Geographical-environmental factors extraction and analysis for optical astronomical site selection based on multi-source remote sensing in Lenghu, Qinghai Province

Haocheng Liu [1], *Xinhua* Huang [1], and *Qingkai* Meng [1,2*]

[1] School of Water Resources and Electric Power, Qinghai University, Xining 810016, China
[2] State Key Laboratory of Plateau Ecology and Agriculture, Qinghai University, Xining 810016, China

Abstract. At present, there are scarce sites that can require high-quality astronomical observations over the world, therefore, analysis of geographical-environmental factors and extraction of the potential places for astronomical observations is of significance. Remote sensing has the specific advantage for rapid and widespread monitoring and geo-spatial analysis. In this paper, Precipitable Water Vapor (PWV), clear nights, altitude and surface coverage, these four parameters associated with optical astronomical observation was selected, Analytic Hierarchy Process (AHP) evaluating model was adopted to determine the weighting parameters and calculated geo-environmental suitability. The results show that: (1) The lenghu region is characterized by seasonal variation with high PWV in summer and low PWV in the winter, representing non-summer periods are the best observation time. (2) The Lenghu region has relatively high clear nights with more than half of times through one year is suitable for observation. (3) Based on Geoenvironmental suitability mapping,Saishiteng Mountain is selected as a priority site for optical astronomical sites.

Keywords: Water vapor content, Spatiotemporal distribution, MODIS data, Land cover, Lenghu area.

1 Introduction

There are only a few high-quality astronomical sites on the earth's surface that can meet the requirements of very large next-generation facilities[1], so the locating the site of astronomical observations is very important. An excellent astronomical observatory must have very low Precipitable Water Vapor (PWV), high altitude, and very high night clear rate, such as famous Mauna Kea Observatories[2]. Precipitable Water Vapor (PWV) refers to the precipitation that can be formed when all Water Vapor in the air column of unit value

* Corresponding author: mengqk@qhu.edu.cn

is converted into rain and snow, which is also called atmospheric Precipitable Water. PWV content is one of the important parameters affecting optical astronomical observation. High water vapor content will increase infrared thermal background and reduce atmospheric transparency, which is not conducive to astronomical observation[3]. A large number of studies have shown that there are obvious spatiotemporal differences in the distribution of PWV content[4]. Understanding the spatial and temporal distribution characteristics of PWV content is necessary for determining the location and observation time of optical observatories. Meanwhile, from the definition of clear nights, we conclude that the percentage of clear nights is the most straightforward and high-priority parameter in the site merit function[5] based on the experience gained from studies of the Thirty Meter Telescope (TMT) [6]. In addition, elevation and land cover also affect the location of the observatory[7]. At present, the field of astronomy rarely utilizes satellite data to monitor meteorological and environmental factors for astronomical site selection, In this paper, the atmospheric water vapor content and night clear rate were extracted and analyzed by using MODIS data of 1095 scenes from 2016 to 2019, covering an area of 280,000 km2 with a resolution of 1 km. Land cover type data with 30 m resolution and DEM data were used to determine the area proportion of land cover type and optimal elevation in the study area. The Analytic Hierarchy Process (AHP) was used to determine the weights of the above parameters and obtain the geographical environment suitability of optical astronomical observation in Lenghu Qinghai Province, China.

2 Study area

The study area includes Lenghu and its surrounding areas (89° 35'E ~ 97° 36'E, 35° 30'N~ 39° 06'N), covering an area of 280,000 km2. This area has a plateau continental climate, with an average annual temperature of 2-3 ℃ and very little precipitation, and is extremely dry in China [8]. The natural conditions are harsh, cold and windy all year round, with little rain and drought, and a large number of Yadan landforms are developed [9]. Due to the high altitude, lack of rainfall and extremely low population density in the study area, the quality of the night sky is excellent, and the number of clear nights is up to 276 days in the whole year, which meets the requirements of topographic conditions for excellent observatory sites. The overview of the study area is shown in Figure 1.

