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RESEARCH ARTICLE

An Overview of Sky Brightness Surrounding Timau National Observatory (TNO), Indonesia

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Abstract This study aims to analyze skylight conditions surrounding the newly constructed Timau National Observatory (TNO) in Kupang, Indonesia. The analysis was carried out with the primary reason of determining the initial conditions and surroundings of the area, thereby providing valuable information for future observers who will be using the facility. To achieve the stated aim, the sky brightness in the study area was measured in units of magnitudes per square arcsecond (mpsas) at a 20-kilometer radius. Furthermore, numerous observations were conducted at 32 distinct observation points using Sky Quality Meter (SQM) LU-DL (SQM-LU-DL), which was directed towards the zenith. The results obtained from these observations were subsequently analyzed using Surfer software with the primary aim of determining sky brightness in the study area. The analysis showed variations in sky quality in a 20 km radius, ranging from 21.64 to 20.37 magnitudes per square arcsecond (mpsas). The measurements showed that sky quality fell between the categories of great dark and semi-suburban transitional skies. However, it was important to comprehend that recent investigations had identified bright areas surrounding the observatory area, capable of diminishing the visual quality of sky if left unaddressed.

1. Introduction

Artificial lighting is a form of illumination which have significantly impacted modern society, serving both functional necessities such as indoor illumination and street lighting, and decorative elements adorning buildings and public monuments. However, the continual rise of these ubiquitous anthropogenic lighting emissions, which are being used across various environments, has led to the rapid degradation of the global night sky brightness (Falchi and Bará, 2020). According to Wesołowski (2019), this phenomenon poses a significant threat to the sustainability of ground-based scientific and educational space endeavors, particularly in optical astronomical observatories. The world map, as presented by Cinzano et al. (2001) and Falchi et al. (2016), vividly shows the encroachment of bright areas that obscure the dark sky due to the atmospheric scattering of artificial light sources. As observed, this scattered light diminishes the contrast between celestial entities and associated surroundings, rendering faint objects imperceptible.

Numerous studies have thoroughly examined the ecological repercussions of lighting disturbances (Gaston et al., 2013; Manfrin, 2017; Ściężor, 2021), including threats to biodiversity and human health (Chepesiuk, 2009; Cho, 2015; Lunn et al., 2017), as well as the loss of starry skies for recreational and cultural heritage preservation purposes. In accordance, Gallaway et al. (2019) stated that the rise in artificial lighting had presented several new challenges, such as an increase in energy demands and the necessity for efficiency. This demand is considered a challenge primarily because the presence of excessive artificial lighting has been observed to obstruct the effective operations of astrotourism establishments such as Observatories.

Before selecting the observatory area, substantial consideration is given to sky conditions. For instance, the establishment of Timau National Observatory (TNO) Amfoang, Kupang Regency, was based on the correspondence with the prerequisites for the observatory site. This area comprises favorable climatic conditions, including cloud coverage, sky brightness, and precipitable water vapor, among others (Hidayat et al., 2012). In particular, sky brightness assumes the most significance in this context. It defines the visual aspect of sky and the light scattering properties, which constitutes a very important determinant in ground-based optical astronomical observations. Sky brightness has been found to directly influence the magnitude threshold of observable stars and the observable star count. Accordingly, it is important to establish that several factors, both artificial and natural, can influence sky brightness. Among these factors, light pollution is considered as one of the most significant. Light pollution, in this regard, refers to the excessive presence of artificial light which detrimentally impacts the visual quality of sky. As the Observatory extends access to the surroundings, the foremost concern lies in the potential expansion of the adjacent area, which poses a risk to the quality of sky view in the vicinity.

Light pollution predominantly arises from deficient lighting design practices. Typically, inadequate lighting design leads to the misdirection of light intended for specific areas, resulting in wastage as it disperses towards sky. This sky-directed light reflects off atmospheric particles such as dust and water vapor, scattering far beyond the source area. As a result, the night sky appears brighter, even at considerable distances from the light source, specifically in densely populated areas (Škvareninová et al., 2017). This phenomenon, which is termed sky glow, poses a significant challenge because of its potential to diminish the visual quality of the night sky and obstructs the visibility of stars. As stated in a previous investigation, urban lighting worsens this issue by further saturating the sky with artificial light (Fiorentin et al., 2022a). Addressing the stated challenge is important for the astronomy community, which comprises both amateur and professional astronomers, as it impinges on observation activities, particularly the viewing of faint celestial objects.

The visual quality of the night sky in the observatory area is a very important factor for observers. As a result, extensive investigations and modeling efforts have been carried out to adequately ascertain the night sky brightness levels at observatories (Garstang, 1989; Aubé et al., 2014; Plauchu-Frayn et al., 2017). These studies are considered crucial, specifically considering the fact that continuous monitoring of sky brightness serves as a proactive measure to anticipate and detect any fluctuations (Fiorentin et al., 2022b).

