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ASSESSMENT OF LIGHT POLLUTION AND SUSTAINABILITY USING GEOSPATIAL APPROACHES: A CASE STUDY IN UITM SHAH ALAM SELANGOR

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Abstract: Light pollution is one form of pollution that appears to exist among people without almost any human intervention. This problem has been acknowledged by local researchers in Malaysia since it is capable of posing a long-term threat to humans as well as to biodiversity. This study attempts to describe the status of light pollution in the state of Selangor, specifically in the Shah Alam area from a Geographical Information System (GIS) perspective. Samples were randomly collected from Seksyen 1 to Seksyen 7 (except from Seksyen 5), due to limited access. Observations were performed in the corresponding areas using the Sky Quality Meter (SQM). Findings indicate that the Shah Alam area is badly polluted with light pollution issues. Furthermore, in comparison to other methods (Kriging & Natural Neighbour), the Inverse Distance Weightage (IDW) technique is the best interpolation method for SQM data estimation when addressing light pollution problems. The selection method was based on 3 main criteria, namely previous studies, reliable data obtained by interpolation, and the natural behaviour of light pollution. Findings of this study can significantly contribute to the existing corpus of knowledge on light pollution and help the local government to improve current policies to ensure the sustainability of biodiversity in the country, especially around Shah Alam.

Keywords: Light pollution, sky brightness, geospatial, GIS, SQM.

Introduction

Since the climate has been transformed today due to the increasing global population, the ensuing dangers of this transformation have begun to harm our everyday lives, such as the emerging and startling rates of human morbidities and environmental issues. From a climate perspective, most people around the world are conscious of a particular form of pollution, namely water, and air pollution. Light pollution is a type of pollution that continues to rise and more often people do not notice the impact relative to other environmental issues. Light pollution can be defined as a sort of artificial illumination that alters the natural night sky and makes it brighter (Falchi *et al.,* 2011). Studies on the light pollution issue began after it was first addressed by astronomers as early as 1972 when researchers foresaw the threat it posed to optical observation (Hoag, 1972; Puschnig *et al.,* 2013). In recent years, the world has begun to understand the challenges of light pollution through various studies. One study showed that light pollution is capable of lowering night vision, which involves energy waste that impacts light trespass and sky glow (Rajkhowa, 2012). In America, a non-governmental organization (NGO) called the International Dark-Sky Association (IDA), has defined light pollution as excessive or inefficient use of artificial light that affects humans. The same study reported that light pollution usually occurs in main town areas or areas undergoing development in the region. This has encouraged scientists from around the world who have started to demonstrate their interest in problems concerning artificial lightning.

Artificial lighting has been an integral aspect of technological growth in communities that cannot be ignored as it defines leisure and lifestyles (Wu *et al*., 2012; Ali *et al*., 2019). Thus, it is almost impossible to escape this part of the urbanization process. Most of the light act as a safety measure used to brighten dark areas, especially in the form of lamp posts or streetlights, to ensure that criminal hot-spot areas are less dependent on conditions surrounding the area affected by the light. The government has typically taken notice of the city centre's landscape and vision for future development and how it can attract tourists to the country. Nevertheless, the use of artificial lighting becomes needless, for example, when landscape artists place numerous neon lights on trees and around the park. Thus, from a tourist's perspective, this initiative presents a beautiful and pleasant view, but it has dire consequences on the environment, particularly for sustaining biodiversity (Hölker *et al*., 2010). In comparison, light emission also has an adverse effect on astronomy. Evidently, there are innumerable studies on astronomy that focus on the vision of the sky. A lighter sky is a great drawback for these studies in Malaysia because the view of an object in the sky is diminished and the scope for astronomy studies is immensely limited (Tahar *et al*., 2017). Therefore, it is necessary to reduce light pollution in the country. For example, the Korean government had recently legislated and implemented the 'Light Pollution Prevention Act' for the better management of light pollution (Cha *et al.,* 2014). In the United Kingdom (UK), local authorities receiving complaints about artificial light can now assess whether the light is a nuisance under The Clean Neighbourhood and Environment Act 2005 (Ffrench-Constant *et al*., 2016) Several experts have undertaken a campaign to alert the public on light emission concerns that are dangerous or damaging. This single-step campaign is crucial for ensuring that this generation has a clear view of the sky and not a clouded one.

