DOI: 10.62897/COS2025.3-1.201

10-12, November 2025, Győr

SPECTRAL AND PHOTOMETRIC ANALYSIS OF SELECTED STREETLIGHTS

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Artificial extension of daylight represents one of the key needs of modern society, especially during the winter months when daylight hours are shorter than nighttime. Artificial lighting enables increased productivity in the evening and at night, supports recreational activities, and facilitates the effective use of leisure time. In addition, it significantly contributes to the perception of safety. Despite its numerous advantages, artificial light also has negative effects. Among the most significant are the deterioration of sleep quality, a reduction in local biodiversity, and increased stress levels in both nocturnal and diurnal animal species. In this case study, eleven roadside luminaires located on the Gosposvetska student campus in Maribor, Slovenia were analysed. For each luminaire, consecutive light spectra were recorded and subsequently averaged to reduce measurement error. At the same time, three repeated brightness measurements were performed. The results revealed differences among the eleven analysed luminaires that can be classified into two groups: broad-spectrum cold-white LED sources and narrow-band discharge-type light sources. Measured brightness values ranged from 7.22 to 10.71 mag arcsec-2. The collected data provide a basis for further analysis of the effects of artificial light on living organisms and contribute to a better understanding of the ecological consequences of light pollution.

1. Introduction

The natural nighttime environment has undergone significant changes over the past century due to the introduction of streetlights and other sources of artificial light (Sánchez De Miguel et al., 2022). This has led to increased levels of light pollution, defined as excessive or improperly directed artificial light at night (Puschnig et al., 2022). Artificial light at night (ALAN) has become a widespread phenomenon, predominantly present in urban and industrial areas, but increasingly extending along transport corridors and into rural environments (Borges, 2022). The ubiquity of ALAN – encompassing variations in intensity, spectral composition, light dispersion and duration of exposure – substantially alters natural light cycles and represents a serious environmental threat to ecosystems worldwide (Bará et al., 2023; Hirt et al., 2023; Levy et al., 2024). The extensive use of artificial lighting, ranging from streetlights and advertising billboards to industrial facilities, and in winter, ski resorts, has transformed the nighttime landscape to such an extent that these changes are clearly visible from satellites in orbit (Al-Naggar et al., 2022; Gaston et al., 2022).

The natural alternation of light and darkness is essential for the proper functioning of biological systems, from the molecular level to entire ecosystems. The stability of light cycles is particularly important for organisms whose life processes are closely regulated by photoperiodic signals (Falcón et al., 2020; Sanders et al., 2022). Artificial light at night disrupts the behavioural patterns and physiological processes in many animal and plant species. It also significantly affects humans by disrupting circadian rhythms, reducing melatonin production, and impairing conditions for astronomical observations (Aubé, 2015; Jamal, Falak et al., 2022; Bará et al., 2023).

The effects of ALAN include disruptions in spatial and temporal orientation, alterations in behavioural patterns, reduced sleep quality, psychological impacts, decline in biodiversity, and changes in organisms growth and development. Prolonged exposure to artificial light at night disturbs the natural balance of ecosystems and threatens their long-term stability (Falcón et al., 2020). Light pollution also significantly affects ecological interactions. Certain plant species rely heavily on nocturnal pollination, which is disrupted by artificial lighting. Consequently, their reproductive success declines, leading to broader ecosystems imbalances. The cumulative effects of light pollution may reduce biodiversity, particularly among species unable to adapt to increased light levels. Such species may be displaced into marginal habitats where light exposure is lower. While mobile species may relocate, sessile organisms are forced to adapt rapidly or face local extinction (Onu, 2025).

A particular challenge is posed by the spectral characteristics of modern street lighting, especially the widespread adoption of LED technology. LED luminaires often contain pronounced blue light components, which may exert disproportionately strong biological and ecological effects compared to conventional lighting technologies (Evans, 2023; Hirt et al., 2023). Such alterations of natural light cycles represent a significant stressor for biodiversity and affect nighttime environmental conditions across large geographical areas (Bará et al., 2023).