TNO in Indonesia (located at 123°56"49.2' E, 9°35"47.7' S, with an elevation of 1304.5 m) is the country's newest observatory. This facility is equipped with a 3.8-meter diameter optical telescope as its primary instrument. According to Hidayat et al. (2012) and Herdiwijaya (2018), the importance of constructing new observatories in Indonesia arises from the pressing need to mitigate light pollution, which is a significant detriment to the visual sky quality at existing observatories in the country. Moreover, another study emphasized that the establishment of the observatory was in line with the ambition to reinforce the advancement of Indonesian astronomy (Mumpuni et al., 2018). As also elucidated by another previous investigation, the selection of the observatory establishment area was informed by the prevalence of clear sky conditions, with a clear sky fraction exceeding 70% (Hidayat et al., 2012). It is important to understand that analyses were also conducted in the western part as well as various other locales in the country. The obtained results showed the presence of pervasive light pollution, which rendered the areas unsuitable for astronomical observations (Herdiwijaya, 2018; Admiranto et al., 2019; Priyatikanto et al., 2019). Beyond the luminosity factor, understanding sky conditions in the observatory vicinity is another crucial aspect for optimizing observational data. This statement is supported by Zhang etal. (2015), who stated that for Earth shelf observations, knowledge of sky brightness is indispensable when evaluating the quality of the observatory area. e

Figure 1 shows the geographical surroundings of TNO. Presently, the observatory is enveloped by a protected forest area, as per data sourced from the Forest Area Stakeholder Office BPKH Region IV Kupang. However, interspersed in a 15 km radius of the observatory are residential zones (represented as white), with some situated as close as 2 km. Considering these features, it becomes important to comprehend that the juxtaposition bears the potential for light pollution, thereby posing a threat to the seamless conduct of high-quality observations at the observatory unless the expansion of settlements is carefully managed.

The measurement of sky brightness in this vicinity has been conducted by various studies. However, these measurements were confined to specific areas (Priyatikanto et al., 2023) and were empirically derived using VIIRS satellite data (Prastyo and Herdiwijaya, 2019). The results obtained in this regard showed that the environment surrounding TNO remained largely pristine due to the absence of substantial infrastructure.

At the commencement of observatory operations and improved access roads, it is speculated that the proliferation of residential areas is probable to increase, and this phenomena will consequently worsen the incidence of light pollution. Light pollution, which is predominantly caused by artificial lighting sources, poses a significant impediment to observational activities. Therefore, it becomes important to vigilantly monitor sky brightness conditions in the vicinity of the observatory area and facilitate targeted anticipation measures to mitigate potential disruptions.

On-site measurements of sky brightness were carried out in this study with the primary aim of assessing the initial environmental conditions surrounding TNO. This measurement was considered very important because the state of the observatory surroundings holds paramount significance for prospective observers in delineating the objects available for observation. Furthermore, the data serves as foundational knowledge to address potential light pollution issues by safeguarding the quality of observational outcomes.

2. Methods

During the course of this study, sky brightness measurements were conducted using Sky Quality Meter (SQM) LU-DL (SQM-LU-DL) from designated areas. Totally, the observations were carried out at 32 points in approximately a 20 km radius of the study site, all of which were selected using the Garmin GPS device, model GPS 73. Initially, in accordance with the International Dark Sky Association's guidelines for Dark Sky Park designation, the observatory area was intended to span a 15 km radius (IDSR Guideline, 2018). However, due to accessibility constraints at numerous areas, the radius was expanded to 20 km.

Figure 2 shows the points observed in June and July 2023. The red circle signifies a radius of 15 km, while the yellow circle represents 20 km. A few observation points were situated in the Northeast area due to the absence of road vehicle access.

Sky Quality Meter measurement

As previously mentioned, brightness measurements were conducted using SQM-LU-DL Unihedron. Typically, this instrument assesses the darkness of the night sky and quantifies the results in units of magnitudes per square arcsecond (mpsas). mpsas is a standard unit in astronomy for measuring sky brightness, and it refers to the brightness spread over one square arcsecond in sky. For instance, an SQM reading of 20 mpsas shows light with the brightness equivalent to a 20th magnitude star is distributed over one square arcsecond in the sky. Furthermore, each decrease of one mpsas indicates more than a 2.5-fold increase in light emanating from a specific area of sky. This means a difference of 5 mpsas signifies a 100-fold increase in sky brightness. It is important to also state that in addition to measuring sky brightness, the SQM simultaneously records temperature.

