Article

The impact of light pollution on astrophotography and visual astronomy in varying environments

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SUMMARY

Around the globe, nighttime exposure to artificial lighting is becoming increasingly common, disrupting ecosystems, affecting human health, and negatively impacting the natural environment. Not only does it influence natural cycles, but it also reduces the number of visible stars and distorts the appearance of celestial objects, making it difficult to observe them in detail. While the impact of light pollution on star visibility and celestial observation has been widely researched, its specific effects on astrophotography, a technique that requires optimal light conditions, has not been as extensively studied. This research sought to investigate how light pollution affects the visibility and contrast of celestial objects in both astrophotography and visual astronomy. We compare images of the Milky Way taken in urban and rural locations to find out how location impacts the clarity and contrast of these images. We hypothesized that light pollution significantly reduces the visibility and contrast of celestial objects, especially in regions with higher levels of artificial light. Our results demonstrate that light pollution does have an impact on both visibility and contrast of stars and other celestial objects. These findings highlight the importance of reducing light pollution to preserve our ability to study and appreciate the universe.

INTRODUCTION

Light pollution refers to the artificial increase in outdoor lighting compared to natural nighttime levels (1). It is a widespread issue stemming from the global dependence on electric lighting, which has grown steadily for over two centuries (1,2). The extent of this impact became especially clear during space missions, where astronauts observed Earth's brightly lit cities from the International Space Station (3). Nearly one-third of the global population can no longer see the Milky Way galaxy due to the brightness of artificial lighting in their surroundings (4). Around 90% of all Americans have never seen the Milky Way, and approximately 80% cannot see stars in the night sky near their homes due to light pollution (1,4).

Light pollution gained further attention in 2016 with the release of the World Atlas of Night Sky Brightness, a digital map created using satellite imagery that illustrates the global spread of nighttime artificial light (5). The Atlas revealed that more than 80% of the world's population, including nearly all residents of the U.S. and Europe, live under skies so bright that the Milky Way is often hidden, and significant areas of the planet are obscured by light pollution (6). The Bortle Scale

categorizes night sky brightness into nine levels, with Class 9 representing the most extreme amount of light pollution. It also illustrates the significant impact of artificial lighting, demonstrating that urban environments experience more severe skyglow than rural areas (7). A recent study showed a rise from 6 to 9 in the Bortle Class in the sky's brightness over Rzeszow, Poland, over the past 6 years (8).

Astronomical research and astrophotography depend on dark skies to capture detailed images of celestial objects. Astrophotography, which involves photographing the night sky to document stars, planets, and other celestial objects, can be done with both advanced telescopes and modern smartphone cameras capable of long exposure imaging. Many astrophotographers, professional and amateur, travel to darker locations to obtain clearer, higher-contrast images. However, artificial light interferes with these observations by reducing contrast, washing out faint stars, and distorting colors.

This issue poses a growing threat to professional observatories. The European Southern Observatory, for example, has raised concerns about new industrial development near Chile's Paranal Observatory, which may significantly increase skyglow around this substantial telescope site (9). Furthermore, recent analyses using satellite radiance data have revealed that many of the world's largest observatories have already exceeded critical thresholds of artificial sky brightness, defined as a 10% increase in skyglow above natural levels (10). While numerous studies have examined the impact of light pollution on star visibility, fewer have specifically analyzed its effects on astrophotography (11-13).

To assess the effects of light pollution on astrophotography, we examined several metrics, including star count, brightness levels, positional information, and environmental conditions. We investigated how light pollution affects the visibility and contrast of celestial objects in astrophotography. By using images of the Milky Way taken on the same night, in both high and low light pollution environments, we analyzed the brightness, contrast, and visible stars on many scales. We hypothesized that increased light pollution significantly reduces contrast and visibility in astrophotography and visual astronomy, making it harder to see and capture celestial objects clearly. Our results demonstrated that higher levels of light pollution decrease the number of visible stars and reduce contrast in visual astronomy, making it more challenging to capture them in images during astrophotography. These findings highlight the importance of preserving dark sky environments for astronomical observations and reinforce the need for light pollution mitigation efforts.

