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The Night Sky Brightness Measurement using OZT-ALTS Telescope based on Sky Quality Meter

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Abstract

Sky brightness is an important parameter in astronomical observations. The brightness of the sky is affected by the level of light pollution. The problem of light pollution is faced by observatories around the world, including the ITERA Lampung Astronomical Observatory (OAIL) which has an OZT-ALTS telescope (robotic telescope) that routinely makes observations of celestial objects and is not immune from light pollution, so it is necessary to observe the brightness of the sky to know the source of light pollution, the value and contour pattern of sky brightness. Measurements were carried out on April 9 2022 using Sky Quality Meter (SQM). SQM is directed to each coordinate point with an azimuth interval of 22.5° and altitude of 15°. The measurement data is used to create a contour map of the brightness of the night sky. The contour mapping results are compared with the All Sky Camera image. Based on the sky brightness contour map, at an azimuth of 90° – 360° and an altitude of 20° there are a number of sources of light pollution from street lights and buildings with a sky brightness value of 12,626 mag/arcsec². The darkest sky area is from azimuth 22.5° – 90° and altitude 0° - 90°, the sky brightness value is 19.31 mag/arcsec². Based on observations, the night sky at the OZT-ALTS Telescope is of the City Sky - Bright Suburban type (Bortle Scale), and the visual magnitude limit is less than 5 magnitudes. The All Sky Camera shows the source of light pollution visually and its contour pattern matches the contour pattern from measurements using SQM.

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INTRODUCTION

The construction of the ITERA campus is increasingly becoming more and more significant, along with its location which is adjacent to the city of Bandar Lampung which is the capital of Lampung Province. The development of ITERA began with its inauguration on October 6 2014 through Peraturan Presiden Nomor 124 Tahun 2014 by the President of the Republic of Indonesia located in South Lampung Regency. ITERA development really supports regional government plans. Until now, this development is still ongoing and also around the ITERA area. Lighting from the construction of the ITERA campus and its surroundings distributes light pollution. Light pollution is the result of artificial light being used inefficiently (Tong et al., 2023). ITERA's night sky is not free from light pollution. This economic and population growth has the potential to distribute significant light pollution. The problem of wasting energy in the form of night lighting originates from inefficient lighting direction, as well as errors in selecting power-intensive lamps (Gao et al., 2023). The increased use of outdoor lights without effective lampshades leads to increased sky brightness (Kocifaj et al., 2021). The increase in the brightness of the night sky caused by light pollution also harms life on Earth (Wesołowski, 2023), such as astronomical observation activities, and ecology, and also can affect human health (Anderson et al., 2024).

An increase in the brightness of the night sky has a negative impact, one of which is on astronomical observations at ITERA. Currently, the OZT-ALTS Telescope is a robotic telescope used for observing the Moon and other celestial objects. Spread across various parts of the world, one is located on the ITERA campus which is managed by OAIL. In connection with astronomical observation activities, it is very important to know the value and type of sky brightness (Barentine et al., 2023). With astronomical observation activities on the ITERA campus, it is necessary to conduct research on the quality of the brightness of the night sky. Sky Quality Meter (SQM) is a tool for measuring sky brightness values (Wang et al., 2024). SQM shows results in MPSAS or mag/arcsec units2, so it can be practically done every time (Wang et al., 2020). SQM can be used to measure the level of light pollution in a place (Fiorentin et al., 2023). The SQM is a relatively cheap, light, pocket-sized photometer with a measuring angle of 20° to the sky and less than 3% accuracy (Bartolomei et al., 2021). SQM is quite popularly used to read the sky quality at a location (Fiorentin et al., 2022). The brightness of the sky read by SQM can provide a direct picture of how sky conditions change at any time (Puschnig et al., 2022). Therefore, SQM can be used to analyze various factors that can influence sky brightness (Cavazzani et al., 2020).

This research aims to determine the distribution pattern of the brightness of the night sky towards the zenith at the OZT-ALTS Telescope, as well as to determine the types of sources of light pollution in the night sky at the OZT-ALTS Telescope. Analysis was carried out on the results of equalizing the polar contours of the sky from SQM measurements with All Sky Camera images to see the similarity of contour patterns, classify ITERA night sky classes using the Bortle Scale, and find out which points contribute to light pollution.

METHOD

Time and Location of Data Collection

This research was carried out from April 1, 2022, to October 21, 2022, at the OZT-ALTS Telescope. The location chosen to take measurements was the OZT-ALTS Telescope. The OZT-ALTS telescope is located within the ITERA campus area, precisely in the ITERA MKG Equipment Park. The location coordinates are 5.362803° S, 105.311566° E, and an altitude of ~123 m above sea level.

Instruments

Sky Quality Meter (SQM)

The instrument used to measure sky brightness is the Unihedron SQM-LU (Sky Quality Meter-Lens USB) as in Figure 1 which is connected to a computer and smartphone using a USB B (device) to USB A (computer) cable or micro-USB (smartphone). SQM-LU dimension is 6.5 x 2.5 x 9 cm and weighs 75 grams. SQM has a lens with a field of view of 20° (Shalaginov et al., 2020). The narrow field of view of SQM-LU makes observations towards the zenith free from the influence of light on the horizon (Espenshade & Yoo, 2023). SQM specifications can be seen in Table 1.

Figure 1. Front and Back Views of SQM-LU

Table 1. SQM Specification Table

Specification	**Information**
Connectivity	USB
HWHM	~10°
FWHM	~20°
Dimensions	3.6×2.6×1.1 inch
Maximum light sampling time	80 seconds
Minimum light sampling time	1 second

Tripods and Mounting Alt-Az

The SQM is mounted on a tripod with mounting Alt-Az secara Portable for easy data retrieval. Mounting on a tripod Figure 2 is mounting mini robotic assembly (concept Mounting) and the programming is set for each its rotation is calculated according to 22.5° azimuth and 15° elevation angle. Just by pressing a button, mounting moves by itself, so its use is easier, more practical, and more precise.