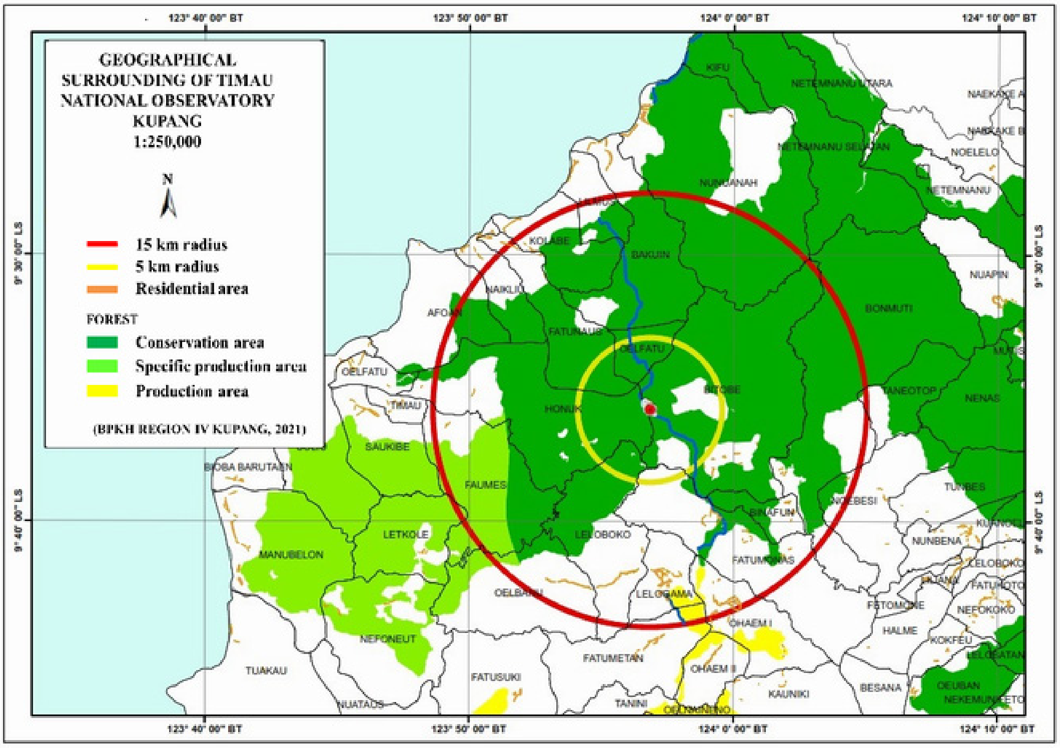

Figure 1. Area (map) of TNO. The yellow and red circles shows a radius of 5 km and 15 km respectively (source: BPKH Region XIV Kupang)

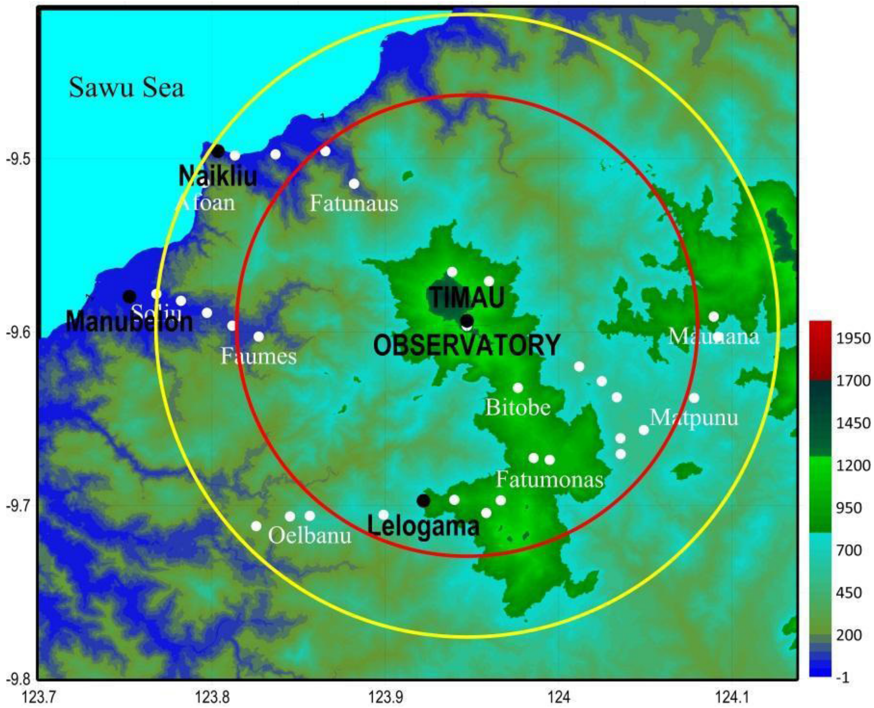

Figure 2. Observation points for sky brightness on 15 - 18 June and 16 - 17 July 2023. The red circle shows a radius of 15 km, while the yellow circle has a radius of 20 km.

Measurements were conducted with this tool in the period from June 15th to 18th, and July 16th to 17th, 2023, at a time frame from 19:00 to 02:00 local time. These observations were carried out during moonless nights to ensure that moonlight did not impact the results, and the absence of twilight during the period was verified.