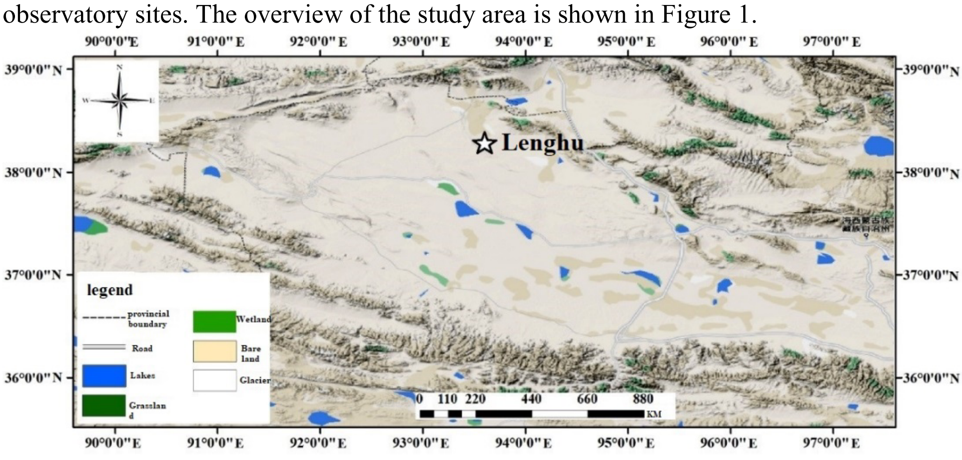

Fig. 1. Sketch map of study area**.**

3 Data and method

In this study, satellite data were selected as MODIS remote sensing data product, GlobeLand 30 land cover type thematic data, and DIGITAL Elevation Model (DEM) with a resolution of 30m. The MODIS data were obtained by the Moderate Resolution Imaging Spectroradiometer (MODIS) on The Terna and Aqua satellites launched by the United States. The selected time is 3 years from 2016 to 2019. The temporal resolution of MODIS data is daily-scale, spatial resolution is 1 km, and there are 36 spectral bands, covering an area of 280,000 km2. Land cover type data were GlobeLand 30 thematic data with a resolution of 30 m. The projection coordinate system of the three data is WGS84. The data resolution selected meets the research requirements. Table 1 shows the data details. In this paper, several aspects and standards of optical astronomical site selection are analyzed, and AHP is used to determine the influence weight of each evaluation index, so as to obtain the suitability of optical astronomical sites in the study area. Analytic Hierarchy Process (AHP) is a pairwise comparison method, which is a highly reliable technique for comparing the weights of two criteria at the same time to avoid unnecessary complexity for decision makers [10].

Table 1. Dataset of the study area.

No	Source	The data type	Date	Resolution
1	LAADS (Atmosphere Archive and Distribution System)	Precipitable Water Vapor	2016.09～2019.10	1 km
2	LAADS	clear nights	2016.09～2019.10	1 km
3	GlobeLand 30	Land Cover	2018	30 m
4	SRTM	Altitude	2000	30 m

4 Results and analysis

4.1 Spatial and temporal distribution characteristics of PWV content

The spatial and temporal distribution of annual average PWV content in the study area from 2016 to 2019 is shown in Figure 2. It can be seen that the PWV content is relatively low on the whole, with the three-year average of 0.29-3.22 g/cm^2 and the overall annual average of 0.59 g/cm^2. Meanwhile, it is found that there are significant seasonal differences in PWV content in the study area (spring is defined as March to May, Summer is defined as June to August, autumn is defined as September to November, and winter is defined as December to February), as shown in Figure 3. The average PWV content ranges from 0.17 to 2.65 g/cm^2 in spring, 0.61 to 4.26 g/cm^2, 0.26 to 4.00 g/cm^2, 0.09 to 2.51 g/cm^2 in winter in The Lenghu region from 2016 to 2019, respectively. The annual average PWV content is 0.43, 1.17, 0.53, 0.21 g/cm^2, respectively. It can be seen that the PWV content in the study area is low on the whole, and there is an obvious seasonal difference. The PWV content is higher in summer and decreases successively in spring, autumn, and winter.