Different spectral compositions of street lighting affect organisms in different ways. Most terrestrial organisms, including humans, perceive light within the 400-700 nm range, defined as visible light. However, certain groups, such as aquatic organisms, birds, and insects, have developed specialised sensory adaptations. Birds and insects are often more sensitive to ultraviolet (UV) and blue wavelengths, whereas many aquatic organisms are particularly responsive to wavelengths between 450 and 500 nm, which can penetrate deeper into the water column. Some species are also capable of detecting infrared radiation, including certain reptiles, insects, and aquatic organisms. Light is a fundamental driver of key biological processes, particularly photosynthesis, which underpins most food webs and sustains atmospheric oxygen levels essential for aerobic life. This process relies on two main photosystems: photosystem II (PSII), with peak absorption around 680 nm, and photosystem I (PSI), with peak absorption around 700 nm. Consequently, light plays a central role in numerous photobiological and photochemical processes that support the functioning and stability of the biosphere (Staff, 2023). In addition to its effects on circadian rhythm, exposure to blue spectrum of light has been associated with increased production of reactive oxygen species (ROS), which can contribute to oxidative stress and inflammation in biological systems (Staff 2023). Despite the growing awareness of these impacts, defining threshold levels of artificial light that remain acceptable for living organisms while preserving the societal benefits of lighting remains a major challenge. Further research is therefore needed to better understand the effects of different spectral compositions, particularly in interaction with other environmental stressors.

The aim of this study was to conduct a preliminary assessment of the spectral characteristics and photometric parameters of public lighting within a selected area, using spectrometric analysis and photometric brightness measurements obtained with a Sky Quality Meter (SQM). By combining these measurement approaches, we sought to determine the spectral signatures of the light sources and the variability in emitted light intensity in the surrounding environment. The resulting data enable the identification of differences among lighting technologies and provide a basis for further investigation of the effects of artificial light on living organisms.

2. Methodology

2.1 Location

Measurements were carried out on eleven roadside luminaires within the Gosposvetska student campus in Maribor, Slovenia (Figure 1). The study area included roadside lighting in the vicinity of the student campus on Gosposvetska cesta, where residential areas, traffic infrastructure, and zones with high pedestrian traffic intersect. The location was selected due to the presence of various types of street luminaires, enabling a comparative analysis of spectral characteristics in an urban environment.

Measurements of spectral characteristics and light intensity of roadside lighting were conducted in October 2025, between 6 and 7.30 PM, under dark evening conditions with negligible twilight contribution. The time window was selected to ensure a representative assessment of evening lighting conditions, corresponding to the period of highest human exposure to artificial light in urban environments. During measurements, sky conditions were clear, with no precipitation or fog, ensuring minimal atmospheric scattering.