Figure 2. Installing SQM-LU on a Tripod

All Sky Camera

All Sky Camera used is a Canon 5D Mk II camera as shown Figure 3. This camera has a high-resolution monitoring system with a field of view of 180° in every direction of the sky. The system makes it possible to do monitoring real-time, monitor satellite or airplane tracks, take pictures of meteors, monitor zodiac light, and makes it possible to make observations day and night. This camera is equipped with housing which is designed to protect the camera and lens from environmental disturbances. The specifications of the Canon 5d Mk II camera can be seen at Table 2.

Figure 3. All Sky Camera

Table 2. Specification of All Sky Camera

Specification	Information
Dimensions	240 × 330 × 328 mm (width × length × height)
Sensor	36mm × 24mm, 5616 × 3744 Pixel (22 Megapiksel), Sensor CMOS Color (warna)
Exposure Time	1/8000 sec - 30 sec
Format *File* Picture	JPG or RAW (14 bit)
Power Consumption	About 30W for the camera unit
Lens Construction	11 Elements in 6 groups
Point of View	180°
The minimum is opened	f22
Minimum Focus Distance	13,5cm / 5,3 in
Maximum Magnification	1 : 4,6
Heavy	400 gram
Dimensions	73.5 × 68.6 mm / 2.9 × 2.7 in (diameter × length)

Data

The data used is night sky brightness data at the OZT-ALTS Telescope from direct measurements using SQM and All Sky Camera image data from the OZT-ALTS Telescope on April 9, 2022. SQM measurement data is in the form of a DAT format file. File consist of header which contains location information (point coordinates) that have been entered on software UDM, data sequence information, and data. Deep data file contains UTC Date and Time data, Local Date and Time, Temperature, Counts, Frequency, and MPSAS that can be seen in the attachment. The data in the MPSAS column is the data used for the contour plot. The data obtained as many as 97 files correspond to 97 data collection points (sum of coordinate points from the division of each 22.5° azimuth and 15° elevation). All Sky Camera data taken in JPG format. Image data was taken with exposure settings of 15 seconds and ISO 800. In the measurements several images were taken, the clearest image was selected.

Data Collection Method

Data collection was carried out using quantitative methods in the form of data on the brightness level of the night sky from measurements using SQM. Measurements were carried out at the OZT-ALTS Telescope using SQM-LU (Sky Quality Meter-Lens USB). The SQM was mounted on a tripod and connected to a laptop. The unit of direction for the data collection coordinate point is azimuth (horizontal rotation angle 0° - 360°) and elevation angle 0° - 90° as x and y. Sky brightness data is taken as a z value on a polar contour plot. SQM is directed in different azimuth and altitude directions according to what has been determined. The azimuth and altitude coordinate points are divided for each distance of 22.5° for the azimuth and 15° for the altitude angle.

Grid coordinate points and an illustration of data collection can be seen in Figure 4 and Figure 5. Data is taken every 1 second for 5 seconds at each azimuth and altitude coordinate point via the Unihedron Device Manager software installed on the laptop. The data recorded in one data collection produces 97 data files. Image capture at All Sky Camera, use software Canon EOS Utility. Set the exposure to 15 seconds and ISO to 800. The image is saved in JPG format. Image capture at All Sky Camera carried out simultaneously with SQM data retrieval.

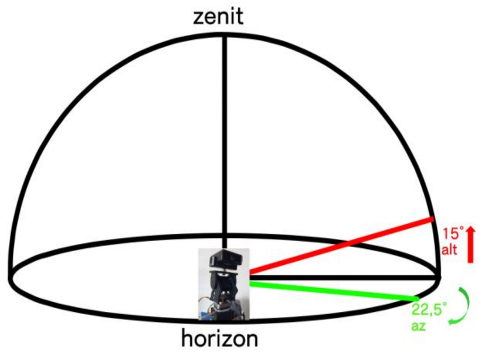


Figure 4. Illustration of SQM Data Retrieval

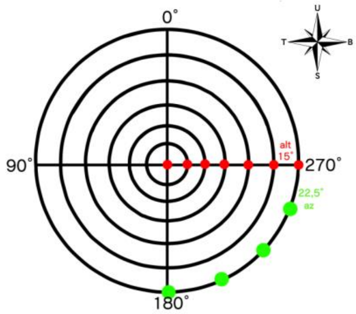


Figure 5. Grid Data Retrieval

Data Processing Methods

SQM Data Processing

The SQM measurement data has first been selected and sorted according to each polar coordinate point. In one point there are five data, so the average value will be calculated for each data file (the difference in data is not too significant) to get one value to represent each point and arranged in order. SQM measurement data is converted into values flux (light intensity scale). The polar coordinate points are converted to radian values and the values are recorded in a CSV file along with SQM measurement data and calculation data flux. Complete data can be seen in the attachment. The data is plotted into a polar contour map of the sky using the polar contour plot feature of Python programming that has been created (programming script can be seen in the attachment). The modules used in programming consist of numpy, scipy, pandas, and matplotlib modules. Array data is formed with numpy.linspace which starts at 0 and stops at 2π. Because the data samples obtained are not dense (there are empty gaps between data), interpolation is required. Interpolate data to fill in the blank parts of the data to form a contour pattern using the cubic method. Cubic method used because the amount of data is quite large, so it uses the cubic method will give better plot results. Compared with methods linear or quadratic, cubic method produces smoother lines because the polynomial order is higher. Polynomial order used in the cubic method is order 3. Order 3 uses 4 data points for interpolation, so the interpolation will be more accurate.

Line contour plots use the same data as the data used in contour fill plots. For script line contour plot programming is largely the same as script of contour fill plot programming. Formation array data and contour plot programming using the matplotlib imshow function from the pyplot module in library matplotlib. The images already displayed in the window are stacked with the line contour plotting function.

Data Processing All Sky Camera

Image data from All Sky Camera (sky image with polar appearance) is selected to select the best image with clear resolution. JPG files are imported to Photoshop software to process it to produce a contour image. The raw image is converted into grayscale by changing the mode to grayscale on the menu Image. The formula used to convert an RGB image to grayscale can be seen in the attachment.

