

Article

# Landscape Potential and Light Pollution as Key Factors for Astrotourism Development: A Case Study of a Slovak Upland Region

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**Abstract:** Astrotourism is considered to be a modern form of ecotourism. The main resource for astrotourism is a high-quality night sky, but this is very sensitive to natural as well as anthropogenic factors; for example, land utilization and expansion of urban areas often cause the negative effect of light pollution. The aim of the study is to perform a lighting survey by night sky brightness (NSB) measurements using the sky quality meter (SQM-L) at 20 study sites of the Slovenské stredohorie Upland region (Slovakia) and to assess the region's potential for astrotourism development (PAD) using a multicriteria analysis. The NSB values ranged from 19.90 (city Žiar nad Hronom at Žiarska kotlina Basin) to 21.54 mag/arcsec<sup>2</sup> (recreation area Poľana at Poľana Mountains). At 14 out of 20 study sites, the NSB values even reached 21.2 mag/arcsec<sup>2</sup>, as recommended by the International Dark-Sky Association for dark-sky parks. Four study sites were categorized as sites with medium PAD, and sixteen with low PAD. No study site reached a high or very high PAD. The best conditions for astrotourism development are fulfilled mainly by the Poľana Mountains geographical unit. The findings can be used for sustainable astrotourism development, land management, and planning to ensure socioeconomic development, together with nature and dark-sky conservation.

**Keywords:** astrotourism; landscape potential for astrotourism; night sky brightness; light pollution

## 1. Introduction

Since the start of the 21st century, new kinds of tourism, including astrotourism, have emerged. Fayos-Solá et al. [1] defined astrotourism as tourism using the natural resource of unpolluted night skies and appropriate scientific knowledge of astronomical, cultural, or environmental activities. Astrotourism epitomizes the tendencies towards more meaningful tourism experiences based on the conservation of natural resources. In 2008, Weaver [2] used the term celestial ecotourism, which we understand to be synonymous with astrotourism. He defined celestial ecotourism as ecotourism where the interest of visitors is focused on the observation of naturally occurring celestial phenomena. The term “dark sky tourism” is also in use, which can be drawn from astral and celestial tourism to refer to tourism based on unpolluted night skies, involving observation and appreciation of naturally occurring celestial phenomena [3].

Astrotourism is a form of ecotourism, which is synonymous with wilderness tourism, adventure tourism, green tourism, scientific tourism, agrotourism, and rural tourism. Its greatest assets never need maintenance or development, are always available, are completely unique in its features,

and are continuously considered one of the most sustainable attractions [4]. Sustainable tourism is a phenomenon of global interest [5]. It is focused on the balance between economic, sociocultural, and environmental sustainability and integrational equity [6,7]. In addition, astrotourism can be classified as a rural tourism sector that can improve the local economic status and local development by being community-based and private-sector-driven [8,9]. Rural areas typically have low population and low economic activity (usually in the agricultural sector) and are dominated by open areas such as fields, pastures, woods and forests, and mountains. They lack sustainable development alternatives, usually offer affordable land, and require high transaction costs due to the vast distance from urban areas and poor infrastructure [10,11]. The importance of rural tourism increased during the coronavirus pandemic when the international tourism economy was heavily hit. In the future, it is expected that domestic tourism, including rural tourism, will offer the main chance for driving and supporting the recovery of the tourism sector [12]. Slovakia has excellent natural, cultural, and social conditions for the development of modern winter and summer tourism, e.g., recreational climbing, mountain biking, recreational horse riding, alpine and nordic skiing, ski mountaineering, water sports, and the collecting of wild berries and medicinal plants [13–17]. Astrotourism is also considered to be a modern form of scientific tourism that is designed for individuals as well as for groups.

The main resource for astrotourism is a high-quality night sky, but this is very sensitive to natural as well as anthropogenic factors. Atmospheric and meteorological conditions are very important; however, night sky brightness (NSB) is also affected by human factors such as land utilization, and the expansion of urban areas often causes the negative effects of light pollution, especially if smart and flexible lighting systems are not applied. However, the local weather results from large global patterns in the atmosphere caused by the interaction of solar radiation. In addition, the atmosphere and the land surface interact in multiple ways, for instance, through the radiative energy balance, the water cycle, or the emission and deposition of natural and anthropogenic compounds [18–20]. The topography and geographic range, slope and elevation, and direct solar radiation and diffuse-sky radiation difference make the load of solar radiation on the ground vary from place to place. Atmospheric conditions are also highly variable natural factors that play a key role in astronomical observations. Anthropogenically caused light pollution is another important factor determining astronomical observations and, thus, astrotourism development. Location is a key to looking deeper into space by means of a clear, dark night sky, free from artificial light. Light pollution is unwanted or excess artificial light at night (ALAN) with a negative impact on humans and the environment. Especially since World War II, city lighting growth has been literally exponential and continues to the present, as can be seen from satellite data. Thus, the artificial lighting of urban spaces overflows its objective by polluting the night to the point that the stars disappear from the night sky [21,22].