In Malaysia, several institutions, including Agensi Angkasa Malaysia (MySA), Universiti Sultan Zainal Abidin (UniSZA), Universiti Malaya, and Universiti Teknologi Mara (UiTM), have carried out this program. It was suggested in 2016 that Malaysia formulate light pollution legislation after it was found that severe light pollution in Kuala Lumpur City affected observation work at Planetarium Negara in Kuala Lumpur (The Star, 2018). According to Tahar (2020), the Langkawi National Observatory (LNO), under the supervision of the Malaysian Space Agency (MySA) program, experienced a light pollution condition, which increased from 21 mags/arcsec^2 in 2013 to 19.6 mags/arcsec^2 in 2018. There are several light pollution sources detected, such as High-Pressure Sodium (HPS), Mercury Vapor (MV) used by the local authorities, Metal Halide (MH) and white LED spotlight. Whereas Teluk Kemang Observatory and LNO were affected by the use of white coloured LED. Teluk Kemang Observatory is one location that should be free from light pollution since it is one of the locations around Malaysia used for sighting the crescent moon (Ahmad *et al.,* 2020). LNO for example is affected by green MV, which is used on a large scale for squid fishing around the entire island. Sustainable light pollution needs to be protected to maintain low light pollution levels in LNO for future research on astronomy, especially for optical observations (Tahar *et al*., 2017; Tahar *et al*., 2020. The KUSZA Observatory in Terengganu (20 mags/arcsec^2 in 2018) was established in 1992 and is one of the pioneer optical observatories in Malaysia that should be protected from light pollution by nearby artificial light (Umar *et al*., 2018).

These new regulations proposed to reduce community usage of artificial light because it has a huge effect not only on optical astronomy but also on the natural environment (nocturnal insects and sea turtles) as well as to ensure that these tourist spots remain low light pollution areas (Brei *et al.,* 2012; Firebaugh *et al.,* 2019). In fact, UiTM has initiated talks and campaigns throughout Malaysia for this purpose. It has formed collaborations with a selected number of secondary schools in Malaysia to raise awareness among students about light pollution issues and provide them with hands-on experience in measuring sky brightness (Shariff *et al*., 2016). Shariff (2012) also performed a study using the Sky Quality Meter for determining twilight time for scheduling Islamic Prayer times (Shariff *et al*., 2012). In this study, 23 sites are selected to cover 6 sections in Shah Alam according to the Geographical Information Perspective (GIS). In GIS mapping, three other methods (Kriging, Natural Neighbour, and the Inverse Distance Weightage (IDW) are applied to interpolate Sky Quality Meter (SQM) data to estimate the light pollution profile in Shah Alam. This profile (light pollution mapping) serves an important purpose for the government, policymakers, and the MySA agency, specifically for predicting, improving, and administering light pollution policies in Malaysia.

Study Area

Shah Alam is the area of focus in this study, which is mainly located in the District of Petaling in Selangor, Malaysia, while some parts of it are located in the Klang district. Shah Alam is one of Klang Valley's largest cities as well as in Selangor too due to Selangor's exponential growth. The city is divided into 56 sections (Seksyen) altogether. Coordinates for the study area are 3.076687, 101.500245 for the latitude and longitude respectively, with its average humidity and temperature are 97% and 25°C. As for this study, only a few sections were selected, namely Seksyen 1, 2, 3, 4, 6, and 7. These areas (seksyens) were selected mainly based on the massive development plan outlined by the Selangor government, specifically the on-going i-City project in Seksyen 7 deemed as a hub for international business due to the commercial, residential, and leisure components planned leading to its nickname "The Pulse of Selangor" (NST Online, 2017). Besides that, it was also noted that this area has become a domestic tourist spot, especially for the younger generation (Farahin & Rahman, 2019). Therefore, the chosen area is significant and should to explored together with other close sections to determine their light pollution status. Unfortunately, this study could not cover the whole of Shah Alam because of adverse weather conditions at the particular time (raining season) with unpredictable heavy rain and excessive cloud cover throughout the other sections that severely affected the reading of SQM data. This was especially so due to the moonset condition, while some areas were denied access by the Selangor government and some were declared private property. These study areas are also ideal for studying the state of light emissions. Figure 1 shows the location of the study area from Google image view.