 https://doi.org/10.1051/itmconf/20224703034

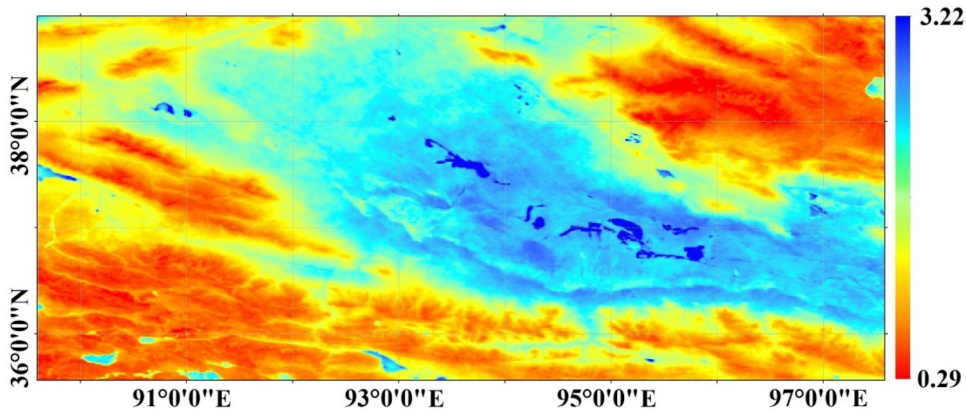

Fig. 2. 2016～2019 Average PWV Content Distribution in Lenghu Region (1*1 km^2).

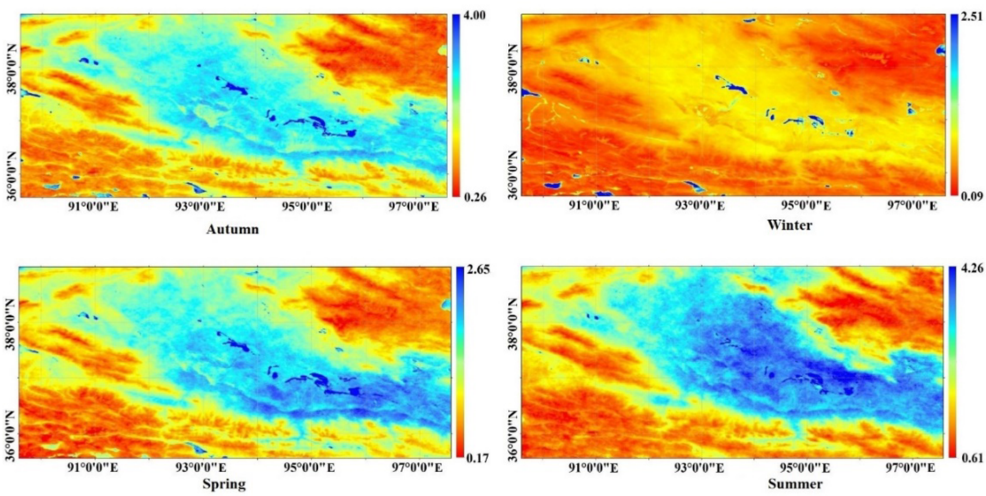

Fig. 3. 2016～2019 Annual Seasonal Mean PWV Content Distribution in Lenghu Region (1*1 km^2).

It can be seen from Figure 3 that the average annual PWV content in the study area from 2016 to 2019 ranges from 0.3 to 1 g/cm^2, accounting for 99.23% of the total area of the study area. The average PWV content in spring, autumn, and winter ranges from 0 to 1 g/ cm^2. The areas within the range of water vapor account for 96.12%, 99.17%, and 97.51% of the total area, respectively. It can be seen that the PWV content in spring, autumn, and winter in the study area is very low, and the PWV content is the most abundant in summer, and the areas with water vapor content between 0.6 and 1.5g/ cm^2 account for 79.78% of the total area of the study area. In general, except for a few maximum values, the PWV content in the study area is always at a low level. The main distribution range and area proportion of PWV content in each season were also analyzed, as shown in Table 2.

