The feasibility study of Barus city as the new astrotourism destination from astronomical and meteorological aspect

Arwin Juli Rakhmadi Butar-Butar¹,２, Singgih Prana Putra², Muhammad Hidayat², Haryadi Putraga²

¹ University of Muhammadiyah North Sumatera, Medan, Indonesia
² Falak Science Observatory, University of Muhammadiyah North Sumatera, Medan, Indonesia, 2022

Email: arwinjuli@umsu.ac.id

Abstract. Astrotourism is a tourist activity that shows attractions in the form of astronomical phenomena and outer space. Astrotourism activities that can be carried out by tourists are such as studying and exploring astronomical phenomena such as eclipses, meteor showers, and so on in the conditions of the night sky. An important condition for the advancement of astrotourism in an area is that the area has dark skies that are characterized by no severe light pollution and had adequate atmospheric conditions such as at least clouds covering the sky so that celestial objects can be observed properly, temperature, humidity, wind speed, and good rainfall so that visitors or tourists can comfortably be at astronomical tourist sites for a long time. We’ve done collecting atmospheric data using portable weather station and sky brightness data using Unihedron Sky Quality Meter LU-DL type device from July 10th - 11th 2021 and we collected data from windy.com for atmospheric particle content and cloud coverage during those dates. The results showed that Barus can become a new potential astrotourism destination specifically in Northern Sumatera or broadly in Indonesia where the Light pollution in Barus city is quite low, with a maximum value of brightness sky of 21.6, 20.8, and 21.8 MPSAS for the east, zenith, and west directions, respectively; Atmospheric conditions are quite good with an average temperature of 25.9 °C, the humidity of 89.2%, wind speed of 2.07 km/h, rainfall of 33.1 mm, amount of particles in the atmosphere 0.13 AOD and heat index of 27.2 °C. Future study is needed from other aspects to make Barus become a new astrotourism destination in Indonesia.

1. Introduction

Astrotourism is a tourism activity that aims to educate and explore astronomical objects and phenomena in an area or city such as observing planets and stars without optical instruments help [10]. It also can be interpreted as a form of sustainable tourism that involves the public in observing the night sky and celestial objects (such as planets, moon, sun, and stars) [2]. Astrotourism can be done as a place to observe certain astronomical events such as aurora, eclipse, meteor shower; or can go to locations that have astronomical monuments such as observatories or rocket launch sites.

A location that suits an astrotourism destination must meet the criteria that have determined by Hudson and Simstad [5], like the position of the observer, the percentage of clear skies, sky darkness, sky transparency, weather conditions, regulations and laws, legislation, infrastructure access, costs, and risk factors. This paper only examines the criteria besides regulations and laws, infrastructure access, costs, and risk factors.
A suitable position of the observer for the perfect observation must be in a latitude around the equator since they can see the entire northern and southern sky, the wider the area of the sky. The percentage of clear skies can be determined by how much percent of a night in an area where no clouds are covering the sky, the less the better. The darkness of the sky can be determined from the value of the sky brightness, the darker the sky the better. Seeing causes the celestial object to become unclear. The transparency of the sky is determined by the amount of pollutants and molecules in the air, the fewer these molecules the better. Weather conditions in the form of temperature and wind also can affect astronomical observations.

Yuna [12] has made a map of the potential destination of astrotourism in Indonesia by assessing the potential of each of the 88 National Tourism Strategic Areas (NTSA or KSPN in Bahasa) [7], based on data on light pollution, the average percentage of rainy day annually, altitude of location and air pollution. She found that out of 88 NTSA only 1% was in class A (the best). Barus looks to be in class C on her research, this is more because the altitude of Barus city is in the lowlands so the seeing can be more severe and the percentage of cloudy days is high while the other criteria were good. Map of astrotourism potential from Yuna [11] can be seen in figure 1 with the position of Barus city on Sumatra Island.

![Figure 1](image1.png)

Figure 1. (Left) Map of Potential Astrotourism in Indonesia, (right) Potential of astrotourism on the island of Sumatra Island with Barus city in the red circle

In this research, we estimate the astrotourism potential of Barus city using the criteria from Hudson and Simstad [5] namely the observable hemisphere, percentage of clear sky (cloud coverage), sky brightness, sky transparency (amounts of aerosol), and weather conditions (heat index, rainfall) using data retrieval method with weather station, SQM and weather data taken from windy.com. The second section is our methodology which contains the procedure and process of our research. The next section is our result and discussion in which we will analyze each of the parameters that we obtained. We will give our conclusion in the last section.