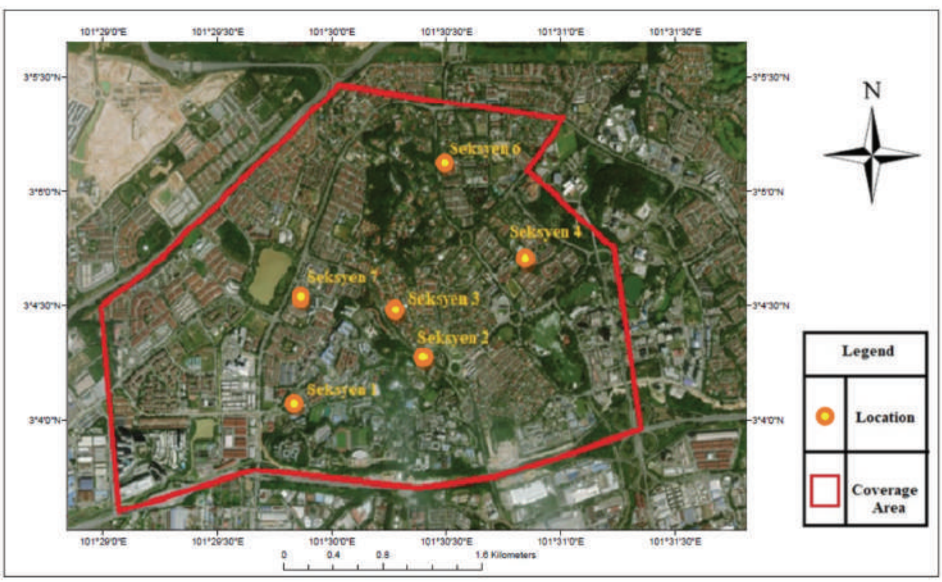


Figure 1: Map of the Shah Alam area based on the selected sections

Materials and Methods

In-Situ Data Observation

The data sample was analysed using specialized devices such as the SQM. Data were collected in November 2018. It is mandatory to correctly follow the guidelines stipulated by the creator (Unihedron) of the device in order to perform a sky quality survey using SQM. Observations began by pointing to the SQM system's zenith position when attached to the monitor. The computer screen displays the significance of the light in the sky in astronomical units at that particular moment (magnitudes per square arc second). This unit is rather counterintuitive in that the darker the sky is at the moment, the better the value of the number. This study took at least six measurements per position per visit and it is suggested that the first measurement should be discarded from the sample. However, for better elucidated results, data were obtained for 10 minutes per position every 1 minute. Data were averaged in order to obtain the exact value of the data, A reminder in the guidelines and also in previous studies mentioned not to carry out observations directly below the light source or anything that blocks the clear sky view, since even excessive cloud cover could influence the accumulated data (Faid *et al*., 2016). Moreover, it is advisable to keep a distance of at least 100 meters away from the light (Tahar *et al*., 2017). Observations are frequently made while the moon is below the horizon on clear nights (moonset). Figure 2 shows the SQM devices applied in this study.

Figure 2: Sky quality meter device

Sky Brightness Indicator (Bortle Scale)

In order to visualize the quality of the sky in the study, the Bortle scale was used. This scale was introduced by a distinguished astronomer named John. E Bortle, who wanted to explain the extent of darkness in the sky. This scale consists of nine classes (darkest to the brightest moon), Naked-Eye Limiting Magnitude (NELM), and a SQM approximation to calculate the brightness of the sky. Table 1 shows the level of sky brightness based on the Bortle Scale.

Table 1: Sky brightness indicator (Bortle Dark-Sky Scale)

Level/Class	**Title**	**NELM**	**SQM mag/arcsec^2**
1	The high dark sky area	7.60 -8.00	21.70 - 22.00
2	The typical truly dark area	7.10 -7.50	21.50 - 21.70
3	Rural sky area	6.60 -7.00	21.30 - 21.50
4	The rural or suburban area	6.10 - 6.50	20.40 - 21.30
5	Suburban sky area	5.60 - 6.00	19.10 - 20.40
6	Bright with the suburban sky area	5.10 - 5.50	18.00 - 19.10
7	Suburban or urban transition area	4.60 -5.00	
8	City sky area	4.10 - 4.50	Less than 18.00
9	Inner-city sky area	≤ 4.00	