Astronomers have highlighted the reduced visibility of the night sky [23]. At an international conference in the defense of the quality of the night sky and the right to observe the stars, organized in 2007 at La Palma (Canary Islands, Spain), the La Palma Declaration was adopted. The declaration invites authorities to take appropriate measures to safeguard the cultural and natural heritage of starlight and to formulate action plans to provide effective protection of the night sky [24]. There are driving forces behind initiatives for dark-sky protection [25]. In order to protect sites of significant ecosystems, natural beauty, or astronomical interest, it is important that light pollution reduction is included as a top priority of national parks, protected areas, wilderness areas, and astronomical observatories, as well as public policy [26,27]. VIDAs (very important dark areas) are areas that, according to satellite data and a skyglow model, are below a certain threshold for skyglow [28]. The VIDA network in Europe might be a basis for the protection of biodiversity from the consequences of artificial light at night, and it can also serve as a key education center for increasing the awareness of the problem of light pollution of the night sky [29].

Excessive artificial light added to the nocturnal landscape is a serious ecological burden on the environment. Much recent attention has been paid to the impact of exposure to direct emissions of ALAN. However, much less is known about the environmental consequences of indirect light exposure.

Light that is reflected or directly emitted upwards can be scattered back to Earth by atmospheric constituents, causing skyglow. This raises the overall background nighttime light level over vast areas and can screen out celestial signals from individual stars, the Milky Way, and the polarization pattern of the moon [30,31]. ALAN has an adverse impact on the biorhythms and behavior of living organisms [32,33], with unintended physiological consequences. Plant growth and development are influenced by light spectral quality, quantity, and duration [34,35]. In vertebrates, the production of melatonin (the “hormone of darkness”) and a key player in circadian regulation can be suppressed by ALAN [36], and there is a suspected adverse impact of outdoor lighting on public health, particularly metabolic disorders and breast cancer development [37]. At the EU level, specific legislation for light pollution is missing. While protection is predominantly provided for species with special protection status that reveal avoidance behavior of artificially lit landscapes and associated habitat loss, adverse effects on species and landscapes without special protection status are often unaddressed by existing regulations [38].

Light pollution levels can be determined by NSB, which is used as an environmental assessment indicator. New instruments and methods for assessing the illumination of the night sky have been developed [39,40]. A standard method for performing night sky brightness measurements is the use of sky quality meters (SQMs) [41]. This method is also used for continuous measurements and the establishment of dark-sky parks [42]. A more precise measurement system is the method introduced by the US National Park Service [43], where an astronomical CCD camera is used to produce a mosaic of the sky. Although this technique provides the most precise measurements, there are cheaper and more feasible methods for all-sky photometry, such as DSLR (digital single lens reflex) or MILC (mirrorless interchangeable-lens camera) digital cameras [44].

The scope of this paper is to perform a lighting survey by NSB measurements using SQMs at localities selected as suitable for astrotourism in the region of the Slovenské stredohorie Upland and to assess the potential of the selected study sites for astrotourism development using multicriteria analysis.

## 2. Materials and Methods

### 2.1. Study Area

The study area was the Slovenské stredohorie Upland, a geomorphological region located in the Inner Western Carpathians. The Slovenské stredohorie Upland occupies an area of 4.229 km<sup>2</sup>. The highest peak, called Poľana (1.458 m), is located at Poľana Mountains. The region is represented by Javorie Mountains, Kremnické vrchy Mountains, Ostrôžky Mountains, Pohronský Inovec Mountains, Poľana Mountains, Štiavnické vrchy Mountains, Vtáčnik Mountains, Pliešovská kotlina Basin, Žiarska kotlina Basin, Krupinská planina Plain, and Zvolenská kotlina Basin (Figure 1). These units can be divided into further subunits [45]. The region is geologically heterogeneous with the dominance of the Neogene volcanites (traditionally named neovolcanites). There are two protected landscape areas (Štiavnické vrchy Mountains and Poľana Mountains Protected Landscape Areas) in the region.