2. Methodology
The research was conducted near Barus city with coordinates 2°00'27.8" North Latitude, 98°25'54.4" East Longitude that is on the outskirts of Barus city in Kedai Gedang sub-district. The location is very close to the planned location for the new branch of Falak Science Observatory (OIF UMSU) of Barus. The research was conducted in two days from Saturday and Sunday on July 10th and 11th 2021.
The instruments used to collect the data are weather stations and Sky Quality Meter (SQM). The weather station is a portable weather meter that can be disassembled. This device contains many instruments like an instrument to measure temperature (thermometer), air pressure (barometer), wind speed (anemometer), and humidity (hygrometer). The weather station is installed at least 10 meters above the ground so that the anemometer at the weather station can work properly [6]. We got parameters of temperature, humidity, wind speed, and rainfall from the weather station.

The other parameter that can be calculated from the weather station output parameter is heat index. The heat index can make astrotourism activities more enjoyable. The comfortable range of the heat index for humans is below 26 °C, while if the heat index is in the range of 26 – 32 °C, humans can adapt as long as they are not exposed to the sun for too long. The equation for heat index parameter can be seen in equation (1) with a to i are constants with each value is: -8.78469475556, 1.61139411, 2.33854883889, -0.14611605, -0.012308094, -0.016424827778, 0.002211732, +0.00072546, -0.000003582; h is humidity; T is the temperature.

\[
HI = a + (bxT) + (cxh) + (dxTxh) + (-exT^2) + (-fxh^2) + (gxT^2xh) + (hxTxh^2) + (-ixT^2xh^2)
\]  

(1)

We gathered the data for 2 days and immediately stored it in csx format so that it can be processed into graphic form. For other supporting data, we took data from windy.com (windy) for parameters such as cloud coverage and the amount of aerosol particles in the air. An example of the display of cloud coverage and aerosol particles from the Windy application can be seen in Figure 2. We wrote data of cloud coverage and the number of aerosols every hour because windy.com can record the data every hour for five days [8].

![Figure 2. Windy.com application interface: (left) cloud coverage view; (right) view of aerosol particles. The data taken is at the point, because it corresponds to the coordinates of the observer](image)

The second device that we used is SQM. We used three SQMs directed in three different directions, east, zenith, and west. Each SQM is set to retrieve data every 2 minutes so that a smooth sky brightness
is obtained. We took data using SQM after midnight, this was done to get the dawn time so that the tool did not work for a long period. The position of SQM is shown in figure 3.

![Figure 3. The position of SQMs according to wind direction](image)

3. Result and Discussion

We separate this section based on the Barus City position, atmospheric, and sky brightness parameters.

3.1. Barus Position

Indonesia's very strategic position which is not far from the equator (0°) is very advantageous in astronomical observations because it covers a wide sky from north to south. In the 20s, only large telescopes were in the northern hemisphere, therefore an observatory was built, initiated by the Dutch East Indies astronomy group [4]. Barus city, which is located at latitude 2°00′27.8″N, can cover a wider night sky compared to the Bosscha Observatory in Lembang (6° 49′ 28″S). Since Barus at 2° latitude of Northern Hemisphere, we got 97.7% of the Night Sky width which was mostly could capture more celestial objects, since the Barus position is also near the equator, Barus could give more data about the sun, the phenomenon such as twilight research, and also the verification of sunset time and the atmospheric disturbance, also more probability to take documentation about lunar crescent, comet visibility, and since there is no obstacle near the horizon, Barus could give more data to celestial object that could only be seen near the twilight. Meanwhile, Lembang has 93.3% sky coverage and cant observe celestial objects near the north sky axis/north sky pole where the Polaris resides. Today, in Lembang, the sky pollution getting higher making it difficult to observe more celestial objects, and they plan to move the main research to another place that has more similar conditions to Barus city.