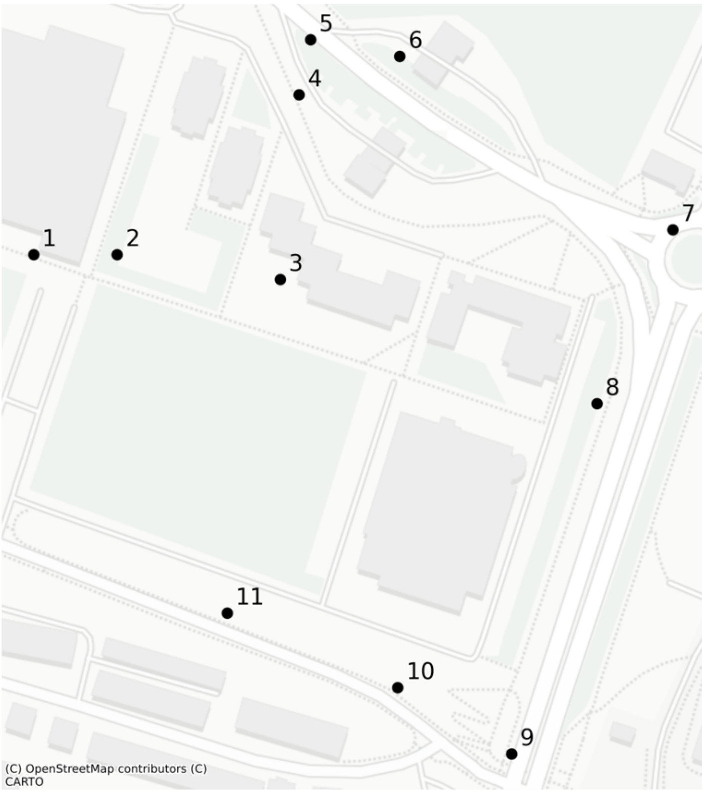

Figure 1: Measurement locations. The numbered points indicate luminaires at which the measurements were performed

2.2 Spectrometry

A portable spectrometer Vernier Go Direct UV-VIS with an attached fibre optic probe was used to analyse the spectral composition of street lighting (Vernier, n. d.). Measurements were performed by positioning the device directly beneath the selected street luminaire, with the fibre optic oriented vertically upward toward the light source. All measurements were taken at a height of 2 m above the ground. Prior to data acquisition in the Vernier Spectral Analysis software, the device was preheated to stabilize the CCD detector. Ten spectral measurements were recorded for each luminaire. The resulting emission spectra, ranging from 220 nm to 850 nm, were used to identify characteristic spectral features of the different types of lamps.

The spectrometer data were processed by averaging the ten relative intensity measurements at each wavelength, and measurement error was calculated. This procedure minimized the effects of random detector noise and short-term fluctuations in the power supply of the light sources. Using the processed data, graphs of relative intensity versus wavelength of light were generated for all luminaires, and spectral peaks of each lamp type were determined.

2.3 Photometry

Although not designed for direct luminaire measurements, the Unihedron SQM-L (Sky Quality Meter – Lens) was used as an approximate indicator of local brightness. The device employs a silicon photodiode sensor and an integrated lens that limits the field of view to approximately 20° (Welch et al., n. d.), allowing for directional measurements of the brightness of a specific part of the sky or the immediate vicinity of a light source. Although the SQM-L is primarily designed to measure night sky brightness, in this study it was used to measure the directional brightness of individual streetlights and their immediate vicinity.

The SQM-L reports a logarithmic measure of angular sky brightness in units of mag arcsec-2, representing apparent magnitude per square arc second. The apparent magnitude (m) of a light source is related to the radiance (j) emitted by that source. The relationship between the magnitudes of two lights m_1 and m_2 and their corresponding radiance j_1 and j_2 is described by Equation 1:

$$\mathbf{m_1 - m_2 = -2.5 \cdot \log \frac{j_1}{j_2}} \quad (1)$$

Lower mag arcsec^2 values correspond to higher brightness. Because the SQM spectral response differs from the human photopic response and from laboratory radiometric instruments, SQM-L values should be interpreted as relative broadband brightness indicators rather than as direct measurements of illuminance or radiance.

3. Results with discussion

The analysed roadside luminaires exhibit differences in spectral composition, indicating that the lighting system in the selected urban area is not uniform. Based on the analysis, we can classify luminaires into two main groups: broad-spectrum white LED sources and narrow-band discharge-type light sources.
The spectrum of luminaire 3 (Figure 2) is characterized by one pronounced peak at approximately 440 nm and a broader emission between 500 nm and 650 nm, with a maximum around 580 nm. This spectral profile is typical of cool-white LED lighting, specifically of phosphor-converted white LEDs (Pimputkar et al.,

2009). The relatively high intensity of the blue peak is particularly relevant, since it has been associated with stronger effects on circadian rhythms and nocturnal organisms (Levy et al., 2024). A similar spectral structure was observed for luminaire 8 (Figure 3), with a dominant peak at 460 nm and a secondary broad maximum around 580 nm. Compared to luminaire 3, the overall intensity of the emission is lower, but the spectral profile remains consistent with white LED. Despite their different geometries, luminaire 3 being flat and downward-tilted, and luminaire 8 spherical and shielded, their spectral profiles are similar.