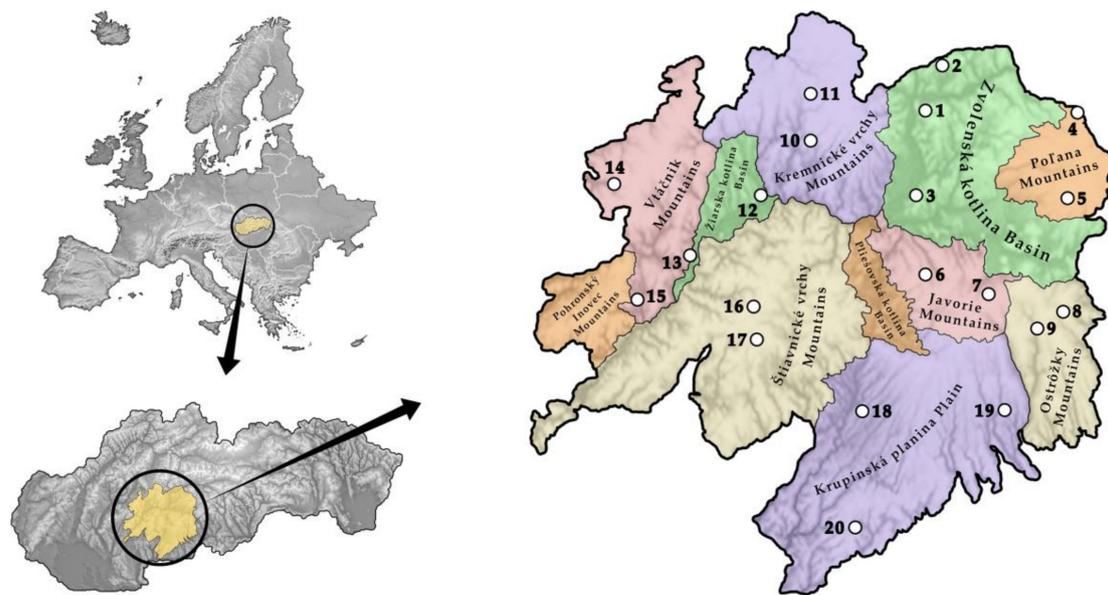
We selected 20 study sites in the region, of which 8 are recreation areas situated near villages, 7 are rural areas, 1 is a tourist cottage, 1 is a tourist hotel, 1 is a spa, 1 is an astronomical observatory situated in the district city vicinity, and 1 is a planetarium with an observatory situated in the city. Table 1 gives the geographical coordinates, elevation, and specification of the selected study sites, measured and determined directly at each study site, including basic climatological characteristics [46–48]. A more detailed description of the natural conditions of the Slovenské stredohorie Upland region is given by Škvarenina et al. [49].

**Table 1.** Site geographical and climatological characteristics.

No.	Name	Geographical Unit	Site Specification	Latitude Longitude	Elevation (m a.s.l.)	Clear Day (n) [46]	Overcast Day (n) [46]	Fog Day (n) [47,48]	Average Annual Cloudiness (%)[46]
1	Vartovka	Zvolenská kotlina Basin	astronomical observatory (district city vicinity)	48°43'04.70" 19°09'13.38"	568	45	129	45	62
2	Fugerov dvor	Zvolenská kotlina Basin	recreation area	48°47'21.84" 19°10'53.41"	655	42	136	43	63
3	Sliač	Zvolenská kotlina Basin	spa	48°36'44.70" 19°09'46.25"	390	47	125	88	61
4	Chata pod Hrbom	Poľana Mountains	tourist cottage	48°44'11.95" 19°27'16.17"	1090	51	137	79	63
5	Horský hotel Poľana	Poľana Mountains	recreation area	48°37'28.75" 19°27'56.58"	1260	42	138	140	64
6	Kráľová	Javorie Mountains	recreation area	48°30'16.89" 19°10'56.00"	660	45	131	40	62
7	Stará Huta	Javorie Mountains	village vicinity	48°28'45.29" 19°20'40.97"	785	44	132	47	62
8	Jasenie	Ostrôžky Mountains	village vicinity	48°27'50.14" 19°28'15.07"	760	48	125	45	61
9	Ábelová	Ostrôžky Mountains	village vicinity	48°27'23.06" 19°25'29.92"	720	46	128	45	61
10	Nevol'né	Kremnické vrchy Mountains	village vicinity	48°40'12.55" 18°56'12.42"	730	43	133	43	62
11	Krahule	Kremnické vrchy Mountains	recreation area	48°43'32.25" 18°56'31.30"	890	40	141	75	64
12	Žiar nad Hronom	Žiarska kotlina Basin	planetarium (in city)	48°35'09.96" 18°51'05.06"	270	50	121	51	60
13	Revište	Žiarska kotlina Basin	recreation area	48°31'14.86" 18°43'43.54"	220	51	120	60	60
14	Lomy	Vtáčnik Mountains	tourist hotel	48°34'50.31" 18°34'04.20"	560	43	135	40	63
15	Hrabiny	Pohronský Inovec Mountains	recreation area	48°28'05.04" 18°38'10.82"	395	50	122	35	60
16	Štiavnické Bane	Štiavnické vrchy Mountains	recreation area	48°26'09.81" 18°50'54.65"	760	50	124	48	61

Table 1. Cont.

No.	Name	Geographical Unit	Site Specification	Latitude Longitude	Elevation (m a.s.l.)	Clear Day (n) [46]	Overcast Day (n) [46]	Fog Day (n) [47,48]	Average Annual Cloudiness (%)[46]
17	Počúvadlo	Štiavnické vrchy Mountains	recreation area	48°24'03.72" 18°51'21.93"	660	51	121	50	60
18	Bzovík	Krupinská planina Plain	village vicinity (monastery ruins)	48°18'55.31" 19°05'23.19"	360	54	115	30	59
19	Veľký Lom	Krupinská planina Plain	village vicinity	48°20'27.24" 19°22'21.53"	430	51	119	25	60
20	Prašný vrch	Krupinská planina Plain	village vicinity	48°10'04.62" 19°05'34.14"	500	53	117	25	59



**Figure 1.** Map of the location of Slovakia in Europe and of the Slovenské stredohorie Upland in Slovakia, their geographical units, and selected study sites.