3. Result and Discussion

Table 1 presents the measurement values obtained from the observations carried out at the 32 different points in this study. Using Surfer software, a map was generated to graphically represent the observation results (Figure 3). Furthermore, given the non-uniform distribution of the data, the kriging interpolation method was used following the criteria outlined by Oliver & Webster (1990).

Based on Figure 3, it can be seen that most of the observatory surroundings in a 20 km radius had similar characteristics of a rural dark sky type, with some sections classified as truly dark sites. As found by Bortle (2001), under this sky conditions, stars with magnitudes ranging from 7 to

Table 1. Measurement Result

No	Geographic coordinate			Date (LT)	Time (LT)	Average of Sky Brightness (mpsas)	Standard deviation σ	Average temperature during observation (°C)
	Longitude	Latitude	Elevation (m)					
1	123°46′04.3″	-9°34′41.4″	23.8	16-Jun-23	20:00 - 20:08	21.40	0.06	24.3
2	123°46′55.4″	-9°34′55.8″	36.7	16-Jun-23	21:11 - 21:19	21.55	0.03	23.4
3	123°47′49.3″	-9°35′20.7″	43.6	16-Jun-23	22:01 - 22:09	21.64	0.06	25.7
4	123°48′42.1″	-9°35′47.5″	46.5	16-Jun-23	22:52 - 23:01	21.60	0.05	23.5
5	123°49′36.8″	-9°36′10.0″	117.0	16-Jun-23	23:40 - 23:48	21.35	0.07	23.6
6	123°50′11.7″	-9°29′51.7″	15.9	17-Jun-23	22:01 - 22:08	21.16	0.07	23.8
7	123°51′55.1″	-9°29′45.1″	34.1	17-Jun-23	22:48 - 22:55	21.37	0,11	24.7
8	123°49′36.8″	-9°36′10.0″	88.3	17-Jun-23	23:36 - 23:44	21.40	0.14	22.3
9	123°48′47.4″	-9°29′54.1″	4.5	18-Jun-23	00:45 - 00:53	20.70	0.12	22.6
10	123°47′44.2″	-9°30′50.8″	27.6	18-Jun-23	01:41 - 01:49	21.38	0.03	21.9
11	123°56′49.2″	-9°35′47.7″	1304.5	18-Jun-23	19:53 - 20:01	21.53	0.03	19.4
12	123°58′34.9″	-9°37′56.4″	1098.6	18-Jun-23	21:09 - 21:17	21.53	0.01	18.3
13	123°59′07.6″	-9°37′40.1″	1004.4	18-Jun-23	21:51 - 21:59	21.53	0.02	18.3
14	124°00′42.2″	-9°37′12.1″	480.0	18-Jun-23	22:48 - 22:56	21.44	0.04	19.6
15	124°01′29.0″	-9°37′42.6″	621.8	18-Jun-23	23:37 - 23:45	20.37	0.19	19.8
16	124°02′02.4″	-9°38′22.0″	597.8	19-Jun-23	00:19 - 00:26	21.59	0.04	19.6
17	124°02′07.9″	-9°39′41.1″	538.8	19-Jun-23	01:05 - 01:13	21.71	0.06	20.7
18	123°59′40.9″	-9°40′25.9″	1062.6	19-Jun-23	20:12 - 20:20	21.32	0.06	18.1
19	123°57′59.4″	-9°41′50.0″	1087.3	19-Jun-23	20:53 - 21:01	21.32	0.04	18.2
20	123°58′23.0″	-9°41′48.9″	951.3	19-Jun-23	21:57 - 22:05	21.48	0.03	16.3
21	123°59′19.3″	-9°42′16.1″	923.7	19-Jun-23	22:44 - 22:52	21.22	0.11	17.7
22	123°49′31.5″	-9°42′43.4″	312.4	15-Jul-23	19:03 - 19:11	21.39	0.02	21.39
23	123°50′41.8″	-9°42′23.3″	406.5	15-Jul-23	19:42 - 19:50	21.55	0.16	23.27
24	123°51′22.9″	-9°42′22.1″	592.2	15-Jul-23	20:37 - 20:46	21.16	0.06	23.14
25	123°53′59.6″	-9°42′20.0″	633.5	15-Jul-23	21:31 - 21:39	21.16	0.08	22.86
26	123°57′35.0″	-9°34′15.1″	1038.4	16-Jul-23	00:32 - 00:38	21.30	0.18	15.84
27	123°56′18.5″	-9°33′55.8″	1125.5	16-Jul-23	01:07- 01:12	21.38	0.07	15.25
28	124°05′21.6″	-9°35′28.6″	882.2	16-Jul-23	18:57 - 19:06	21.50	0.06	17.77
29	124°05′30.1″	-9°36′10.6″	706,0	16-Jul-23	19:52 - 20:00	21.45	0.06	20.94
30	124°04′40.8″	-9°38′17.3″	608.8	16-Jul-23	21:10 - 21:18	21.21	0.05	21.89
31	124°02′56.5″	-9°39′23.9″	562.8	16-Jul-23	22:07 - 22:14	21.23	0.04	20.72
32	124°02′08.4″	-9°30′13.9″	566,0	16-Jul-23	22:58 - 23:06	20.78	0.07	20.84