RESULTS

To evaluate the impact of light pollution on astrophotography and visual astronomy, we captured images of the Milky Way on the same night, using the same camera and identical settings, from two locations with differing levels of artificial light, approximately 62 kilometers apart. The first imaging session was conducted in an urban environment with significant light pollution (Bortle Class 7.6), while the second took place in a rural location with minimal artificial lighting (Bortle Class 4.4). The urban environment had a humidity of 64% and temperature of 17°C, while the urban area had 77% humidity and 15°C. Wind speeds remained low (4-6 km/h), and barometric pressure was consistent at 1020 mbar in both locations. In the high-light pollution environment, the artificial light was visible to the naked eye as a yellowish glow, covering most of the night sky (**Figure 1**). The artificial glow led to reduced contrast and fewer visible stars. The Milky Way was not visible in this image, although it was expected to be present based on Stellarium, the app used to locate it (14). The higher levels of light pollution obscured its visibility, making it undetectable. On the other hand, the rural location with low light pollution yielded a much darker sky and stronger contrast, allowing the Milky Way to be clearly seen with the naked eye. This highlights how artificial lighting can severely interfere with astrophotography and visual astronomy (**Figure 1**).

Background extraction analysis: assessing light pollution's impact on image contrast

To enhance image quality, we used Siril: An Advanced tool for Astronomical Image Processing. In Siril, we stacked images from each session into a single composite. We used background extraction and histogram transformation to compare brightness levels and color distortions in both environments (15).

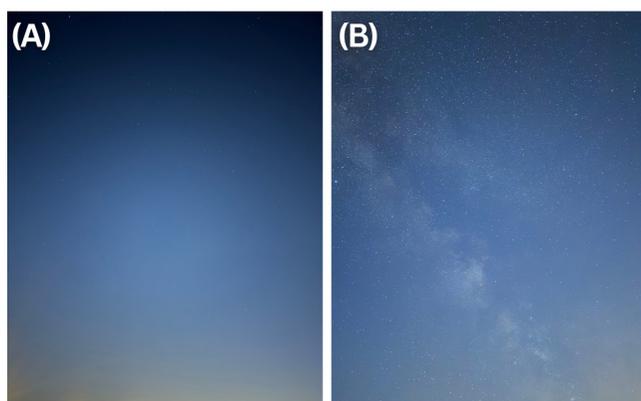In the image from the rural area, the background extraction successfully removed most of the artificial glow, making the Milky Way's structure more detailed and contrasted (**Figure 2**). Alternatively, in the image captured in the urban environment, the light pollution was so intense that the background extraction could not fully remove it, resulting in numerous rainbow-like light pollution artifacts. This not only resulted in significant pixel damage and uneven color bands across the sky, but also distorted the visibility of the Milky Way, appearing more like a faint, featureless cloud (**Figure 2**).

To further enhance image quality, we applied histogram transformation, which balanced brightness levels and increased contrast. In the rural image, the process revealed more contrasted stars and emphasized the Milky Way's structure, making it appear more vivid and defined. In contrast, the urban image showed limited improvement, as the artificial light left the Milky Way featureless and made the light pollution gradients more visible.

Image localization and constellation mapping

To accurately determine the photographed region of the night sky, we uploaded the background-extracted images into an astronomical analysis program (astrometry.net) and used its mapping feature. The tool identified the central coordinates of both photographs: the urban image was centered at RA 18h 13m 35.165s, Dec +02° 50′ 13.925″, while the rural image was centered at RA 18h 26m 48.850s, Dec +03° 40′ 28.565″. The program also provided additional data, such as field of view, pixel scale, and orientation point, along with four images: two showing the original photographs with highlighted constellations, and two sky maps marking the exact sky regions captured in each image (**Figure 3**). These data confirmed that both images were capturing the same region of the sky and allowed for an informed comparison between the urban and rural views, in the context of artificial lighting affecting the same area of the night sky in different seeing conditions.
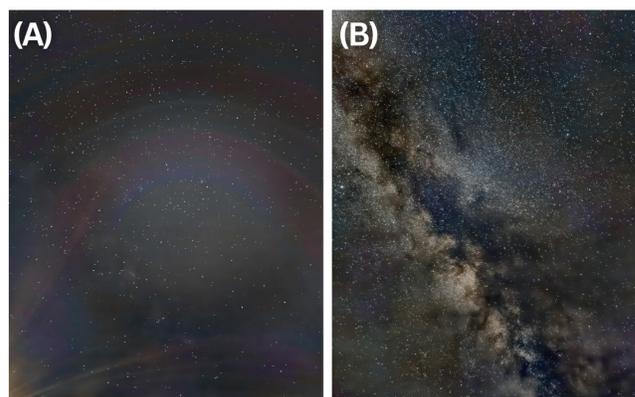