## 2.2. Night Sky Brightness Measurement

The SQM-L with a measuring angle of  $20^\circ$  (narrow-angle), manufactured by Unihedron (Canada), was used in this study to measure NSB in field observations. NSB is a short-hand term for the radiance of the night sky, integrated across wavelengths within the photometric band of the detector and angularly averaged across its field of view [50]. The SQM-L instrument consists of a specially calibrated sensor that is able to detect light in a given field of view. The result is a numerical logarithmic value in units of magnitude per square arc second.

Traditionally, astronomers measured sky brightness in the astronomical magnitude system ( $\text{mag}/\text{arcsec}^2$ ). The idea behind this system is that if an area on the sky contained only exactly one magnitude  $X$  star in each square arcsecond, the sky brightness would be  $X \text{ mag}/\text{arcsec}^2$ . The magnitude system was introduced by the ancient Greek astronomer Hipparchos, who assigned a magnitude of 1 for the brightest stars visible to the naked eye, and a magnitude of 6 for the faintest stars visible to the naked eye (in a time before widespread light pollution). For this reason, larger values in  $\text{mag}/\text{arcsec}^2$  indicate darker skies. Astronomers measure radiance in different wavelength ranges. Similar to the photopic system standardized measurement of “human visible” light, the “UBV system” or “Johnson system” of ultraviolet (U), blue (B), and green (visual = V) filters allows astronomers to make and report consistent observations in other color bands. The green V spectral band is not greatly different from the visual photometric spectral band, so astronomical brightness values in  $\text{mag}_V$  can be approximately transformed to photometric values:

$$\text{Luminance (cd/m}^2) \approx 10.8 \times 10^4 \times 10^{-0.4 \cdot \text{mag}_V} \quad (1)$$

The unit indicates the surface brightness of the sky and ranges from  $24 \text{ mag}/\text{arcsec}^2$  (almost complete darkness) to  $0 \text{ mag}/\text{arcsec}^2$  (dawn and dusk). The darkest places on Earth have a sky brightness of about  $22 \text{ mag}/\text{arcsec}^2$ , rural areas  $19.0\text{--}21.6 \text{ mag}/\text{arcsec}^2$ , suburban areas  $16.0\text{--}20.4 \text{ mag}/\text{arcsec}^2$ , while in bright cities, it is often  $16\text{--}17 \text{ mag}/\text{arcsec}^2$  [39].

For night sky brightness measurement, a nine-level numerical scale called the Bortle Dark-Sky Scale is also used. It quantifies the observability of celestial objects and the interference caused by light

pollution and skyglow. The scale ranges from Class 1, the darkest skies available on Earth, through to Class 9, inner-city skies [51].

The SQM-L instrument allows the measurement of brightness gradually over the whole sky, which provides more information about the different brightness of the sky in specific areas and directions of the sky. The measurement was performed according to the manufacturer's recommended methodology [52] by measuring the value at the zenith and then, in the direction of the four sides of the sky, at the height of 60° above the horizon. At each study site, we realized five replicates at 5-minute intervals, for which basic statistical characteristics were calculated.

The survey started on 5 July 2019 and finished on 20 June 2020. The measurements were done during clear nights in the absence of the moon or during a new-moon phase. The measurements were done under conditions of astronomical darkness, meaning that the sun was at least 18° and the moon at 10° below the horizon. The Milky Way was at least 60° above the horizon. During the winter, the measurements were done during nights without snow to avoid the possible negative effect of snowglow [53].

Correlation analysis was conducted using the Spearman correlation coefficients to identify relationships among NSB and the selected factors. The statistical analysis was conducted using PASW Statistics software (version 18.0).

### 2.3. Potential for Astrotourism Development Evaluation

The region's potential for astrotourism development (PAD) was evaluated by multicriteria analysis. In this work, we propose, for the first time, a set of parameters and a ranking system that can be applied to any other region in the world. A similar but only region-specific approach applied Kaniansky to the Banská Bystrica self-government region [54]. We selected 7 parameters, of which 3 (NSB, elevation, number of clear days) are natural and 4 (possibility of a professional guide, vehicle accessibility, proximity to food and accommodation facilities, proximity to other tourism units) are anthropogenic in character. All parameters were scaled. The level of each parameter is shown in Table 2. The NSB parameter was scaled from 20.5 mag/arcsec<sup>2</sup>, which corresponds to the fourth Bortle class (rural/suburban transition), to 21.8 mag/arcsec<sup>2</sup>, which corresponds to the first Bortle class (excellent dark sky). The upper limit for the elevation parameter was determined above 3000 m a.s.l. because of possible negative health effects connected with altitude sickness at high altitude. The number of clear days is a standard and accessible measured meteorological parameter. However, for dark sky certifications, parameters like visibility or transparency could be required. Anthropogenic parameters were determined based on practical experiences.