Create contours from the image All Sky Camera used features Trace Contour from Stylize on the menu Filter. The contour level options will appear in the window Trace Contour. The layer is duplicated and the contour level is adjusted to a range of 10 levels to produce a number of layers with different levels. This is done to obtain each contour pattern from each contour level. All layers are flipped to adjust their direction to the results of the SQM data contour plot. Next, change the blending mode to each multiply layer to unite each contour level that has been, so that all the contour patterns are piled up and look unified.

Data Analysis Method

Analysis was carried out by comparing the results of the polar contour plot with the image All Sky Camera. Image All Sky Camera provides a visual appearance of the night sky conditions at the OZT-ALTS Telescope from the horizon to the zenith polarly. The contour plot of the SQM measurement data will show the pattern of variations in the distribution of sky brightness at the OZT-ALTS Telescope. From the contour pattern, you can also know the maximum and minimum values of the measurement points as well as the quality class of the night sky at the OZT-ALTS Telescope. The pattern will be adjusted to the contour pattern and visual appearance of the image All Sky Camera to find out what sources of light pollution affect the brightness of the sky at the OZT-ALTS Telescope and compare the contour patterns. Classification of types/classes of the night sky was also carried out at the OZT-ALTS Telescope based on the Bortle Scale. The Bortle Scale table can be seen at Table 3.

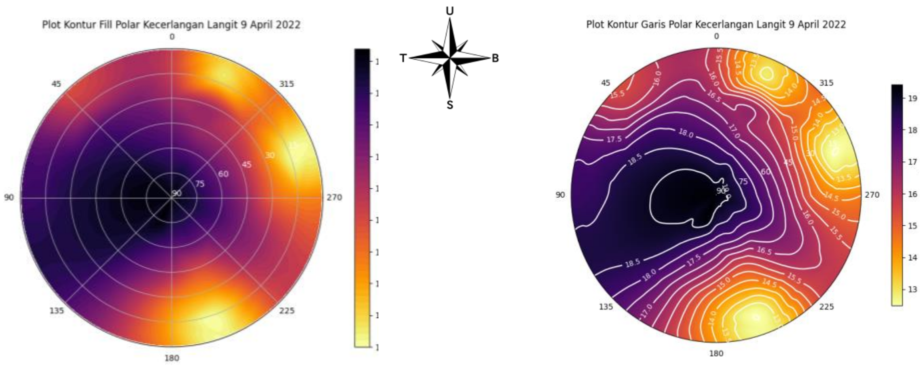
Table 3. Bortle Scale

Magnitude Color	Sky Clearness (MPSAS)	Bortle Class	Description
7.6 – 8.0	>21.90	1	Excelent dark-sky site
7.1 – 7.5	21.90 – 21.50	2	Dark-sky site
6.6 – 7.0	21.50 – 21.30	3	Rural sky
6.3 – 6.5	21.30 – 20.80		
6.1 – 6.3	20.80 – 20.10	4.5	Rular/ Suburban transition
5.6 – 6.0	20.10 – 19.1	5	Suburban sky
4.6 – 5.5	19.1 – 18.00	6,7	Bright Suburban, Urban transition
<4.5	<18.0	8,9	City sky, Inner-city sky

RESULTS AND DISCUSSION

The data used is data on April 9 2022 because this data is data with the most suitable environmental conditions within the data collection range. The OZT-ALTS sky conditions on April 9 2022 were quite bright with a few thin clouds. The environmental temperature is 25°C with humidity of 84% and wind speed of 2.6 kph (data obtained from AWS). The cloud cover scale is Clear and Moon Phase ~48% with the position already set at the time of data collection. Measurements were carried out at OZT-ALTS starting at 01.20 for ±30 minutes and finished at 01.50 WIB 9 April 2022 (the moon set at 23.27 WIB 8 April 2022 at position HA = 07h 34m 40.0s RA/Dec = 06h 54m 01 .3s/+26° 43' 37.7" and Az/Alt = 296° 30' 10.5"/-23° 54' 35"). The unit of direction for data collection coordinates uses azimuth (horizontal rotation angle 0° - 360°) and altitude angle 0° - 90° as x and y. The data is a measurement value for the brightness of the sky as a whole, which is measured based on a polar pattern with a distance of 22.5° azimuth and 15° altitude. The location coordinates are 5.362803° S and 105.311566° E, with a height of ~123 m above sea level. Sky brightness data as z values on a polar contour plot.

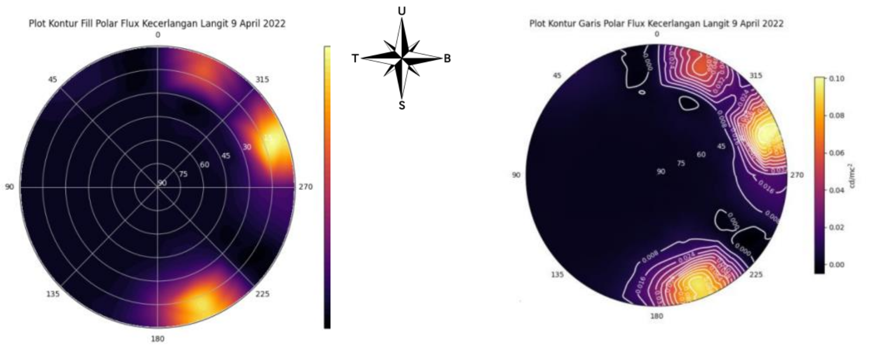
The results of SQM data processing on April 9 2022 produced the plot at Figure 6 part (a) which displays the contour mapping fill and Figure 6 part (b) which displays a polar contour plot of sky brightness lines. There are a number of points with low sky brightness surrounding the location of the OZT-ALTS Telescope. Azimuth 0° is the North point, continued to the East (90°), South (180°), and West (270°) poles in a counterclockwise direction because the projection is seen from below (Earth's surface).