Figure 1: Single raw images of the Milky Way taken in high light pollution (urban) and low light pollution (rural) environments. A) Picture captured in the high-light-pollution area was taken in an urban location. Artificial light created a yellowish glow visible to the naked eye, originating from the city center, located 3 km away. B) Picture captured in the low-light-pollution area was taken in a rural location, with the nearest source of artificial light approximately 31 km away. The only visible glow appeared near the horizon, above the nearest source of artificial light.

Figure 2: Background extraction effectiveness in stacked urban and rural images. Background extraction, stacking, and histogram transformation were performed on images taken in both urban and rural environments. Each image is a composite of 13 images. A) In the urban image, the intense artificial brightness overwhelmed the background extraction process. B) In the rural image, nonetheless, most of the artificial glow was removed, revealing greater details in the Milky Way's structure.

Estimating the number of stars and visual clarity

To further assess the impact of light pollution, we compared astronomical images from rural and urban areas using Siril's StarNet tool. This process extracted visible stars, creating a starmask (detected stars and their count) and a starless image (original with stars removed), highlighting differences in Milky Way visibility.

The starmask results showed a large difference in the number of stars detected. The rural image contained 11,425 stars, while the urban image revealed only 663 (**Figure 4A-B**). Subtracting the urban count from the rural count showed an outstanding difference of 10,762 more stars captured in the rural environment.

The starless images further demonstrated this contrast. The rural image displayed rich, deep colors across the Milky Way, while the urban image appeared faint and colorless, heavily affected by artificial lighting. The urban sky showed a whitish, cloudy overlay in several areas, obscuring the Milky Way and limiting celestial visibility (**Figure 4C-D**). These findings strongly demonstrate the negative impact of light pollution on our ability to observe and photograph the night sky.

Comparing the brightness levels by using a magnitude scale

Using the Stellarium application, we identified one of the faintest stars visible in the image taken in the urban area, HD

176076, which had a magnitude of 7.56 (**Figure 5**). On the magnitude scale, lower magnitude numbers represent brighter objects, while higher numbers indicate fainter ones. We also examined one of the faintest stars visible in the picture taken in the rural area, TYC 5118-348-1, with a magnitude of 11.38 (**Figure 5**).

We were able to calculate the difference between these two stars' magnitudes as 3.82 (on the magnitude scale). Thus, the faint star captured in the urban environment (HD 176076) was 30.73 times brighter than the faint star from the rural area (TYC 5118-348-1), meaning that many stars with a magnitude higher than 7.56 were not visible in the urban area, but markedly visible in the rural area (**Figures 5 and 6**).

Quantitative analysis of sky brightness

To obtain quantitative data on sky brightness, we used a couple of up-to-date light pollution maps, including those from lightpollutionmap.app and lightpollutionmap.info. Environmental conditions such as humidity, temperature, wind speed, and visibility were recorded in both locations (**Table 1**). They remained relatively stable between locations, minimizing differences in the quality of observations and capturing both night skies. The Sky Quality Meter (SQM), which refers to the brightness of the night sky overhead (at the zenith), was measured at 18.58 mag/arcsec² in the
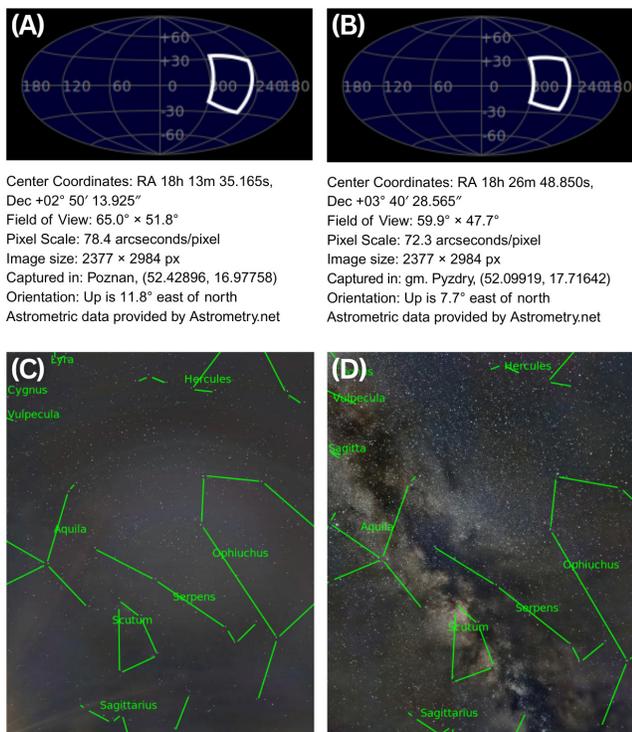