**Table 2.** Level of selected parameters.

Parameter	Subcriteria	Point Rating
1/Night sky brightness (mag/arcsec <sup>2</sup> )	>21.80	10
	21.61–21.80	8
	21.41–21.60	6
	21.21–21.40	4
	21.01–21.20	3
	20.81–21.00	2
	20.50–20.80	1
	<20.50	0
2/Elevation (m a.s.l)	>3000	6
	2501–3000	5
	2001–2500	4
	1501–2000	3
	1001–1500	2
	500–1000	1
<500	0	

Table 2. Cont.

Parameter	Subcriteria	Point Rating
3/Number of clear days	>300	6
	251–300	5
	201–250	4
	151–200	3
	101–150	2
	50–100	1
	<50	0
4/Possibility of a professional guide	yes	1
	no	0
5/Vehicle accessibility	yes	1
	no	0
6/Proximity to food and accommodation facilities (km)	<1	3
	1–5	2
	5–10	1
	>10	0
7/Proximity to other tourism units (km)	<5	3
	5–25	2
	25–50	1
	>50	0

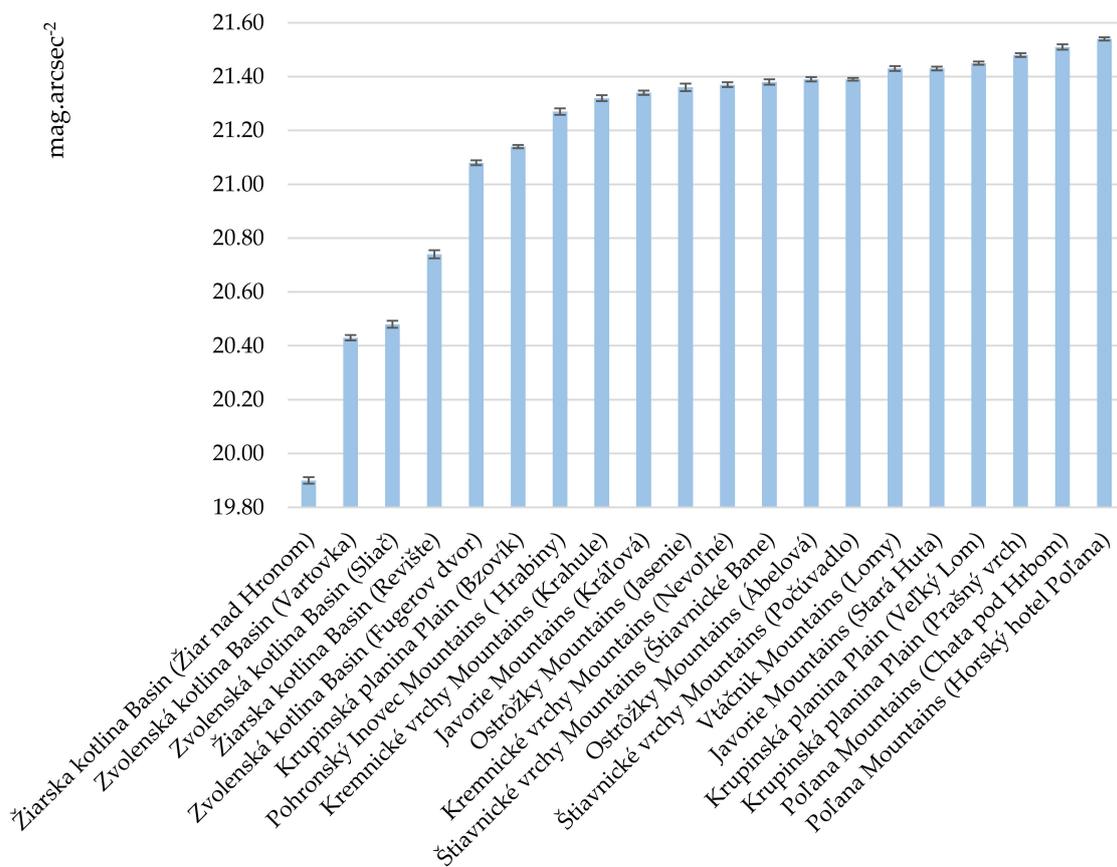
But there are many types of tourists who have different demands of a destination. Thus, we can distinguish two main categories of tourists in astrotourism, namely, group (or family) tourists and individual (or enthusiastic) tourists. Natural parameters are more important and appreciated by individual (enthusiastic) tourists, but for group (family) tourists, anthropogenic parameters are also very important.

- very high: 24–30 points,
- high: 18–23 points,
- medium: 12–17 points,
- low: <12 points.

### 3. Results and Discussion

#### 3.1. Night Sky Brightness Assessment

In astrotourism, the place people perceived the sky must have a required set of attributes to be defined as an appropriate sky observation site. This site is a landscape where there are dark skies at night without light pollution [55]. Light pollution is a key factor influencing astrotourism development. Figure 2 shows the measured NSB values of 20 study sites as the indicator of light pollution sorted by measured data from the lowest value. The brightest night sky was detected in the city Žiar nad Hronom at Žiarska kotlina Basin, with a measured NSB value of 19.90 mag/arcsec<sup>2</sup>. Conversely, the darkest night sky was detected in Horský hotel Poľana at Poľana Mountains with a measured NSB value of 21.54 mag/arcsec<sup>2</sup>. The overall average NSB value for the 20 study sites representing the Slovenské stredohorie Upland was 21.18 mag/arcsec<sup>2</sup>.