7.5 remain visible. In a 15 km radius, the sky was observed to retain the darkness compared to brighter rural areas and an exception occurred in a few locations situated southeast of the observatory, where sky appeared brighter compared to the other points. However, in a 20 km radius, certain areas were found to transition into the semi-suburban or transitional sky category. This locality comprises a residential area characterized by extensive outdoor lighting usage. Hence, the sky quality value obtained in the locality was greater than that of the Bosscha Observatory from 2011 to 2018 (ranging from 19.73 to 19.03) (Herdiwijaya et al., 2020). Meanwhile, at TNO, sky brightness value recorded during the June 18, 2023 measurement was approximately 21.53.

Associated with the temperature recorded during SQM measurements (refer to Table 1 and Figure 4), it was evident that the observatory site experienced lower heat compared to its surroundings due to higher altitudes. Locations with dense residential areas typically have higher temperatures and are prone to generating light pollution. Specifically, regions to the northwest, southwest, and southeast of the observatory are of particular interest in this context. The northwest direction, situated approximately 20 km away (123°48’47.4’, -9°29’54.1’, elevation 4.5 m), comprises both residential areas and the sea, resulting in warmer temperatures. Meanwhile, the southwest direction, also approximately 20 km distant (123°51’22.9’, -9°42’22.1’, elevation 592.2 m), leads towards Kupang. Finally, the southeast direction, which is approximately 9.4 km away (124°02’07.9’, -9°39’41.1’, elevation 538.8 m), constitutes a residential area.