Spatial Data and the Conversion Process

One characteristic of buildings and roads is spatial data, which is derived from this analysis by composing data of comprehensive attributes. Spatial data for this process was obtained for free from the Open Street Map. The Open Street Map contains information according to the OSM format style. Only a few sections in Shah Alam are involved in this study, namely Seksyen 1 to Seksyen 7 (except for Seksyen 5). Besides that, other data, such as water sources and vegetation pertaining to these study areas were also collected. However, these data attributes were only used for the base map layer and no detailed analysis was conducted using these data. Since extracted data were in the OSM format, further conversion was needed to format the data according to Shapefile (.shp) format. At this point, using a free converter from an open-source platform, such as the MyGeodata Converter, enabled the extraction of spatial data, which was converted accordingly into the Shape.file format. This converter is specifically designed to convert OSM files to Shape.file files. Polygon construction and road details were the final output of the conversion. The spatial data conversion phase is shown in Figure 3 comprising (a) the open-source converter that used the MyGeodata Converter, and (b) results after the conversion of spatial data related to certain areas in Shah Alam according to the Shape.file (shp.) format.

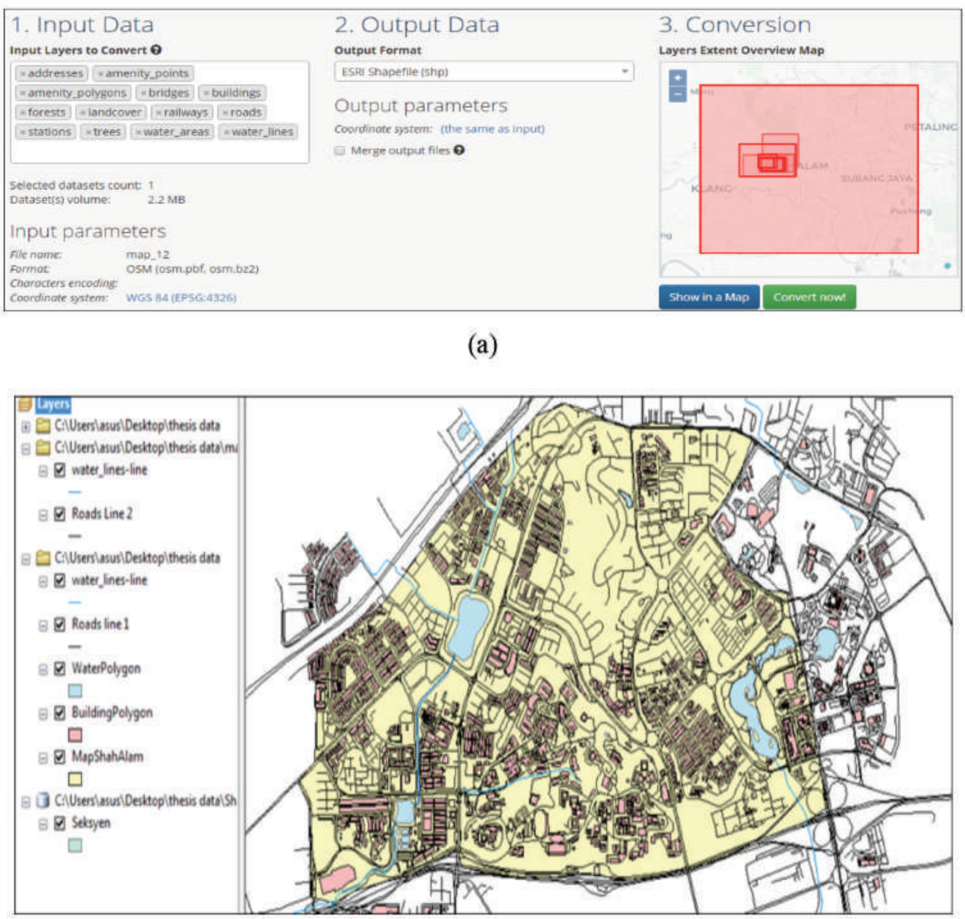


Figure 3: Spatial data concerning the Shah Alam study areas

Interpolation Techniques (Inverse Distance Weightage, Kriging, and Natural Neighbour)