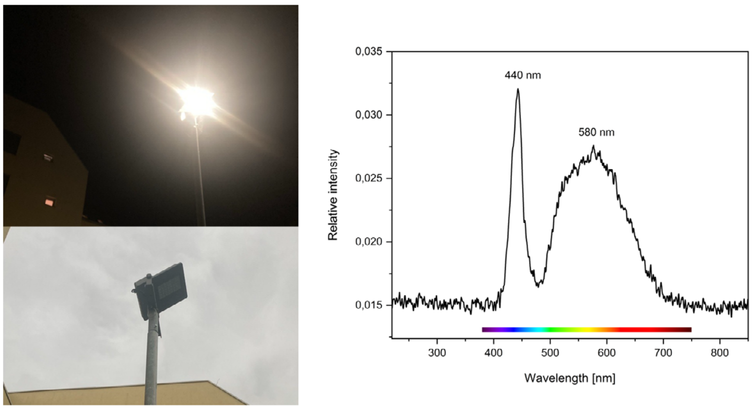

Figure 2: Luminaire 3 in nighttime and daytime and its emission spectrum showing dominant blue peak at 440 nm, characteristic of cool-white LED

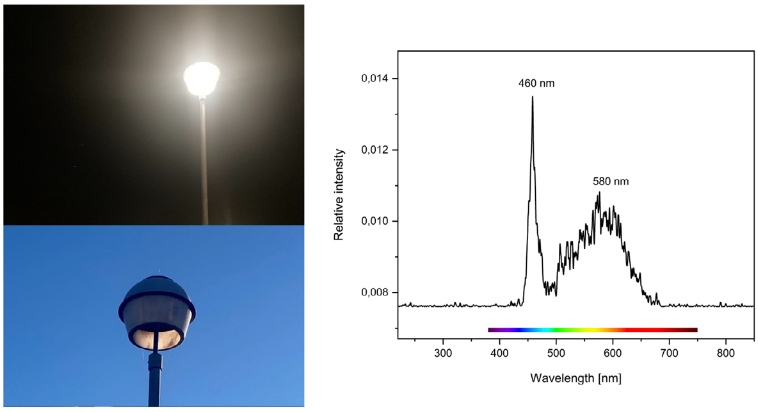

Figure 3: Luminaire 8 in nighttime and daytime and its emission spectrum showing dominant blue peak at 450 nm

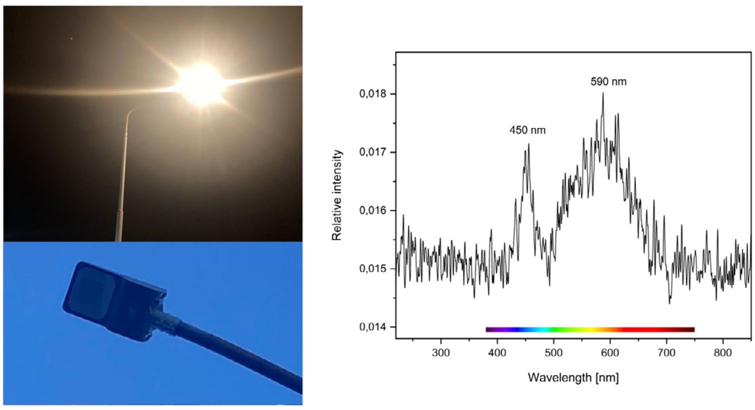

Figure 4: Luminaire 6 in nighttime and daytime and its emission spectrum, which is noisier than others, with smaller peak at 450 nm and broader at approximately 590 nm