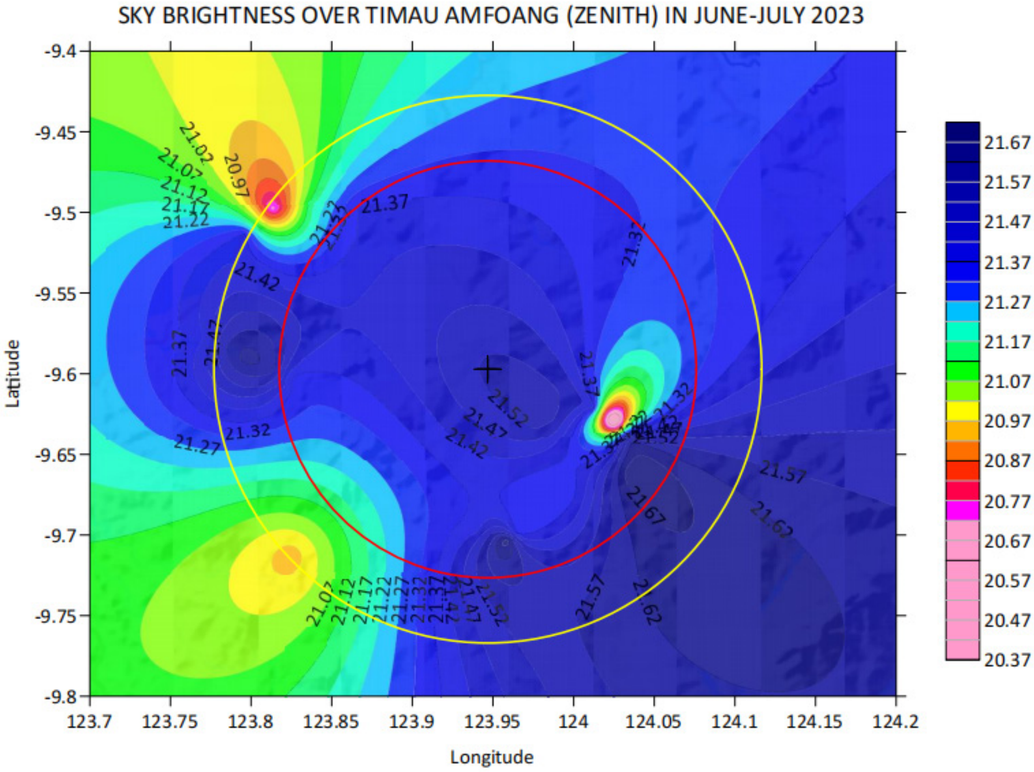

Figure 3. Map of sky brightness around TNO

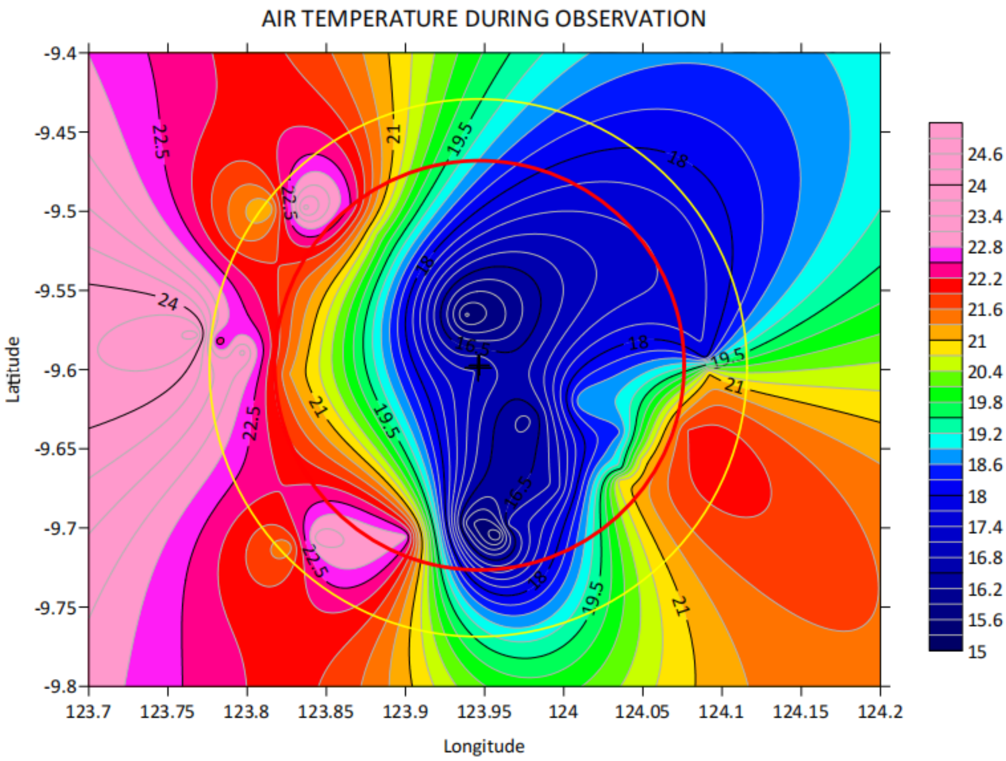

Figure 4. Temperature profile during observation

VIIRS data

Radiance, expressed in watts per steradian per square meter (W·sr−1·m−2), quantifies the power transmitted, reflected, emitted, or received by a surface per unit angle and unit area. In optical systems, radiance is a reliable indicator of the brightness appearance of an object and is often interchangeably referred to as brightness.

Data on the global night-time lights observed by satellites provided insights into the area and intensity of light emitted into space. These data were obtained from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) with the aim of facilitating the detection of electrical lighting on Earth's surface. The data points comprised monthly and annual light source monitoring values, with measures taken to eliminate background noise, solar and lunar contamination, and data degradation due to cloud cover and other factors such as fires, flares, and volcanoes (Elvidge et al., 2017). Figure 5 shows a night-time light emission map derived from VIIRS

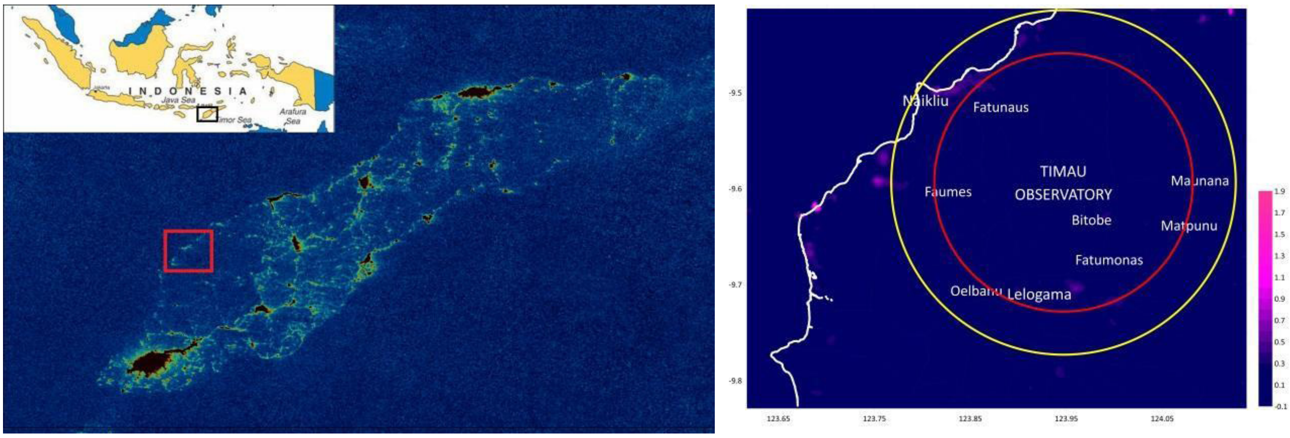

Figure 5. VIIRS of Timor Island (left) and the area surrounding TNO (right). The red circle in the right figure has a radius of 15 km, while the yellow circle has a radius of 20 km (right).