Values obtained from the Shah Alam study areas using SQM data were thoroughly optimized to perform the interpolation techniques. These 3 approaches have an approximation of SQM data, which comprised minimal observation data for Shah Alam. The formulas of (1) IDW, (2) Kriging, and (3) Natural Neighbour are as follows:

$$\hat{Z}(S0) = \sum_{i=1}^{N} \lambda i \, Z(Si), \qquad (1)(2)$$

where $Z(s_i)$ is a measured value of the location at the ^{i}th location; λi: unknown weight for measure value of ^{i}th location; S_0: prediction of the location and N: the number of measure values. Both IDW and Kriging can use the same formula, however, the weighting λi in IDW is primely determined by the distance to the projection location. Meanwhile, the Kriging method is highly dependent on the overall spatial arrangement of the measured points as well as the distance between the measured points and the prediction position. The Kriging and IDW methods are used in a number of study areas, including mineral resource prediction and astronomy (Tahar *et al*., 2017; Tahar *et al*., 2020; Du *et al*., 2018). The Natural Neighbor method is based on an equal distance from the interpolation point, thus, giving the northernmost and northeastern points similar weights.

$$V(\text{n1}) = \{x\, \varepsilon \in Rd : d(x, xI) < d(x, xJ)\ \forall J \neq I\}, \quad (3)$$

where V(n1) is the first order of Voronoi cells for the node n1 within the convex hull is a convex polygon (polyhedron) in R2 (R3); and d(x, xI) is an appropriate Euclidean distance function (Cueto *et al*., 2003). This method is widely used in water management and elevation estimation (Curtarelli *et al*., 2015; Setianto & Triandini, 2015).

Results and Discussions

The Behaviour of Sky Brightness in Shah Alam

In order to analyse the behaviour of sky brightness in the Shah Alam area, SQM data were processed using the simple overlaying process with the dataset feature obtained from an open street map. The reliability of the location in the open street map was verified using the Google Map application. Figure 4 shows the distribution points for SQM data collected in the Shah Alam area by using SQM, while Table 2 below shows the overview of the observation results of SQM data for the Shah Alam area.