3.2. Atmospheric and sky brightness parameters

The atmospheric conditions and the brightness of the sky in Barus are quite good. The first parameter is the brightness of the sky. This study found the maximum value of sky brightness for two days was 21.6, 20.8, and 21.8 MPSAS for the east, zenith, and west directions, respectively. This value is below the maximum average value obtained by Rakhmadi et al [9] which is 21.67 MPSAS, this is because at the time of observation the clouds cover the sky thick enough so that it affects the brightness value of the sky (sky brightness becomes smaller due to the reflection of light from the earth's surface caused by clouds). The graph of sky brightness can be seen in figure 4 while the graph of cloud coverage can be
seen in figure 5. As seen in figure 4, the maximum value of sky brightness is higher on July 10th than on July 11th, this corresponds to the percentage level of cloud coverage which date July 10th is lower than July 11th.

Our sky brightness values range from 20.8 to 21.8 MPSAS which are in the Bortle scale of class 4 based on the analysis provided by Yuna [11]. Meanwhile, based on the 2013 International Dark-Sky Association (IDA) criteria, the sky brightness value of 20.8 – 21.8 is included in the bronze and silver category [3]. The Bortle class 4 and the bronze and silver categories have one of many characteristics which are that the clouds are illuminated by a light source so that they look a little brighter. This characteristic matches the conditions during the observation, namely the sky was covered with thick clouds.

During data collection on July 10th and 11th, the average percentage of cloud coverage was 69.5%, the rest of the sky that was not covered by clouds (clear skies without clouds) was 30.5% throughout 2 days. If we only see at night, then the average percentage of sky coverage is 67.2% or the percentage of the sky without clouds is 32.8% with scattered cloud positions. The value of 32.8% is far from the definition of a photometric sky, namely a night sky with a cloudless sky from a height of 5° (the position of the sun must be below 18° below the horizon) [11]. Another criterion for determining the observatory as an astrotourism location is that the minimum limit of cloudless sunny days is 50% annually [1]. The data that we obtained was only for two days, for this reason, longer sampling is needed throughout the year or more than two years.

The other parameter is heat index. It is greatly dependent on the value of temperature and humidity of the area. The heat index formula can be seen in equation 1. Our data were taken from the weather station instrument which was taken in for 24 hours on July 10th and 11th 2021.

The average value of heat index for thus 24 hours is 27.7 °C for July 10th and 26.7 °C on 11th with the average heat index for the following days being 27.2 °C. The HI average value for the day (after Sunrise) on July 10th and 11th are 31.4 °C and 29.8 °C respectively. The graph of heat index on July 10th and 11th can be seen in Figure 6 with the heat index shown in the blue line. The HI range for both days is understandable and acceptable for tourism on the day and the night for longer activity.
Wind speed and rainfall will affect the dynamics of the amount of aerosol particles in the air. If strong winds are accompanied by heavy rain, the amount of aerosol particles in the air becomes thinner and vice versa. The average value of wind speed, rainfall, and aerosol amount for the two days of data collection was 2.07 km/h, 33.1 mm, and 0.13 AOD, respectively. The relationship between these three parameters can be seen in figure 7.
Figure 7. Rainfall, wind speed and amount of aerosol molecule on (left) July 10\textsuperscript{th} 2021, (right) July 11\textsuperscript{th} 2021

Figure 8. Rainy Season Peak (Left) and Cumulative Rain Properties Forecast (Right)

Based on the BMKG forecast release for 2021/2022 [13] in Figure 8, the Barus city included in the unknown forecast area or the data cant provide a forecast because the station near the location is unavailable. On the right, the Barus city has under-normal rain properties so, based on the BMKG forecast release, it gives hope to Barus City to have more clear sky than the cloud-covered sky, which was an advantage it to be the Astrotourism spot.
4. Conclusions

Looking at the data above, we can make the following results: The average altitude of Barus city is 5 meters above sea level surrounded by mountains in the north, northeast, and east. The sea was in the south, west, and southwest which was giving more advantageous to get the horizon view. For astrotourism development, the other advantage of Barus location was positioned close to the equator which could give more sky coverage to observe the celestial Body on the northern and southern sky. The parameters that support Barus for the new astrotourism destination are the amount of aerosol particles, the brightness of the sky, and the heat index are quite good. Rain and Cloud coverage parameter, on the other hand, needs to be investigated further and longer in the period to get more precise data.

The potential for astrotourism in Barus city can be done indoors or outdoors, and during the day or at night. The construction of the new FSO in Barus city [9] is a good step for the potential for astrotourism in Barus because FSO can be the first location for people who want to study and explore more about astronomy and Falak science. And this research needs the continuation to give more aspects and data to make sure the Barus city was very Potential as an Astrotourism spot in North Sumatera, Indonesia.

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