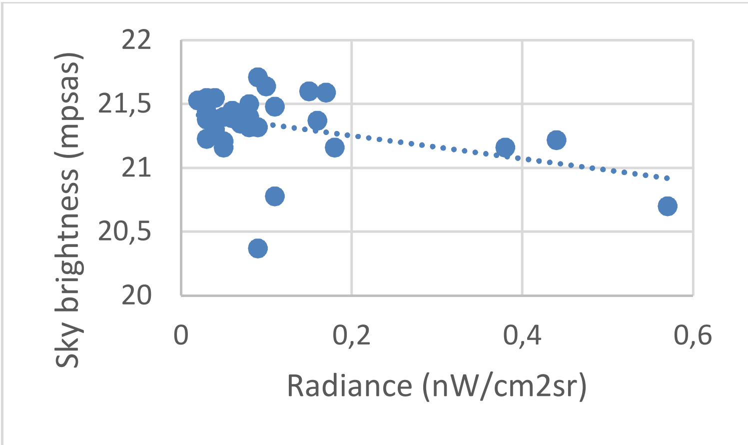

Figure 6. SQM measurement results compared with night light from VIIRS data for the same observation point

data for June 2023. Bright areas on the map indicate the extent of light pollution in respective locations. Concurrently, the adjacent figure portrays a night-time light emission map delineating the observatory surrounding.

This map shows that the area around the observatory remains predominantly dark, with several localized spots having higher light levels than the others. However, when correlating SQM measurements obtained at observation points with VIIRS data corresponding to those locations, a discernible pattern was found, as presented in Figure 6.

Despite the limited data obtained from on-site measurements, an inverse relationship was found between the quality of sky and the radiance observed. Radiance, as previously defined, quantifies the power transmitted, reflected, emitted, or received by a surface per unit angle per unit area. Therefore, higher radiance values correspond to a decrease in sky quality or brightness, as evidenced by reduced sky brightness values measured in mpsas. It is important to state that although a direct correlation between the measurements conducted and radiance data have not been established as at the time of this study, previous empirical results have suggested a linear relationship between radiance and sky brightness (Priyatikanto et al., 2019).

The map shown in Figure 3 is a graphical representation of the several areas warranting attention, specifically the bright areas situated approximately 20 km northwest (Naikliu pier), 20 km southwest (Oelbanu Village), and 9.4 km southeast of TNO (Binafun Village). The data represented in the figure are not in line with previous analyses conducted from 2013 to 2017, which showed minimal radiance in the vicinity of TNO, suggesting negligible light pollution in a radius of less than 20 km (Prastyo & Herdiwijaya, 2019). Accordingly, an examination was carried out to determine the annual average radiance in the previously mentioned areas, as shown in Figure 7. The results obtained from the examination showed a troubling trend, which was evidenced by the observed discernible increase in radiance, showing a decline in sky brightness. This trend is particularly concerning given the residential nature of the areas, where the influx of artificial light serves as a primary driver behind the observed reduction in sky brightness.

Light pollution mitigation

At the onset of national observatory operations, the initial sky conditions showed exceptional quality, particularly at the core area in the observatory center. In a radius of 15 km from the core area, sky conditions remained favorable, regardless of the fact that some localized spots exhibiting diminished sky brightness were present. However, the light pollution map showed a potential decline in sky brightness surrounding the observatory, specifically in residential areas extending beyond a radius of 15 km. This poses a potential threat to the continuity of astronomical observations in the region if left unaddressed. Various mitigation strategies have been proposed