(a) (b)

Figure 6. Plot (a) Contour Fill Sky Brightness, (b) Sky Brightness Line Contour

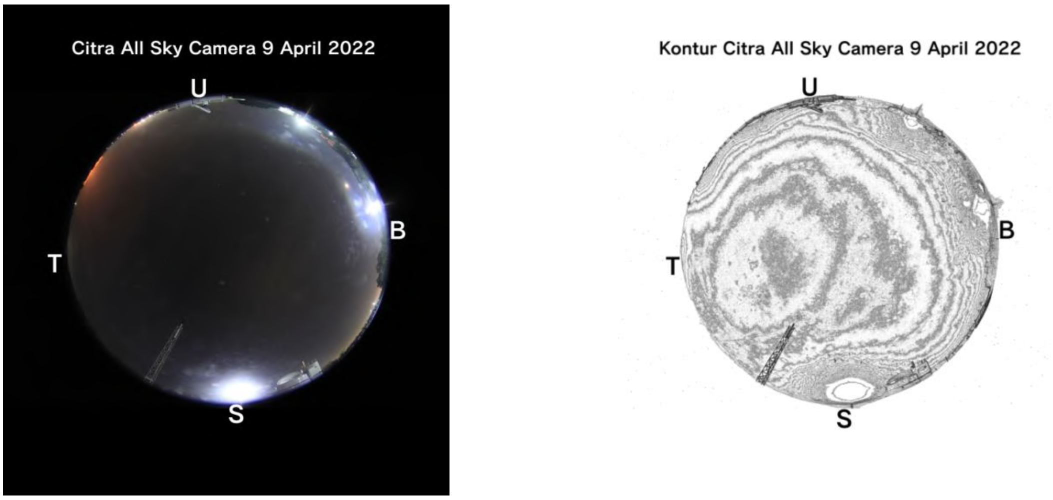
In addition to the contour of sky brightness on a magnitudo scale, a contour plot is also made from the conversion of sky brightness values into flux. The sky brightness value is converted into light value units (candela). The results of the contour fill plot of flux values can be seen in Figure 7 part (a) and contour lines on Figure 7 part (b).



(a) (b)

Figure 7. Plot (a) Contour Fill Sky Brightness, (b) Sky Brightness Flux Line Contour

Data retrieval All Sky Camera carried out simultaneously with SQM data collection. Image data All Sky Camera This is used to visually determine the polar appearance of the sky and the light sources that produce light pollution around the OZT-ALTS Telescope location. Image on Figure 8 part (a) was taken with an exposure of 15 seconds and ISO 800. After processing in Photoshop, the image All Sky Camera converted into a contour image that can be seen on Figure 8 part (b).



(a) (b)

Figure 8. Image All Sky Camera, (b) Contour All Sky Camera

Analysis and Discussion

Analysis and Discussion of Contour Plot Results of SQM and All Sky Camera Data

The results between the sky brightness contour plot (magnitude scale) and the flux contour the brightness of the sky has significant differences. Sky brightness contours produce smoother plots compared to flux contours. On fux contour has a data range that is too small, resulting in a lack of color contrast and some invisible light features that can be seen on Figure 7. On a magnitude scale, there is a high contrast approach so that thin light features remain visible and makes the sky brightness contour on a magnitude scale more suitable for this study.

There is one point with quite low brightness, but it is dimmer than other bright points. The center of this point (see Figure 9) is in quadrant I (0° - 90° azimuth) precisely at 45° azimuth (Northeast). The glow propagates from 22.5° - 50° azimuth and reaches an elevation angle of ~25°. This point can influence the brightness of the sky at an azimuth of 0° - 60°. The minimum brightness value at this point is in the range of 15.40 mag/arcsec^2.

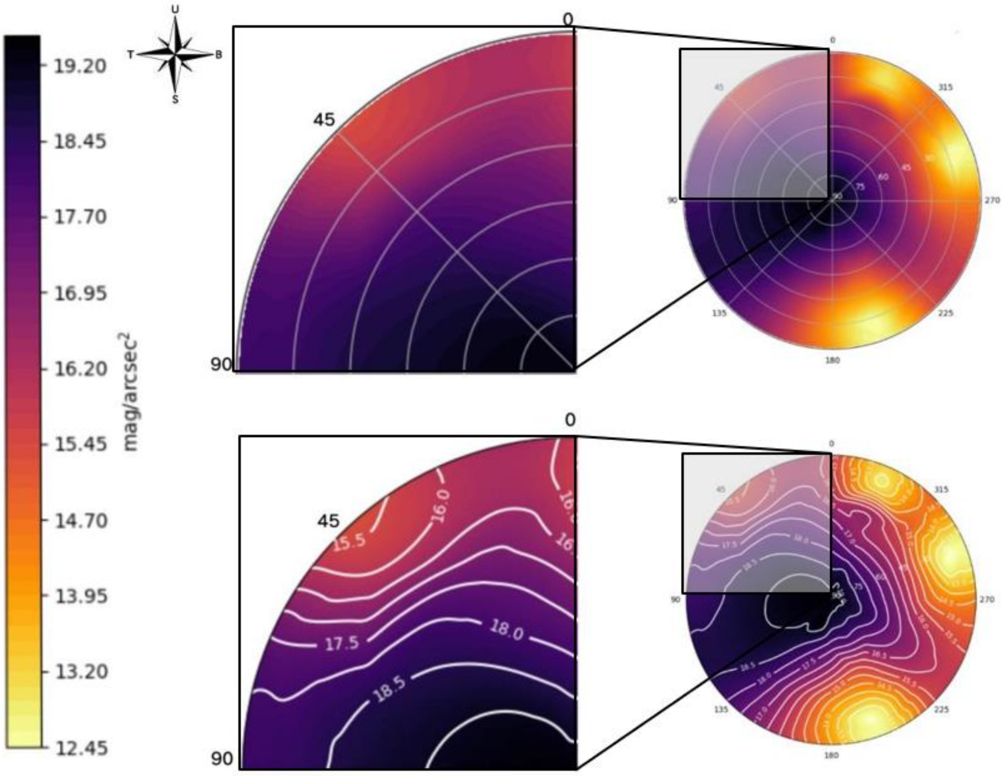


Figure 9. Quadrant I Contour

On the horizon sky of Quadrant 1 there is a beam of light. On Picture 10, can be seen The glow comes from the ITERA Gate lights (red arrows and circles) and the orange spotlights in the F ITERA Building (blue arrows and circles). The position of the lamp is quite far away compared to the previous street lamp, so that only the glow of the light can be seen. The distance from OZT-ALTS to the ITERA Gate is ±690 meters and the distance to the F ITERA Building spotlights is ±280 meters.