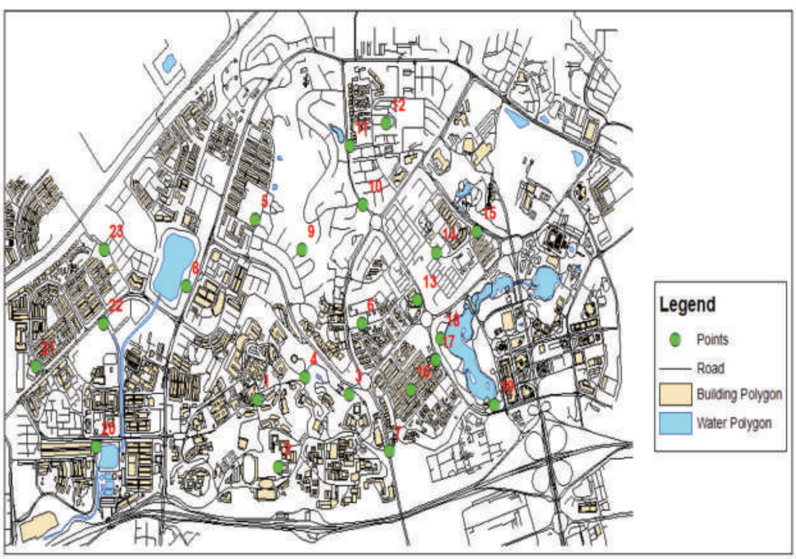


Figure 4: Sample distribution points for SQM value in Shah Alam

Table 2: Summarization of SQM observation data for Shah Alam

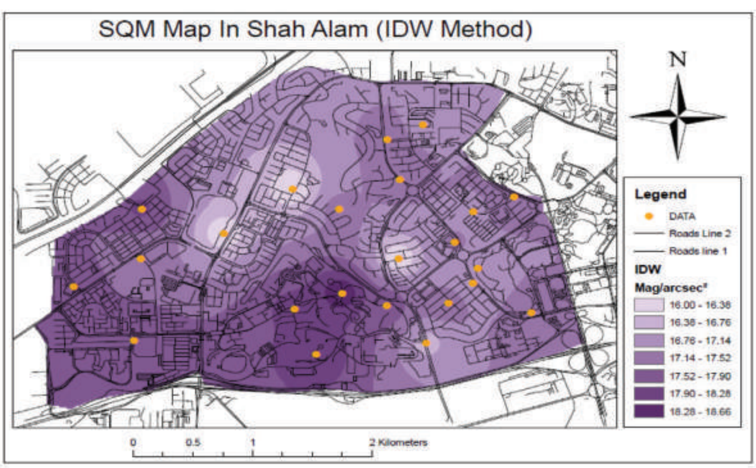
No.	Locations	Latitude	Longitude	Sections	SQM Value
1.	Top hill of UiTM Police Station Seksyen 1	3.06963	101.4984	1	18.03
2.	Behind Perindu College Seksyen 1	3.0658	101.5	1	18.29
3.	Hill of the main gate in Seksyen 2	3.06992	101.5053	2	17.82
4.	Next to Faculty of Computer & Mathematical Science Seksyen 1	3.07092	101.502	1	18.66
5.	Open space in the housing area of Seksyen 7	3.07978	101.4982	7	16.07
6.	Open space in the housing area of Seksyen 3	3.07392	101.5062	3	16
7.	Housing area off Persiaran Raja Muda Seksyen 2	3.06674	101.5083	2	16.61
8.	Edge of Shah Alam Lake in Seksyen 7	3.07601	101.4931	7	16.15
9.	Housing area in Perumahan Elit Seksyen 7	3.07809	101.5018	7	17.25
10.	Housing area off Jalan Persiaran Dato Menteri Seksyen 6	3.080602	101.5063	6	17.36
11.	Close to the junction to Jalan Undan Seksyen 6	3.083965	101.5054	6	17.27
12.	Edge of Kolej Cendana Seksyen 6	3.085232	101.5081	6	17.05
13.	Edge of MAIS's main buiding Seksyen 3	3.075273	101.5104	3	17.18
14.	Edge of Surau Raudhah Al-Mutaqim Seksyen 4	3.077876	101.5119	4	17.1
15.	End road of Jalan Pauh Seksyen 4	3.079101	101.5149	4	17.38
16.	Housing area off Jalan Kekwa Seksyen 2	3.070151	101.51	2	17.35
17.	Edge of Lake in Seksyen 2	3.071837	101.5118	2	16.71
18.	Edge of West Lake Seksyen 2	3.07307	101.5122	2	17.11
19.	End of road West Lake Seksyen 2	3.069315	101.5162	2	17.36
20.	Edge of the Lake in Persiaran Multimedia I-City Seksyen 7	3.066955	101.4863	7	17.85
21.	Edge of Masjid Baru Seksyen 7	3.071502	101.4817	7	17.77
22.	Next to Sekolah Kebangsaan Seksyen	3.07389	101.4868	7	17.15
23.	End road off Jalan Kristal 7/64 Seskyen 7	3.078072	101.4869	7	17.95

Table 1 provides an overall view of how the Shah Alam region has been seriously polluted with light pollution. This inference can be justified if the SQM values are in the range of 16 mags/arcsec^2 to 18.6 mags/arcsec^2, leading to (4.300 x 10^{-2} cd/m^2) until (3.921 x 10^{-3} cd/m^2) . Based on the Bortle table predictor, this range falls into grades 8 and 9, as shown in Table 1. These levels or classes are known to be particularly hazardous and contaminates the region. The Seksyen 3 region (16 mags/arcsec^2), which is equal to (4.300 x 10^{-2} cd/m^2). has the highest value obtained for an affected area in Shah Alam, which is an area close to Seksyen 2.