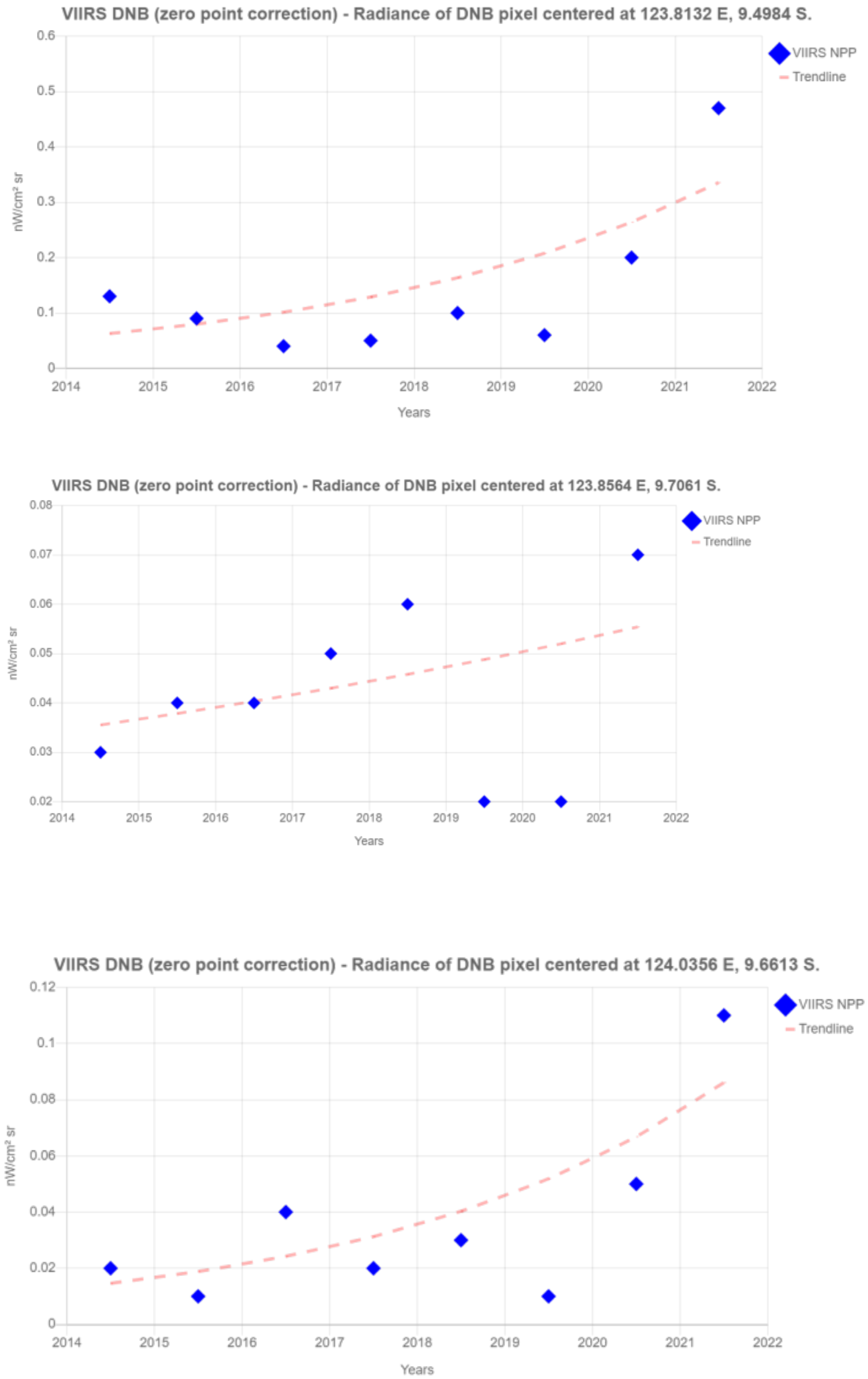

Figure 7. Changes in radiance for bright areas around TNO from 2014 – 2022 at 20 km northwest, 20 km southwest, and 9.4 km southeast

to counteract this trend, including the implementation of lighting regulations governing lamp usage and the exploration of astrotourism as an alternative avenue (Elsahragty & Kim, 2015; Kocifaj & Barentine, 2021). Additionally, factors such as the distance of the observatory area from settlements and major cities (Schneeberger et al., 1979; Ochi, 2019), along with increased public awareness regarding the adverse effects of light pollution (Kaushik et al., 2022), would play crucial roles in averting the threat.

To safeguard and preserve the beauty and significance of the night sky, one effective method is to protect and restore dark sky areas (Blundell et al., 2020; Kanianska et al., 2020; Collison & Poe, 2023). Alternatively, it is important to recognize that sky brightness is influenced not only by artificial factors such as light pollution, sky glow, and aerosols but also by natural factors originating from celestial sources. These natural factors include celestial objects including stars, planets, the moon, and the Sun, as well as phenomena such as the aurora (Hänel et al., 2018; Barentine, 2022). Considering this observation, further comprehensive studies and measurements should be conducted with the aim of providing a more thorough understanding of the conditions surrounding TNO.

4. Conclusion

In conclusion, the establishment of TNO in the Amfoang area of Kupang, East Nusa Tenggara, met the necessary criteria for optical observation. From the analysis conducted, the area was found to feature excellent sky brightness and was reinforced by the surrounding environment, which also met the standards set by the International Dark Sky Association.

However, it is important to comprehend that several indications of increasing brightness were found in some of the observed areas. Based on this result, it becomes important to preserve the initial surrounding regional conditions in order to ensure the continued excellence of astronomical observations.

Several initiatives have been suggested to address this issue, including regulating the growth of settlements around the observatory, imposing restrictions on new development areas, and fostering astrotourism engagement with the local community. These initiatives were observed to possess the capability to increase local awareness and commitment to preserving a dark sky environment. Additionally, collaboration between regional and central governments was considered essential in implementing environmentally friendly lighting practices to manage light pollution effectively. By maintaining these conditions, TNO has the potential to be positioned as an establishment featuring superior sky quality compared to other observatories worldwide (Falchi et al., 2023). Lastly, continuous monitoring was suggested for the prompt detection of any changes and the effective implementation of necessary mitigation measures.

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