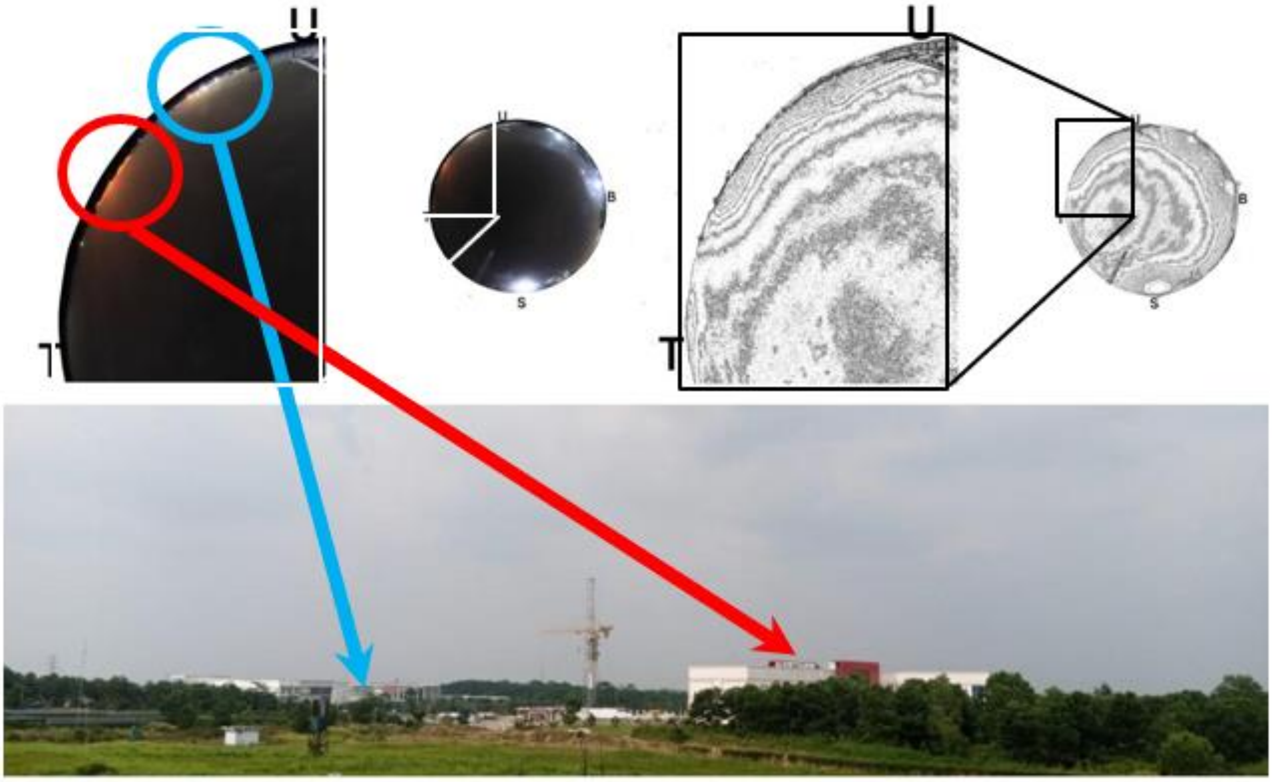


Figure 10. Sources of Light Pollution in Quadrant I Sky

The sky area in quadrant II (90° – 180° azimuth) is the darkest area or has high sky brightness, which can be seen at Figure 11. Found in the range of 90° to ~135° azimuth, reaching the zenith region (90° elevation angle). The range of sky brightness values in this quadrant is between 17.50 – 19.31 mag/arcsec². The maximum value is in the zenith sky region with a sky brightness value of 19.31 mag/arcsec². The sky in quadrant II looks the darkest with maximum sky brightness at 19.31 mag/arcsec2 (precisely in the zenith region). The sky conditions can be seen at Figure 12.