Center Coordinates: RA 18h 13m 35.165s, Dec +02° 50′ 13.925″
Field of View: 65.0° × 51.8°
Pixel Scale: 78.4 arcseconds/pixel
Image size: 2377 × 2984 px
Captured in: Poznan, (52.42896, 16.97758)
Orientation: Up is 11.8° east of north
Astrometric data provided by Astrometry.net

Center Coordinates: RA 18h 26m 48.850s, Dec +03° 40′ 28.565″
Field of View: 59.9° × 47.7°
Pixel Scale: 72.3 arcseconds/pixel
Image size: 2377 × 2984 px
Captured in: gm. Pyzdry, (52.09919, 17.71642)
Orientation: Up is 7.7° east of north
Astrometric data provided by Astrometry.net

Figure 3: Image localization and constellation mapping of rural and night sky photographs. The precise sky regions captured in the (A) urban and (B) rural images, respectively. (C) Stacked and (D) background-extracted photographs, overlaid with constellations such as Aquila, Serpens, Ophiuchus, and Sagittarius.
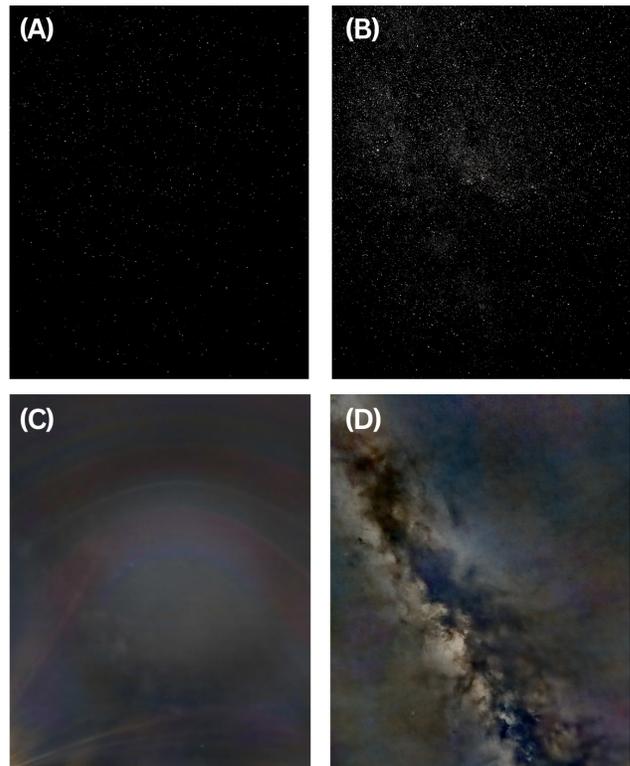

Figure 4: Star count and Milky Way visibility in rural vs. urban skies. The starmasks produced by Siril from (A) urban and (B) rural background-extracted sky images. (C) The urban starless image displays a washed out, faint, obscured by artificial light Milky Way, while the (D) rural image starless image displays vibrant, colorful Milky Way structures. Starless images emphasize differences in sky clarity and Milky Way visibility.