**Figure 2.** Mean and standard deviation for in situ measurements of night sky brightness at selected study sites.

In the 1970s, the International Astronomical Union recommended an NSB level of 21.6 mag/arcsec<sup>2</sup> for conducting astronomical observations [56]. At present, the International Dark-Sky Association (IDA) certifies dark sky places. There are five categories for designation: International Dark Sky Parks, Communities, Reserves, Sanctuaries, and Urban Night Sky Places. Each category has its own set of criteria. In Slovakia, dark-sky parks have been established, but they are not certified by the IDA. The nearest dark-sky park to Slovenské stredohorie Upland is the Veľká Fatra Mountains Dark-Sky Park (Kráľova Studňa), which was declared in 2015. The Veľká Fatra Dark-Sky Park reaches a visual-band zenith luminance of 21.54 mag/arcsec<sup>2</sup>. The IDA recommends an NSB level of 21.2 mag/arcsec<sup>2</sup> for dark-sky parks and reserves [57]. Such a value was measured at 14 out of 20 study sites. Values higher than 21.40 mag/arcsec<sup>2</sup> were measured at six study sites (Poľana Mountains—Horský hotel Poľana, Poľana Mountains—Chata pod Hrbom, Krupinská planina Plain—Prašný vrch, Javorie Mountains—Stará Huta, Vtáčnik Mountains—Lomy), with values higher than 21.30 mag/arcsec<sup>2</sup> at seven study sites (Štiavnické vrchy Mountains—Počúvadlo, Ostrôžky Mountains—Ábelová, Štiavnické vrchy Mountains—Štiavnické Bane, Kremnické vrchy Mountains—Nevolné, Ostrôžky Mountains—Jasenie, Javorie Mountains—Kráľová, Kremnické vrchy Mountains—Krahule). All of these study sites are located in mountains, free landscapes, or rural areas. One reason for the darker night sky at these sites is that these areas are less populated. The other factor is the shadowing effect of mountains: the light emission from nearby light sources is blocked by the terrain. Thus, such NSB values still allow astronomical observations, which is disputable at the brightest study sites represented by the range of NSB values from 19.90 to 21.14 mag/arcsec<sup>2</sup>, localized at basins and plains at lower elevation and near or in urban areas (Žiarska kotlina Basin—Žiar nad Hronom, Zvolenská kotlina Basin—Vartovka, Zvolenská kotlina Basin—Sliach, Žiarska kotlina Basin—Revište, Zvolenská kotlina

Basin—Fugerov dvor). However, these NSB values are still far from the values measured in cities. Globally, cities and towns are losing the ability to view the stars as anthropocentric light (e.g., street lights, advertising, billboards, traffic headlights, and the illumination of buildings) outshines the night sky [58]. Light that is reflected or directly emitted upwards can be scattered back to Earth by atmospheric constituents, causing skyglow. Skyglow is observed to vary over four orders of magnitude, a range hundreds of times larger than was the case before artificial light. Netzel and Netzel [59] measured the brightest areas in cities of Poland (18 mag/arcsec<sup>2</sup>). In the highly populated city of Hong Kong, Pun and So [60] even measured an average NSB of 16.1 mag/arcsec<sup>2</sup>. At the opposite end are NSB values measured at places far from human civilization, e.g., at the research observatory location situated at the darkest possible place, ESO-Paranal (Chile), with the NSB value of 21.71 mag/arcsec<sup>2</sup> [61]. In rural areas and small towns, it is possible to reach a sufficiently low level of light pollution. Posch et al. [42] found that 5 of 26 locations in Eastern Austria reached NSB values down to 21.8 mag/arcsec<sup>2</sup>, so as to allow the establishment of dark sky reserves.

We calculated the correlation rates between NSB, elevation, number of clear days, overcast days, fog days, and average annual cloudiness (Table 3). A positive correlation rate was measured only between NSB and elevation, which is in line with results indicating that sky brightness is a function of elevation [62].

**Table 3.** Spearman’s correlation coefficients (n = 20) for night sky brightness and selected natural parameters.

	<b>Elevation</b>	<b>Number of Clear Days</b>	<b>Number of Overcast Days</b>	<b>Number of Fog Days</b>	<b>Average Annual Cloudiness</b>
<b>Night sky brightness</b>	<b>0.578 **</b>	0.04	0.209	−0.078	0.217

\*\* Correlation is significant at the 0.01 level (in bold).

### 3.2. Potential for Asrotourism Development

For most tourist activities, destination choice is a critical issue. In astrotourism, a destination’s sky features, combined with the landscape features and facilities to attract tourists, are one of the new opportunities to deliver unique tourism products [63]. Although many studies focus on destinations in various ways [64–67], only a few studies have evaluated a destination incorporating sky features [68,69]. Studies evaluating sky parameters with other natural and anthropogenic characteristics are very rare, while these characteristics are essential for astrotourism development assessment. We took three natural and four anthropogenic parameters into account. Figure 3 shows the potential for astrotourism development of 20 study sites sorted by the PAD points from the lowest value. Figure 4 shows the distribution of PAD values within the Slovenské stredohorie Upland region.