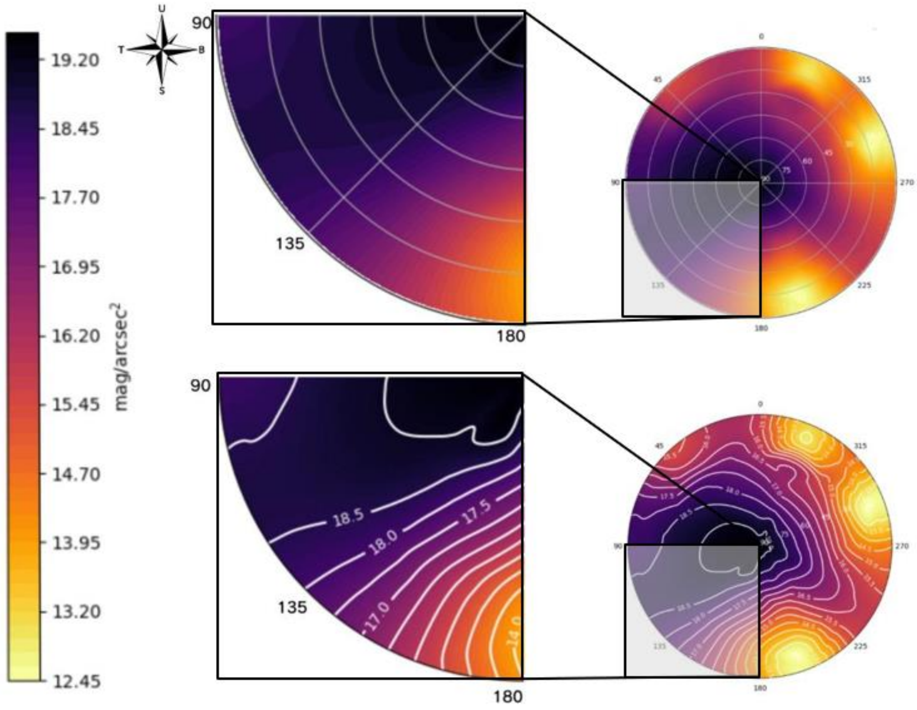


Figure 11. Quadrant II Contour

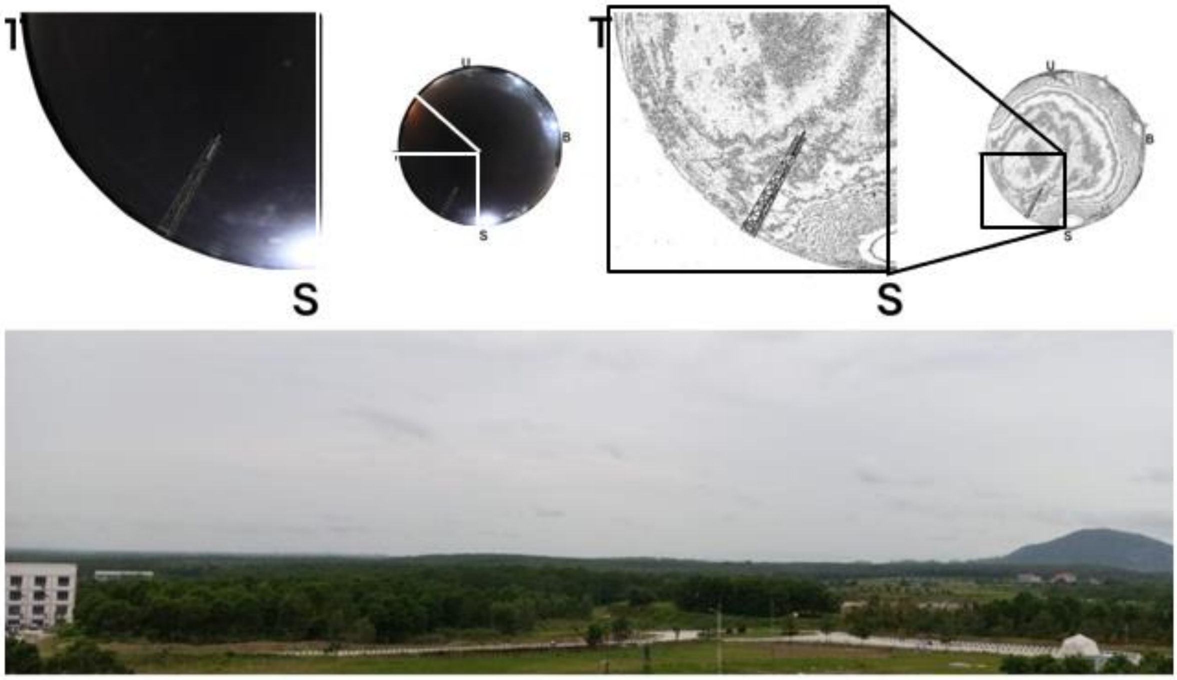


Figure 12. Sources of Light Pollution in the Sky Quadrant II

In the region of quadrant III (180° - 270° azimuth) there is a very low sky brightness value between 15.50 - 12.626 mag/arcsec², more precisely at the azimuth 202.5° which can be seen in Figure

13. A glow can be seen that spreads from 170° - 225° azimuth and up to a height of ~45°. The minimum brightness in the southern sky is at an azimuth of 202.5° and an altitude of 10°.

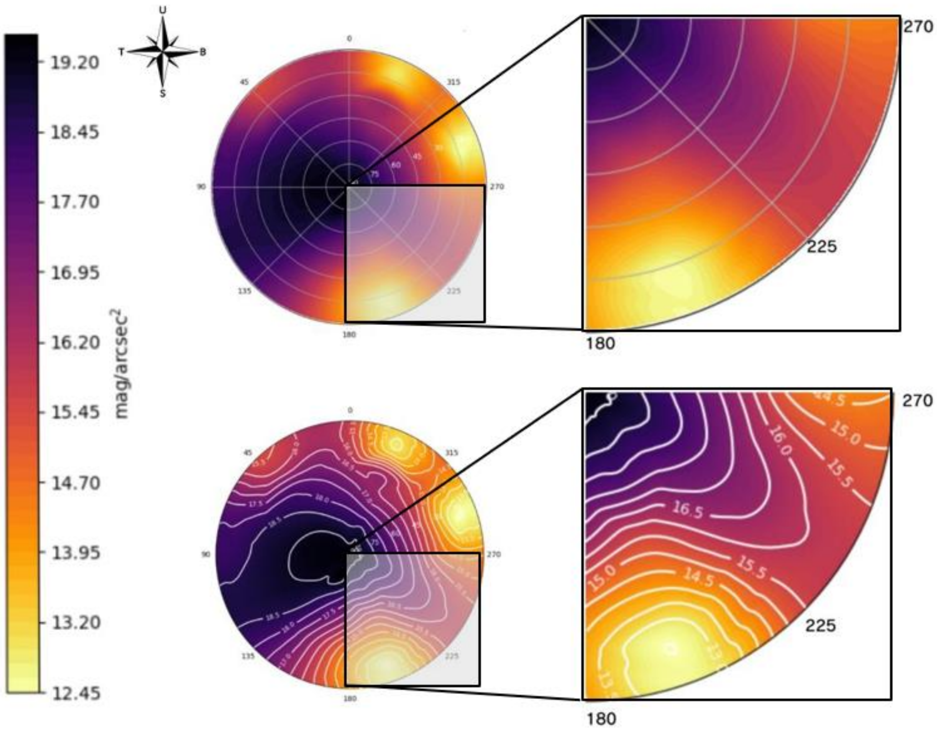


Figure 13. Quadrant III Contour

The light source from the sky region in quadrant III comes from street lights which are ±36 meters from the data collection location which can be seen in Figure 14 (close to the South Pole) is marked with a red circle and arrow. The direction of the street lamp's lighting is pointing directly at the road near the OZT-ALTS Telescope. The metal street lamp pole is higher than the height of the data collection location, causing some of the street lamp light to shine directly towards the location of the OZT-ALTS Telescope.