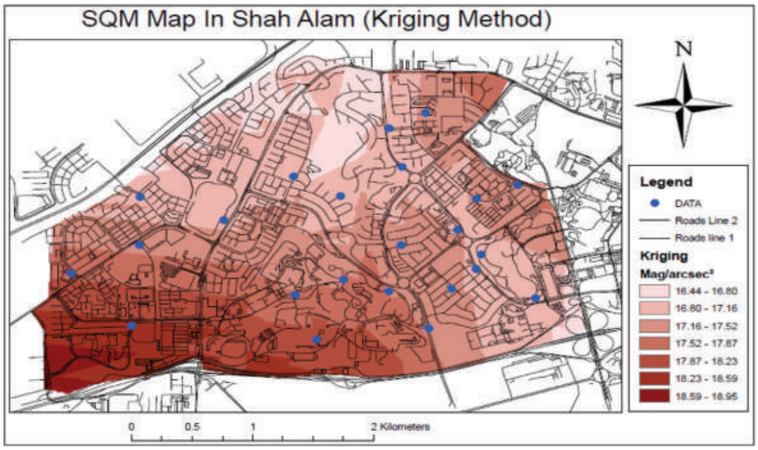
This indicates how the region is associated with the urbanization process in Seksyen 3, which is almost identical to the area in Seksyen 2. The development process plays a crucial role in determining SQM values, especially due to the use of light from buildings and housing in Seksyen 3. Besides, the importance of data gathered can also be impacted by exposure to lamp posts around the housing area. Overall, the data collected indicates that the bulk of areas in Shah Alam is affected by the development process. This result is consistent with Wu and Wong (2012), who emphasized that inappropriate use of light can be a source of light pollution, especially in areas experiencing urbanization and the main city area (Tahar *et al*., 2020). This situation is explained by the condition in the Seksyen 3 area. Next, the second-highest level for SQM observation came from the Seksyen 7 area with a range of 16.07 to 17.95 mags/arcsec^2, which is equivalent to 4.031 x 10^{-2} cd/$m^2$to 7.135 x 10^{-3} cd/m^2. This section shows the highest potential to have the same light pollution level as the leading area in Seksyen 3. The main reason for this situation is the excessive use of light by the public, specifically in residential areas in Seksyen 7. Apart from that, excessive use of neon lights on landscape trees, buildings, and the theme parks in i-City (Seksyen 7), which is also known as the City of Digital Light, might directly contribute to the SQM observation. This type of source (neon light) of light pollution through excessive usage and repeated change in brightness contributes to the eventual skyglow (Tomazs, 2019). Finally, observations also reveal how the lowest polluted area is influenced by Shah Alam's sky brightness coming from Seksyen 1, which is situated near to the Faculty of Computer & Mathematical Science in UiTM, and having a value of 18.6 mags/arcsec² or 3.921 x 10^{-3} cd/m^2.

Comparison Between Estimation Methods used in light pollution studies.

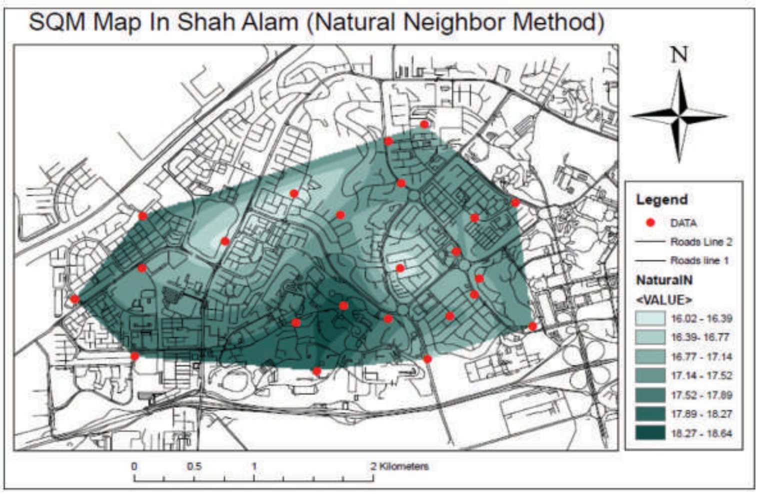
This study thoroughly investigated the outcome obtained by interpolation using the light emission analysis concerning specific areas in Shah Alam. This report determined the most effective approach for further examination of the problem concerning light emission. Inverse Distance Weightage (IDW), Kriging, and Natural Neighbour are the 3 interpolation methods applied in this analysis. Findings were plotted according to a proper mapped format to make the outcome look simple and easy to read consisting of legends, north arrow, and map size. The class level was standardized into seven classes for each procedure to reduce interpolation bias. Figure 5 shows an interpolation map using different methods, such as (a) Inverse Distance Weightage (IDW), (b) Kriging, and (c) Natural Neighbour methods, as part of the light pollution data.



