O. A. K., Maulud, K. N. A., Toriman, M. E., & Kamarudin, M. K. A. 2009, Jurnal Ilmiah Semesta Teknika, 12, 157 (*http://journal.umy.ac.id/index.php/st/article/view/734*)