In the sky region of quadrant IV (270° - 360° azimuth) there are two points with low sky brightness between 12,626 - 15,50 mag/arcsec2. Looks in Figure 15, the point with lower brightness is at coordinates 292.5° azimuth and ~7° elevation. It has a minimum sky brightness value of ~12,626 mag/arcsec^2. The point with slightly lower brightness is at coordinates 337.5° azimuth and ~10° elevation. At this point it has a minimum brightness value of 13.50 mag/arcsec^2. These two points produce a glow that spreads ~250° azimuth (Southwest) to ~360° azimuth (North) to a height of ~30°.

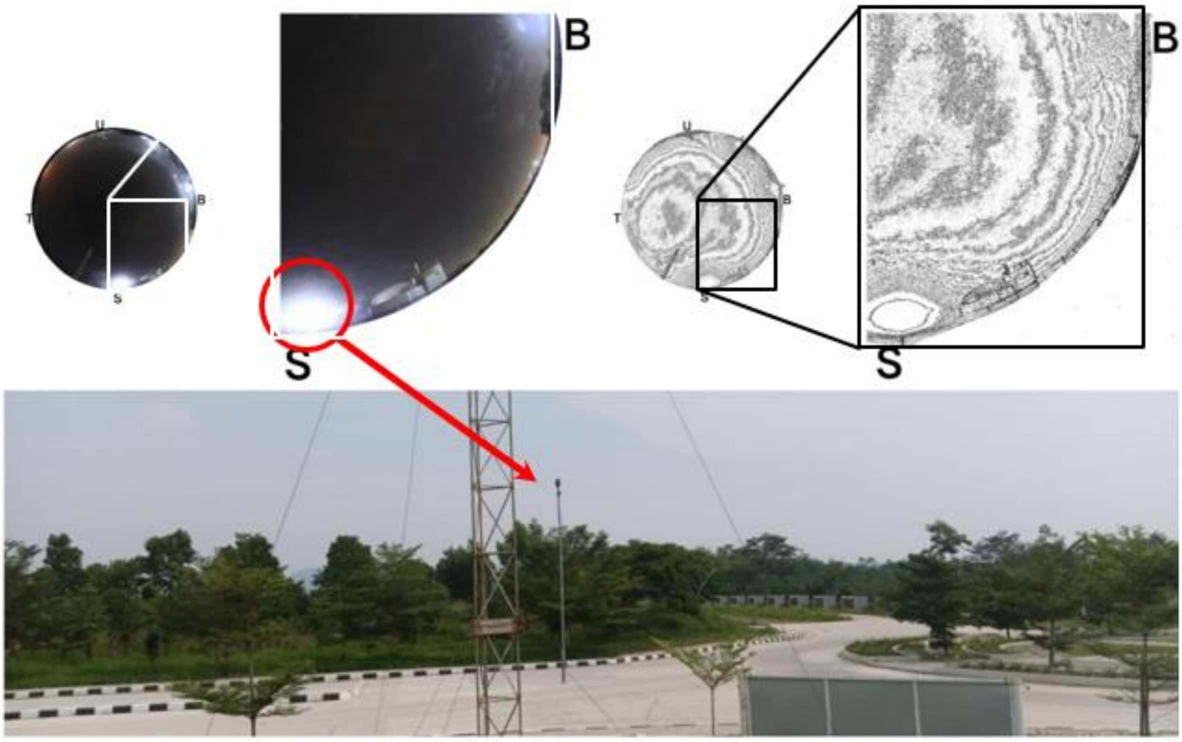


Figure 14. Sources of Light Pollution in the Sky Quadrant III

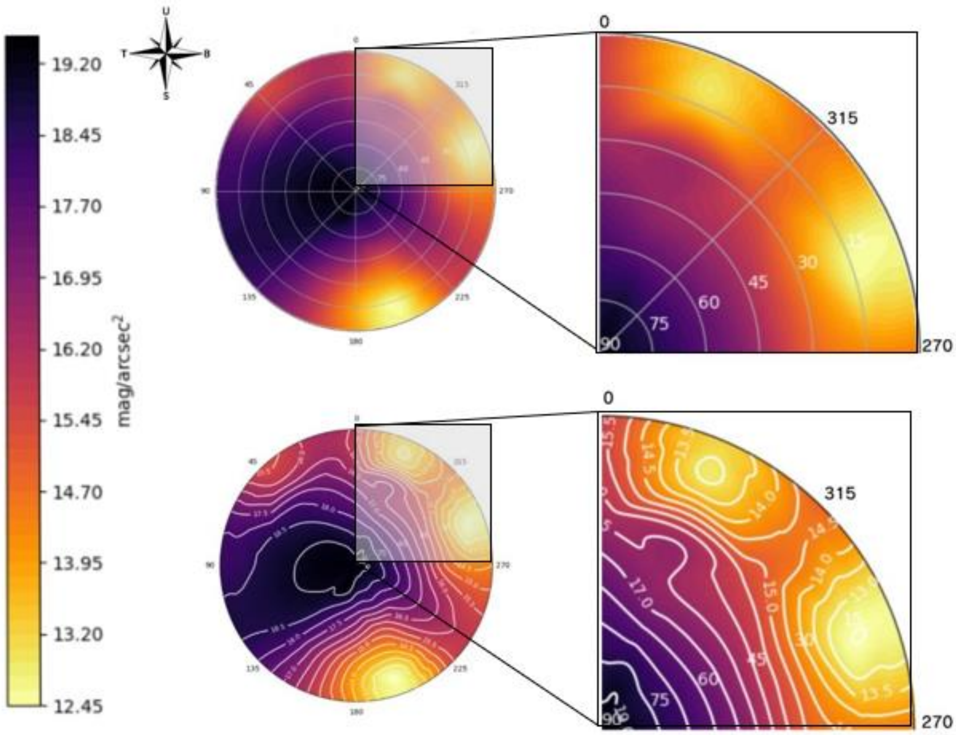


Figure 15. Quadrant IV contour

The sky region in quadrant IV has two light source points marked with red circles and arrows. The first point is at an azimuth coordinate of 292.5° and an altitude of ~7° and is also light originating from a street lamp which is ±35 meters from the data collection location which can be seen in Figure 16 (marked with green arrows and circles). The same conditions as street lights from the south (quadrant III area), causing some of the light beams to also point towards the data collection location. With these close locations, the light causes a wide glow. The second point at coordinates 337.5° azimuth and ~10° altitude is caused by a combined light source from street lights and lighting for the Public Lecture Building and the OZT ITERA Engineering Laboratory Building which is ±113 meters from the data collection location (can be seen in Figure 16 marked with yellow arrows and circles).