Table 2. Main water vapor distribution and area ratio in each period from 2016 to 2019

Period of time	Total pixels	PWV/g·cm^{-2}	Pixel elements	Proportion /%
Annual averag	357 291	0.3 ~ 1	355 177	99.23

Spring	357 291	0 ~ 0.6	303 456	96.12
Summer	357 291	0.6 ~ 1.5	285 070	79.78
Autumn	357 291	0.6 ~ 1	354 322	99.17
Winter	357 291	0 ~ 0.3	348 399	97.51

4.2 Clear nights

The percentage of clear nights is the most direct and preferred parameter in the function of observatory site value. Although ground data is critical to the final site selection, satellite remote sensing data can greatly reduce the need for field testing of ground observations, ensure long-term Spatio-temporal continuity of data, and perform large area screening. In this paper, MOD35 data are used to carry out projection conversion, cutting, and fusion of data. Matlab and ArcGIS software is used to carry out data conversion, identify the four classifications: cloudy, possibly cloudy, possibly sunny, and not cloudy, and extract the valid data. According to the above extraction method, the data of 1095 days from September 2016 to September 2019 in the study area were selected, and the extraction results are shown in Figure 4 showed that the average clear nights rate was63%, and the maximum clear nights rate was 74.2% in the study area. The area with clear nights rate less than 50% accounted for 0.87% of the total area, the area with clear nights rate between 50% and 60% accounted for 19.8%, and the area with clear nights rate between 60% and 74.2% accounted for 79.33% of the total area.

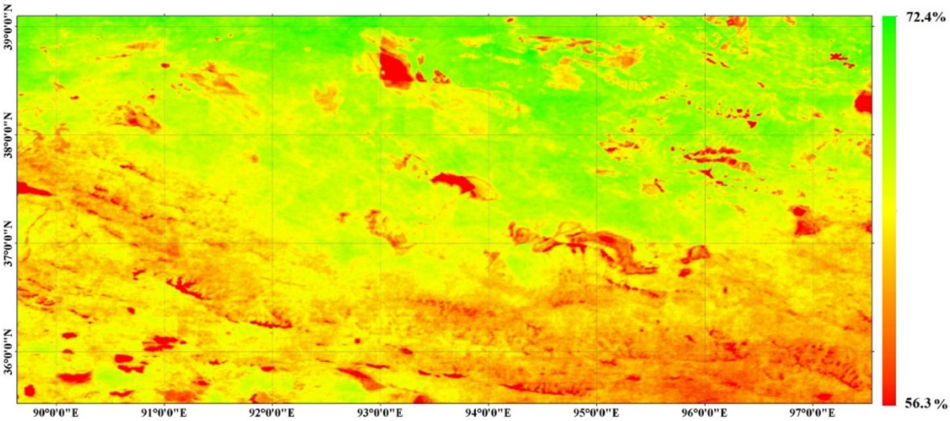

Fig. 4. Clear nights rate of the study area from October 2016 to October 2019.

4.3 Altitude

Altitude is one of the most important criteria affecting astronomical data. As a rule of thumb, elevation is considered the main aspect of any astronomical siting study; Anything above 5000 metres is not feasible because of poor accessibility, low oxygen levels, and hostile weather: these areas are not friendly environments. In this paper, according to the grade of equal, the area with an altitude of 3500-4500m is determined as the best area with few human disturbance. It accounted for 29.22% of the total study area (see Figure 5).