Although the NSB values are key for astronomical observations, other parameters also play an important role in astrotourism development. Thus, the Chata pod Hrbom at Poľana Mountains reached the highest number of PAD points, with the calculated sum of 14 points out of 30. This study site reached the second-highest NSB value (21.51 mag/arcsec<sup>2</sup>), which belongs to the category of medium PAD. Conversely, the Vartovka at Zvolenská kotlina Basin reached the lowest number of points, with the calculated sum of points of 6 out of 30, which is the study site with the second-lowest NSB value (20.43 mag/arcsec<sup>2</sup>). This study site belongs to the category of low PAD.

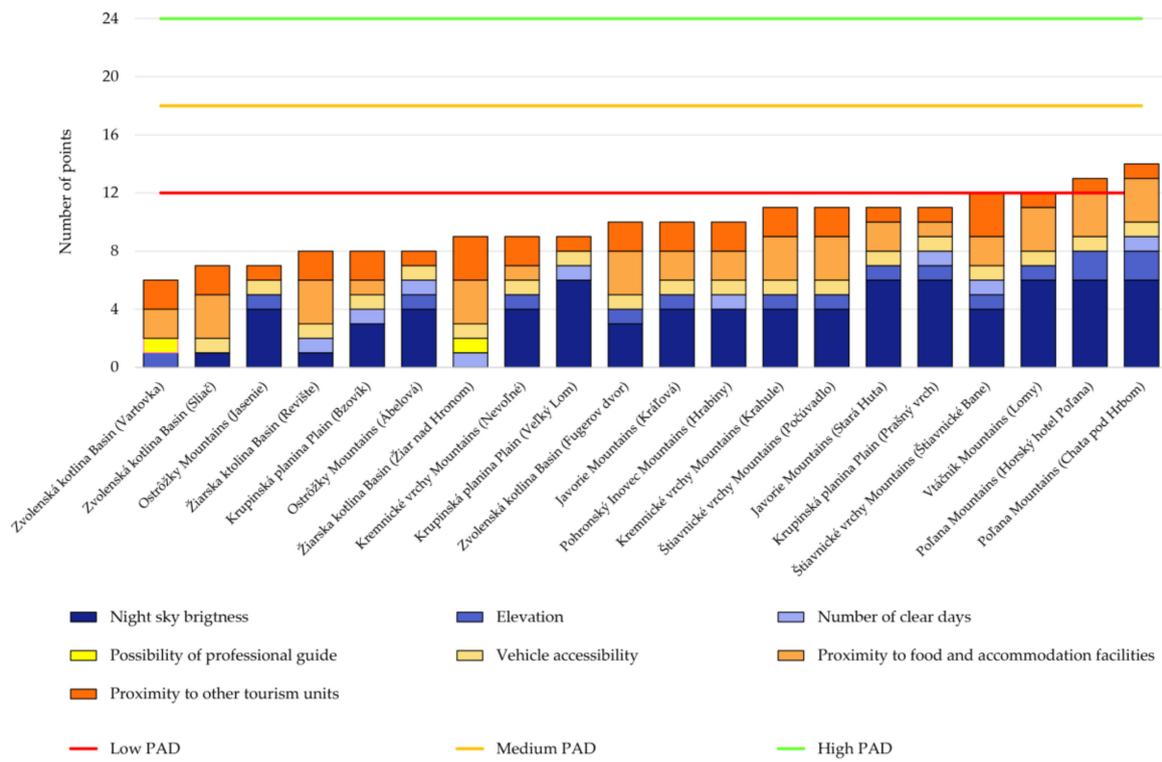


Figure 3. Potential for astrotourism development (PAD) at selected study sites and its categorization.