Feature	High light pollution (Urban)	Low light pollution (Rural)
Humidity (%)	64	77
Temperature (°C)	17	15
Barometric pressure (mbar)	1020	1020
Wind speed (km/h)	4	6
Sky quality meter (mag/arcsec²)	18.58	21.16
Radiance (nW/cm²)	82.21	00.00
Bortle class	7.6	4.4
Elevation (m)	64	76
Milky Way visibility	Barely visible	Visible with clear contrast
Number of captured stars	663	11,425
Approximate maximum magnitude of the visible stars	7.56	11.38

Table 1: Sky brightness measurements for urban and rural location. The urban location represents an area of high light pollution, while the rural location represents an area of low light pollution.

urban area, compared to 21.16 mag/arcsec² in the rural area, showing that the rural sky was noticeably darker (**Table 1**). The elevation at the urban site was approximately 64 meters, while the rural area was at 77 meters, ensuring a fair comparison between them, especially considering that a lower elevation can be a contributing factor to light pollution (16). Radiance, or the amount of light that reflects from the ground, nearby surfaces, and clouds, was measured at 82.21 nW/cm² in the urban location and 00.00 nW/cm² in the rural location (**Table 1**). Additionally, the Milky Way was almost completely absent from the urban sky but appeared with clear structure and colors in the rural setting. These findings confirm that light pollution dramatically reduces the visibility of celestial objects, reinforcing the importance of dark sky preservation for both amateur and professional astronomy.

DISCUSSION

We aimed to investigate the effects of light pollution on the visibility and contrast of celestial objects in astrophotography and visual astronomy. Our results were consistent with our hypothesis, showing that higher levels of artificial light significantly reduce both contrast of celestial objects and the number of visible stars.

While taking the photographs, the difference in artificial brightness between the two locations was immediately visible. In the urban location (Bortle Class 7.6), the sky was heavily illuminated by artificial light. Only one or two stars were visible to the naked eye, and the Milky Way was clearly not visible. In contrast, at the rural site 62 kilometers away (Bortle Class 4.4), the sky was notably darker, with thousands of stars visible to the naked eye, and the Milky Way clearly observable. These visual differences were confirmed by the processed images: in the urban photographs, the sky remained bright with low contrast and minimal star visibility, whereas the rural images revealed a dark background, higher contrast, and a distinctly visible Milky Way. The SQM was significantly higher in the rural area (21.18 mag/arcsec²), compared to the urban area (18.58 mag/arcsec²). The difference of 2.58 mag/arcsec² indicates a much brighter urban sky, aligning with the reduced star visibility and lower contrast observed in the images. This contrast highlights how even minor changes in SQM values can significantly affect the night sky. The comparison between rural and urban images revealed a major loss of visible stars under light-polluted sky. In the urban images,

many fainter stars that were clearly visible on the rural images were not visible, confirming that increased artificial brightness substantially reduces the visibility and richness of the night sky.

These findings corroborate our hypothesis that light pollution limits the ability to observe and photograph celestial objects and draw attention to the need for mitigation strategies, such as shielded lighting and reduced urban illumination, to preserve dark skies for research and astrophotography. Furthermore, they underscore the importance of dark-sky locations for astrophotographers and amateur astronomers seeking optimal imaging conditions. However, while the results of our research support the conclusion that light pollution reduces sky contrast and visibility, they do not represent the exact relationship between artificial brightness and object detectability under all conditions.

The visibility of celestial objects is influenced by both human and environmental factors, beyond light pollution. Technical aspects, such as camera sensitivity and exposure settings, play a key role in determining how faint objects appear in images. More sensitive sensors can capture dimmer stars and preserve color accuracy, while long exposure photography allows more light to reach the camera, enhancing detail but increasing the risk of motion blur (17, 18). To minimize these effects, we used identical camera settings and a tripod in both locations. Environmental conditions also impact image quality and data interpretation. Atmospheric turbulence can blur star shapes, making it harder for astronomic image analysis software to detect them, while cloud cover may obscure stars and alter brightness readings. High humidity increases light scattering, making celestial objects appear dimmer. Although these variables were not major sources of variation in this study, they remain important considerations in astrophotography and may still contribute to minor inconsistencies in brightness, contrast, and star
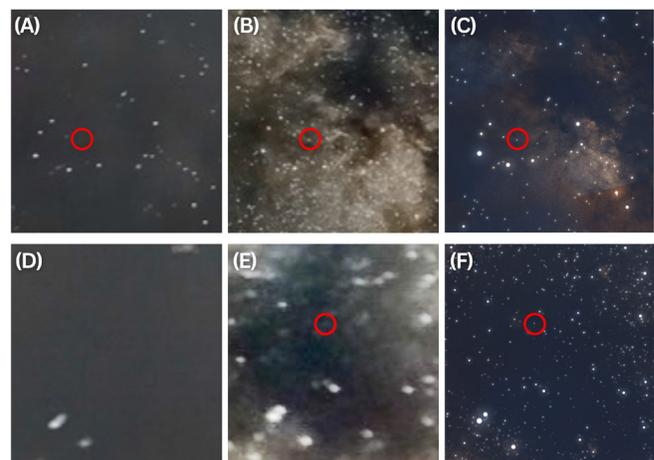