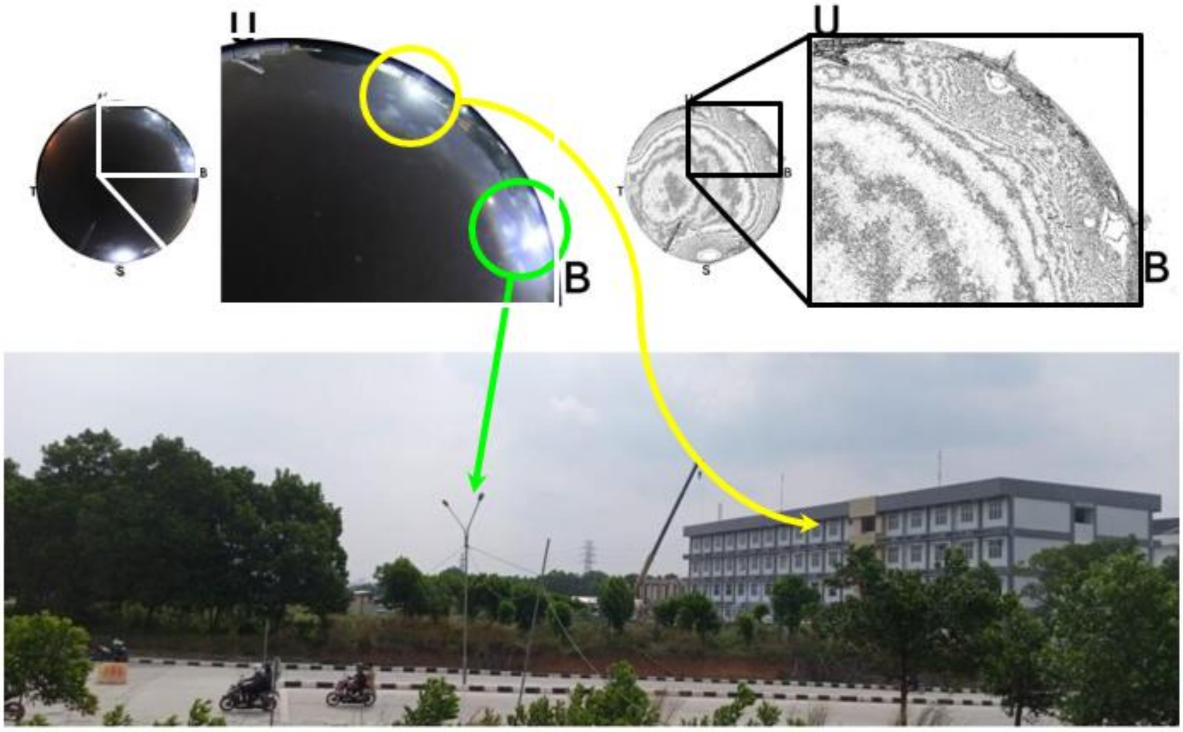


Figure 16. Sources of Light Pollution in the Sky Quadrant IV

From the sky brightness values that have been measured using SQM, overall, the night sky at the OZT-ALTS Telescope is of the type City Sky – Bright Suburban based on the Bortle Scale. The azimuth region of 90° - 140° to a height of 90° (zenith) is an area with this type of Bright Suburban (Bortle class 6.7) with a sky brightness range of 18.00 – 19.1 mag/arcsec^2 and the magnitude color is red. This area is the best area for carrying out astronomical observations from the overall mapping of sky brightness contours on the OZT-ALTS Telescope. For the azimuth region of 0° to 90° and azimuth 140° - 360° at an altitude angle near the horizon of 0° - 45°, it is included in the type City Sky (Bortle class 8.9) with a sky brightness value of less than 18.00 mag/arcsec^2 and the magnitude color is white. Based on the measured sky brightness value, the limit of visual magnitude that can still be seen by the naked eye is magnitude less than 5 when adjusted to the NELM bortle scale.

Image All Sky Camera shows the distribution of lamps and other light sources that cause points with low sky brightness values in the SQM contour plot results. Results of contour processing All Sky Camera shows the similarity of the pattern to the contour pattern from measurements using SQM. This shows that the method used in collecting and processing SQM data is quite appropriate. The difference in rotation between the contour plot results and the image All Sky Camera caused by differences in data collection coordinates. SQM position with All Sky Camera ± 2 meters away. Installation All Sky Camera also not yet polar and the topography of the land is uneven. This causes the cardinal axes to not be exactly straight and intersect in the middle. Reducing the negative impact of light pollution can be done by installing effective lampshades on outdoor lighting and placing the lights in the right position.

CONCLUSION

The conclusions from this research are:

1. Based on measurements of the night sky brightness value of the OZT-ALTS Telescope on April 9 2022, the maximum sky brightness value is in the quadrant II region (azimuth 90° - 135°, altitude 0° - 90°), while the minimum sky brightness value is in the sky horizon region from azimuth 0° - 90° and 135° - 360° which propagates to a height of ~ 45° (quadrants I, III, and IV).
2. From the appearance of the image All Sky Camera, the source of light pollution in the OZT-ALTS night sky is dominated by street lights and surrounding building lights.

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