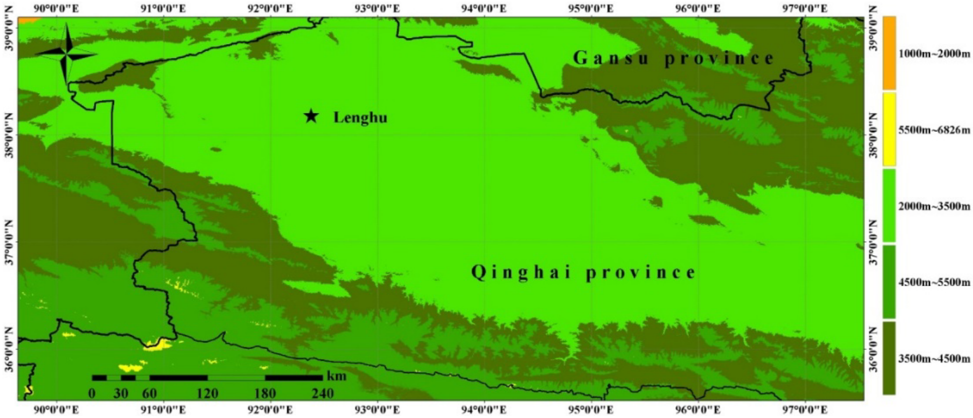

Fig. 5. Altitude (elevation from sea level).

4.4 Land cover

The land cover types in the study area mainly include grassland, bare land, lake, wetland, and glacier. The distribution is shown in Figure 6, where grassland accounts for 26.7% of the total area , and bare land accounts for 58.54%, indicating most regions are suitable for observatory sites except for lakes, wetlands and glaciers.

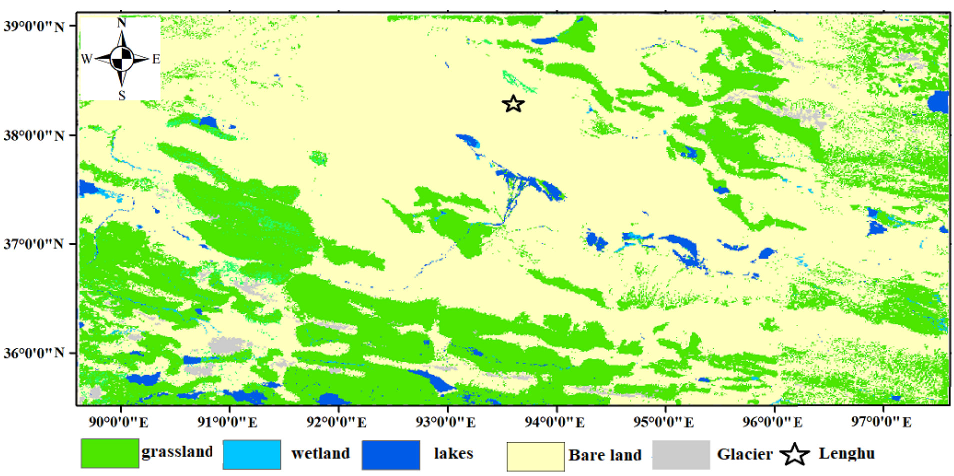

Fig. 6. Land cover types in study area.

4.5 Environmental suitability

This study uses analytic hierarchy process (AHP) to determine the influence weight of each evaluation index. The priority of the above four environmental parameters was selected through the expert scoring system. Table 3 shows the final weight of the four parameters obtained through AHP method.

Table 3. Weight of influencing factors.

Criteria	Influence Weights
Precipitable Water Vapor	0.33

Clear nights	0.31
Altitude	0.26
Land cover	0.10

The fitness result of optical astronomical observation obtained through the superposition of the weight values of each parameter is shown in Figure 7. According to the results of this method, 30% of the Lenghu area and its surrounding area seems to be suitable for the establishment of optical astronomical observatory with geographical-environmental suitability is above 4, and the place named Saishiteng (SST) mountain has the highest suitability, which is the best potential area for optical astronomy research.