(a)



(b)



(c)

Figure 5: Interpolation map involving (a) Inverse Distance Weightage (IDW), (b) Kriging, and (c) Natural Neighbour methods for light pollution data

Table 3: Statistical analysis comparing SQM data with various interpolator(s)

Interpolator	No. of Points	Mean Absolute Deviation (MAD)	Mean Square Error (MSE)	Root Mean Square Error (RMSE)	Mean Absolute Percentage Error (MAPE)
IDW	23	0.01	0.00	0.00	0.06
Kriging	23	0.48	0.01	0.10	2.80
Natural Neighbour	23	0.02	0.00	0.03	0.12

Based on Figure 5, the map displays a summary of the interpolation using Inverse Distance Weightage (IDW), Kriging, and Natural Neighbour methods for analysing light pollution in certain areas in Shah Alam. Selection of the method is based on previous studies, accurate data gathered for deciding on a method and the nature of the pollution. These three requirements are necessary when justifying the selection of a method. According to a previous study, the most common technique used in the interpolation of light pollution is the Inverse Distance Weightage (IDW) method. The IDW approach is a common method used as the first selection criterion in the case of light pollution. This is because the resulting surface generation does not reach extremes in the data point. (Umar *et al*., 2018). This method was also applied in the Shah Alam area as part of the IDW technique, which does not exaggerate the Kriging technique, especially from the highest estimated SQM value. Hence, IDW provides the most accurate form of interpolation for light pollution analysis. The map provides a rough estimate of the highest and lowest SQM values from the data results as the details surrounding the data are almost identical to IDW. This justification is supported by a statistical analysis shown in Table 3 for Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) with significant values of 0.00 and 0.06, respectively. The values show a high accuracy rate between the SQM value and the estimated value (IDW method) as RMSE and MAPE have the lowest values. Simply put, the lower the RMSE value, the higher the accuracy of the method. This result is aligned with findings by Jin *et al*. (2017), who revealed that the use of IDW for studying light pollution can reach an accuracy of up to 95%. As for the Kriging and Natural Neighbour methods, the findings were different. This shows the highest and lowest values of large gaps covering SQM data. Kriging has a lower accuracy value among these 3 methods. The exaggeration of this method is obvious from the map showing RMSE and MAPE values of up to 0.1 and 2.8, respectively. The Natural Neighbour method is the second most reliable method to be applied. The RMSE = 0.03, MAPE = 0.12 values show a significant indication when considering its implementation in light pollution studies.

The last factor that should be considered in light pollution studies is the nature of light pollution itself. Light pollution is dynamic in nature as it is not constant at any one time. The nature of light pollution is similar to other environmental concerns, such as air pollution or heavy snow. Light pollution is a contaminant that cannot be directly observed through the naked human eye and also because the value of the pollution changes at any given moment. Moreover, when illustrating the relationship between them, IDW can be used to provide a reliable and continuously estimated result and how it can be compared with other variables (Ninverola *et al*., 2007). Other studies have shown that physical details, such as soil properties, are most widely used by the Kriging and Natural Neighbour methods. Therefore, this study concluded as a whole that, relative to Kriging and Natural Neighbour methods, the Inverse Distance Weightage (IDW) is a provides a better form of interpolation for light pollution studies.

Conclusion

This light pollution study revealed an important issue that needs to be urgently addressed by the whole world. Malaysia is known to be one of the countries that faces severe light pollution, specifically in areas such as the main cities in a state. There are no specific regulations or policies in Malaysia for curbing issues related to light pollution. This is very important for places such as the National Planetarium in Kuala Lumpur, LNO in Langkawi and the KUSZA Observatory in Terengganu in order to ensure that low light pollution is sustained. In efforts to curb these issues, GIS knowledge has been earmarked for supporting the assessment of light pollution studies. It has been found that the Shah Alam area is badly polluted by light. The Bortle Scale indicator reveals Shah Alam's status (low) as being badly affected by light pollution, which is caused by excessive development around Shah Alam. Other factors that influence light pollution, as mentioned in previous studies, should be further explored. This study found that the SQM value can be estimated with a high degree of reliability using GIS technologies, especially the Inverse Distance Weightage method, compared to the Kriging and Natural Neighbour methods. However, it is suggested that these methods should be further explored as the study's sample size can influence the quality of the results.

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