Figure 5:Comparison of the faintest visible stars in rural and urban images. (A) shows HD 176076 (magnitude 7.56), the faintest star detected in the urban environment. The same star captured in the (B) rural area and (C) on the Stellarium app, respectively. (D) Illustrates the absence of TYC 5118-348-1 (magnitude 11.38), the faintest star visible in the rural image, from the urban image, due to light pollution. (E) Shows the faintest star visible in the rural image, and (F) illustrates the same star on the Stellarium app.
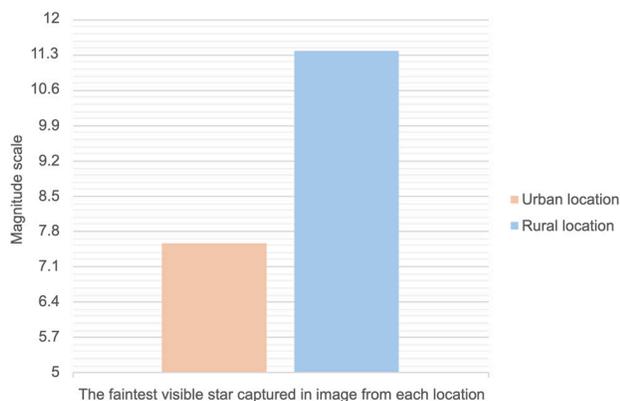
Figure 4: Comparison of the faintest visible stars captured in rural and urban areas. The approximate maximum magnitude of stars captured in both environments. The faintest star in the urban image, HD 176076, had a magnitude of 7.56, while the faintest star in the rural image, TYC 5118-348-1, had a magnitude of 11.38.

visibility. In addition, the elevation difference between the two sites (64 meters in the urban location vs. 77 meters in the rural one) likely played a minor but supporting role. Although not drastically different, higher elevation tends to reduce atmospheric scattering and light interference, contributing to a darker sky in the rural area.

In the next phase of this research, the objectives could be the spectral composition of artificial light and its influence on celestial visibility. Investigating the way specific wavelengths produce skyglow might help one understand focused mitigating techniques. Future research could also examine the impact of atmospheric factors, such as humidity, air pollution, cloud cover, and altitude, on the consequences of light pollution. In particular, long-term monitoring under varying weather conditions could help clarify how these environmental variables affect the visibility of celestial objects.

MATERIALS AND METHODS
Image acquisition

Thirteen images of the Milky Way were captured on the same night at two locations approximately 62 kilometers apart. The imaging sessions were conducted an hour and three minutes apart. All images were taken using an iPhone 15 Pro (Apple Inc.) equipped with a 24 mm camera lens, stabilized with a tripod. The camera settings were identical during both imaging sessions: ISO 2500, aperture f/1.78, and a long exposure mode set to the maximum of 30.00 seconds. Each of the 13 images was captured without any interruptions, with exposure settings at 0.0.

The urban photographic session began at 11.17 PM on June 30, 2025 and finished about 11.23 PM. Images were captured near Bałtycka, Poznań, Poland (52.42896, 16.97758), classified as Bortle Class 7.7. The yellow glow visible in the images was caused by artificial light from the city center, located approximately 3 kilometers away and classified as Bortle Class 8.9. The rural images were taken at 12.20 AM on July 1, 2025, in an open area surrounded by fields and forests in Gmina Pyzdry, Poland (52.09919, 17.71642),

classified as Bortle Class 4.4. The session ended around 12.26 AM. The nearest major source of light pollution was the town of Jarocin, located 31 kilometers away and classified as Bortle Class 5.6. In this study, during observations and capturing pictures of the night sky, visibility was 16 km at both locations. An astronomical app, Stellarium, was used to determine the optimal time and sky location for capturing the Milky Way (14). The app was properly calibrated based on geographic location and time zone to ensure both images were centered on the same region of the sky.