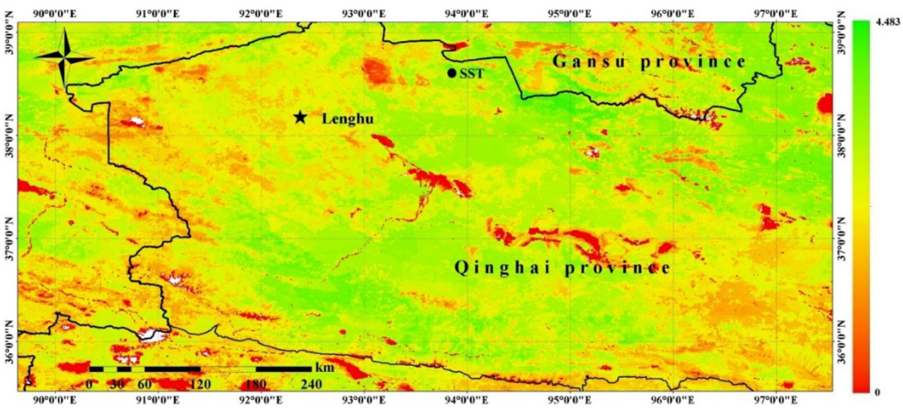

Fig. 6. Environmental suitability of optical astronomical observation in the study area.

5 Conclusion

In this paper, we utilize remote sensing to retrieve and analyze PWV, clear nights, elevations and Landcover for optical astronomical research. The following findings are summarized as follows:

(1) The lenghu region is characterized by seasonal variation with high PWV in summer and low PWV in the winter, representing non-summer periods are the best observation time

(2) The Lenghu region has relatively high clear nights with more than half of times through one year is suitable for observation.

(3) Based on Geoenvironmental suitability mapping, Saishiteng Mountain is selected as a priority site for optical astronomical sites.

This study was supported by the Key Research Project of Qinghai Province 2019-ZJ-A10, and we are grateful for the free access of MODIS data and the careful work of anonymous reviewers in improving the quality of the paper.

Reference

1. Deng L, Yang F, Chen X, et al. Lenghu on the Tibetan Plateau as an astronomical observing site[J]. Nature, 2021, 596(7872): 353-356.

2. Morrison D, Murphy R E, Cruikshank D P, et al. Evaluation of Mauna Kea, Hawaii, as an observatory site[J]. Publications of the Astronomical Society of the Pacific, 1973, 85(505): 255.
3. Hudson, K., & Simstad, T. 2010, The Share Astronomy Guide toObservatory Site Selection, Neal Street Design Inc, 1,10
4. Tu M, Zhang W, Bai J, et al. Spatio-Temporal Variations of Precipitable Water Vapor and Horizontal Tropospheric Gradients from GPS during Typhoon Lekima[J]. Remote Sensing, 2021, 13(20): 4082.
5. Cao Z H, Liu L Y, Zhao Y H, et al. Long-term analysis of clear nights using satellite data considering astronomical sites in western China[J]. Research in Astronomy and Astrophysics, 2020, 20(6): 081.Sanders G H. The thirty meter telescope (tmt): An international observatory[J]. Journal of Astrophysics and Astronomy, 2013, 34(2): 81-86.
6. Kazmi S J H. Optimal site selection for an optical-astronomical observatory in Pakistan using Multicriteria Decision Analysis[J]. Research in Astronomy and Astrophysics, 2019, 19(9): 129.
7. Wang Q C, Qin N S, Tang H Y, et al. Study on Climate Change Facts and Their Characteristics in the Qinghai Plateau in Recent 44 Years [[J]. Arid Zone Research, 2007, 2: 018.
8. Zhu B, Yu J, Qin X, et al. Formation and evolution of sand deserts in Xinjiang, Northwest China: II. The palaeo-environmental reconstruction[J]. Journal of Geographical Sciences, 2014, 24(3): 539-559.
9. Saaty T L. Decision-making with the AHP: Why is the principal eigenvector necessary[J]. European journal of operational research, 2003, 145(1): 85-91.
10. Muchachos Observatory (1996–1998)[J]. New Astronomy Reviews, 1998, 42(6- 8): 537-542.