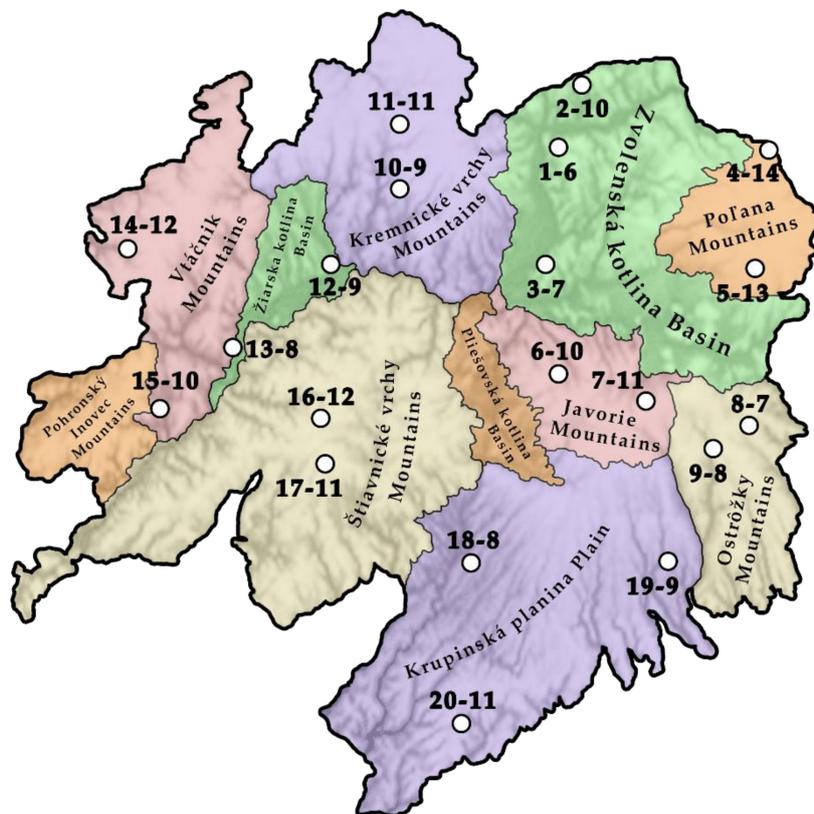


Figure 4. Distribution of potential for astrotourism development (PAD) values at selected study sites within the Slovenské stredohorie Upland region (number of study site–PAD value).

No study site reached the category of high or very high PAD. The overall average of PAD for 20 study sites was 10 points, which means the region is represented by low PAD. Four sites were categorized as sites with medium PAD, and sixteen with low PAD. The best conditions for astrotourism development in the Slovenské stredohorie Upland are fulfilled by the recreation areas of Poľana Mountains. The main reasons are the excellent natural conditions (relatively high values of NSB, higher elevation, and a sufficient number of clear days) and also the good anthropogenic parameters (food and accommodation facilities). At some places with good natural conditions, mainly situated in mountain regions, insufficient anthropogenic parameters (missing infrastructure and facilities) lowered the PAD. Conversely, the sites situated at basins and plains had worse natural conditions, but better anthropogenic parameters moved them forward.

Study sites with weak or no infrastructure, usually located in rural areas, are currently suitable for an individual form of astrotourism. After a restoration of the original traffic infrastructure, the study sites would also be suitable for a group form of astrotourism. An important part of successful astrotourism products is also a professional guarantee secured by the presence of an expert (astronomer), which currently appears to be a weak point at most study sites.

Similar findings are presented by Mitura et al. [70] from the Polish–Slovak–Ukrainian borderland, which has a huge potential for astrotourism development, but the only thing that the region requires is the development of infrastructure (accommodation and catering). Rural or sustainable tourism does not require sophisticated infrastructure [71], while the success of the majority of touristic initiatives depends on the quality of infrastructure [72,73].

#### 4. Conclusions

This study shows that the potential development of astrotourism depends on its unique product, dark sky, as well as other natural attributes, like high elevation, and is also conditioned by general anthropogenic products such as accommodation, transportation, and food.

At 14 out of 20 study sites, the NSB values reached the NSB value ( $21.2 \text{ mag/arcsec}^2$ ) recommended by the International Dark-Sky Association for dark-sky parks. The darkest night sky was detected at Horský hotel Poľana at Poľana Mountains at 1260 m a.s.l., with a measured NSB value of  $21.54 \text{ mag/arcsec}^2$ . Conversely, the brightest night sky was detected in the city of Žiar nad Hronom at Žiarska kotlina Basin, with a measured NSB value of  $19.90 \text{ mag/arcsec}^2$ . The impact of NSB was also reflected in the overall potential for astrotourism development assessment, where Horský hotel Poľana, with the second-highest number of PAD points (13 points out of 30), was ranked in the category of medium PAD. On the opposite end, the Vartovka at Zvolenská kotlina Basin (with the lowest number of 6 points out of 30) ranked in the category of low PAD. No study site reached a high or very high PAD.

Natural factors suitable for astrotourism development are connected mainly with the rural and mountain character of the region. Overall, Slovakia is a rural country, with respect to the nature of the territory and population density, and it is one of the most rural EU nations. The Banská Bystrica self-government region, where the Slovenské stredohorie Upland is situated, is classified as a significantly rural region. In addition, the mountain character of the region contributes an increased number of sites located at higher elevations, with better conditions for astronomical observations. A bigger obstacle to the realization of astronomical observations in the region and a decreasing factor for PAD is the relatively low number of clear days per year, which is a consequence of the overall climatic conditions. Slovakia is a landlocked country in central Europe, located in a middle latitude, and has a transitional climate between maritime and continental. Therefore, the climate in Slovakia is mostly determined by altitude, and the number of clear days is relatively low. Nevertheless, there are sites suitable for astrotourism development and even for the establishment of night sky parks: in particular, two sites located in the Poľana Mountains that reached the highest number of PAD points (Chata pod Hrbom and Horský hotel Poľana) could be considered suitable for night-sky parks. In addition, Poľana Mountains is a protected landscape area. Thus, the study showed that it is possible to improve astrotourism development in this region. The findings can be used for sustainable

astrotourism development, land management, and planning to ensure socioeconomic development, together with nature and dark sky conservation.

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