Image processing and enhancement

To reduce noise caused by satellites, airplanes, or atmospheric interference, and to improve clarity, both sets of 13 photographs from each location were stacked into a single composite image using Siril, a free astronomical image processing software (15). The images were stacked independently for each site.

To minimize the effects of light pollution, background extraction in Siril was applied. The background extraction process was performed with the radial basis function (RBF) interpolation method. The RBF is a flexible tool that removes gradients during the background extraction process. Background extraction is a key technique in astrophotography, allowing for the removal of artificial skyglow and revealing how much light pollution has washed out contrast, stars, sensor noise, and other celestial bodies (19, 20). During the background extraction process for both images, smoothing was set to 80, samples per line to 60, and grid tolerance to 2.00, producing 60 red background samples per line. Attention was paid to remove any background samples overlapping with bright stars before computing the final background model. This step effectively eliminated gradients caused by artificial lighting.

In the initial step, histogram transformation was performed to improve contrast and overall visibility. In Siril, this was done manually by manipulating the histogram slides. Although the histogram interface does not display numerical values, careful and consistent adjustments were made to ensure similar contrast and brightness levels across both urban and rural images.

Data collection and image analysis

Quantitative sky brightness data were obtained using two online light pollution maps: LightPollutionMap.app, which provides Bortle Class and Sky Quality Meter (SQM) values using 2024 data; and LightPollutionMap.info with the VIIRS 2024 overlay (5, 21). Both maps feature search bars where we entered the exact coordinates of our observation areas, which were obtained by saving pins from each location using Google Maps (22). LightPollutionMap.app provided Bortle Class and SQM values, while LightPollutionMap.info supplied radiance and elevation data for both urban and rural sites. Weather data from both sessions was gathered from TimeAndDate.com, which reported humidity levels, wind speed, temperature, and barometric pressure for the exact observation times (23). To quantify the number of stars visible in the images, StarNet removal process was performed individually on each stacked image using Siril. Siril produced two outputs for a starmask and a starless image.

The starmask displays only the detected stars as white points on a black background, based on the software's identification of bright point sources. Siril then counts the stars by noting the detected point sources in the starmask and reports the total number in the command line output. The starless image contains the background sky with the stars removed. To identify the faintest stars in both images, the Stellarium app was used (14). By setting the precise date, time, and location, the app revealed an interactive sky map of that area at the exact time. After identifying a faint star in the urban location image, the exact same star was found and selected on the Stellarium app. The app then provided details about the star, including its name, magnitude, hour angle, and constellation. The same procedure was repeated with the faint star detected in the rural image.

To confirm that the two images captured the same region of the night sky, and to obtain detailed technical data about each photograph, the astrometry.net website was used (24). It provided the center coordinates (RA/DEC), field of view, pixel scale, image size in pixels, and orientation point for each image. Additionally, astrometry.net generated images showing the originally uploaded images with constellation overlays and produced corresponding sky maps, which showed exactly which parts of the night sky were photographed in the urban and rural areas.

Analysis of sky brightness

The difference in sky brightness (82.21 nW/cm^2 - 00.00 nW/cm^2) was calculated based on data from LightPollutionMap.info (5). The magnitude scale is used by astronomers when measuring the brightness of a star. A change of five magnitudes equals a difference in brightness by a factor of 100 (25). This means that a star with a magnitude of 1 shines 100 times more brightly than one with a magnitude of 6. Each step in magnitude represents a brightness change of approximately 2.512 times (26). This relationship is logarithmic and can be described by this formula: $\Delta m = -2.5*\log(1/x)$, where Δm is the difference in magnitudes between the two faint stars. To calculate how much brighter the faint star appears when captured in the urban environment (HD 176076) compared to the rural environment (TYC 5118-348-1), the difference between both faint stars' magnitudes (11.38 - 7.56 = 3.82) was used and applied into the logarithmic formula: 11.38 - 7.56 = $-2.5*\log(1/x) \approx 30.73$.

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