A fundamentally different spectral profile is observed for luminaire 10 (Figure 5), which exhibits several narrow emission lines, with dominant peaks at approximately 570 nm and 600 nm. This line-dominated spectrum is characteristic of high-pressure sodium or similar discharge lamps (Elvidge et al., 2010). Unlike LED sources, this type of lighting has minimal emissions in the blue region, resulting in a warmer spectral output. While such spectra are generally considered less disruptive to circadian systems, they may still affect ecological processes due to their high intensity and strong emission in the yellow-orange region.

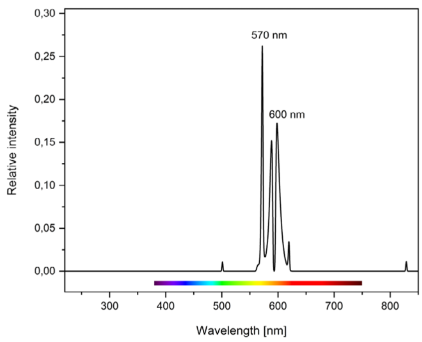

Figure 5: Luminaire 10 in daytime and its emission spectrum exhibiting narrow emission lines typical for discharge lamps

Photometric measurements of luminaires are summarized in Table 1. Measured brightness values ranged from 7.22 mag arcsec-2 to 10.71 mag arcsec-2. These measurements were obtained under varying geometrical conditions (e.g., differing luminaire heights, orientations, and measurement angles) and therefore do not represent directly comparable intrinsic properties of the light sources, but rather local brightness conditions in their immediate vicinity.

Table 1: Measured brightness values of luminaires. L represents the luminaire, and the number indicates the sequential number

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11
m (mag arcsec $^{-2}$)	8.21	10.71	7.22	7.81	8.93	8.41	10.24	8.31	10.18	8.72	10.09

Overall, the results demonstrate that the lighting system in the study area is spectrally heterogeneous, comprising at least two distinct lighting technologies. The coexistence of blue-rich white LEDs and narrow-band sodium-type lamps leads to spatial variability in both spectral composition and potential ecological impact. From an environmental perspective, this inconsistency is significant, as the biological effects of artificial light depend not only on intensity but also strongly on wavelength distribution. The presence of luminaires with pronounced blue emission suggests a higher potential for disruption of circadian rhythms and nocturnal ecosystems in parts of the study area.

4. Conclusions

The results of the preliminary analysis showed that artificial nighttime lighting in the study area is heterogeneous both in terms of the types of luminaires used and their spectral characteristics. The observed inconsistent application of different technologies, including luminaires with a notably high proportion of blue light, underscores the need for systematic management of public lighting. Such inconsistency can substantially contribute to increased light pollution and the associated negative ecological and health effects. The findings of the study highlight the importance of a holistic approach to the planning and regulation of artificial lighting, which should consider both spectral characteristics and light intensity in real environmental conditions. Further research conducted across a larger number of locations will be crucial for understanding the long-term impacts of light pollution on organisms, ecosystems, and human health. The collected data provide an essential foundation for developing guidelines that enable the mitigation of negative effects of artificial light while maintaining its social benefits.

Acknowledgements

Additional affiliations of the co-authors are as follows: Mitja Slavinec: Scientific Union of Pomurje Region, Murska Sobota, Slovenia. Eva Klemenčič: Institute of Energy Technology, Faculty of Energy Technology, University of Maribor, Krško, Slovenia.

This work was supported by the Slovenian Research Agency in the framework of the research program P1-0403 and P1-0192, and by the project Adrisky - Advancing Light Pollution Mitigation for Biodiversity and Nocturnal Habitats Conservation in the Adriatic-Ionian Region, cofinanced by Interreg IPA Adrion.

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