ARTICLES

LIGHT POLLUTION IN SLOVENIA IN 2019 WITH SPECIAL REGARD TO NATURA 2000 AREAS

AUTHOR
Igor Žiberna
Department of Geography, Faculty of Arts, Koroška cesta 160, SI - 2000 Maribor, Slovenia. E-mail: igor.ziberna@um.si

UDC: 911.3:504(497.4)"2019"

ABSTRACT
Light pollution in Slovenia in 2019 with special regard to Natura 2000 areas
The article shows the state of light pollution in Slovenia. Remote sensing data from the Suomi satellite were analysed. Light pollution is shown by radiance expressed in nW/(sr cm^2). In Slovenia, there are large differences in state of light polution. The most polluted areas are located in the area of larger settlements and in areas with higher levels of infrastructure. The spread of light does not stop at the borders of protected areas, so we also analyzed the state of light pollution in Natura 2000 sites in Slovenia. It turns out that the most light-polluted areas are those that lie around larger settlements or suburbanised regions (Ljubljansko Barje, Šmarna gora, Drava).

KEY WORDS
Light pollution, radiance, Natura 2000, Slovenia.

1. Introduction

Humanity has used different ways of illuminating the environment in the night time since prehistory. At first, there were the dominance of oil lamps, but from the 19th century onwards they were slowly being replaced by gas lamps. More intensely, artificial light has started to be used at night since the invention of electric lamps. In the 20th century, the latter appeared in various versions (Mizon, 2012). Today, the problem with night illumination is not only the intensity of the lamps, but also their spectrum. LED lamps, which have been expanding in recent times, are more energy efficient, but because their light is more intensive in the blue part of the spectrum, they leave much greater spatial impact. According to Raylegh's law, scattering in all directions by an object is inversely proportional to the fourth power of the wavelength of the illumination. In other words, scatering of the blue light (with a wavelength of 400 nm) is 16 times more intense in the atmosphere than scatering of the red light (with a wavelength of 800 nm) (Petkovšek Hočevar, 1995).

The problems caused by the mass use of lamps were among the first to draw attention to amateur and professional astronomers, later ecologists, today medicine also draws attention to the negative effects of mass use of night-time lamps. Exposure to artificial light interrupts the production of the hormone melatonin, which makes people more vulnerable to the dangers of various forms of cancer (Falchi et al., 2011; Pauley, 2004). Excessive use of night-time lamps also represents an important source of energy consumption (Light pollution and..., 2010).

Analysis of satellite imagery in the night channel shows that 83% of the world's and 99% of European residents live in a light-polluted night environment (where the sky lights exceed 14 µcd/m2). Due to the light-polluted night sky, a third of the world's population, 60% of Europeans and 80% of the population of North America, are deprived of the view of Milky Way. The most polluted countries are Singapore (100% of the population lives in light-polluted night conditions), Kuwait (98%), Qatar (97%), The United Arab Emirates (93%), Saudi Arabia (83%), South Korea (66%), Israel (61%), Argentina (58%) etc. The light least polluted areas are Greenland, where only 0.12% of the population lives in light-polluted night conditions, central African Republic (0.29% of the population), Somalia (1.2 %) and Mauritania (1.4%) (Falchi et. Al, 2016). The data can, of course, be misleading if we do not know how to interpret them and can be manipulated, yet they point to the fact that the economic performance of a country does not yet guarantee a quality living environment.

Light pollution also affects ecosystems, especially nocturnal animals (insects, bats, etc.) (Bruce-White and Shardlow, 2011; Huemer et al., 2010). Finally, but not least: light pollution also results in cultural ecosystem services

(Hölker et al., 2010) in urban and suburban environments, including the quality of the dark sky. As a result, the light-free night sky could be classified as a natural heritage that needs to be protected. The paper discusses the state of light pollution in Slovenia at the level of statistical regions and municipalities. Also we have placed special atention on the analysis of light pollution in protected areas of Natura 2000.

2. Methodology

Sky Quality Meter (SQM) equipments have been emerging on the market for more than 10 years, manufactured by Canadian company Unihedron and were adopted worldwide as a standardised way of measuring the light pollution. The advantage of using the SQM meter is very easy to use and instant access to data. The disadvantage of obtaining data with SQM is that the data is for point location. If we want to analyse the state of light pollution in the wider area, it is necessary to repeat measurements at a large number of locations in the area of interest, which can be time consuming. The development of remote sensing technology for individual environmental components has enabled the rapid retrieval of light pollution data for a wider area, as all data are georeferenced. In October 2011, the U.S. National Oceanic and Atmospheric Administration (NOAA) launched the Suomi National Polar-orbiting Partnership, or briefly Suomi NPP. Among the sensors mounted on the satellite is the Visible Infrared Imaging Radiometer Suite (or VIIRS), which consists of a set of 22 different sensors, one of which records the surface in a day/night band or DNB. The spatial resolution of the pixel in the nadir (a point on the Earth's surface located exactly below the satellite) is about 750 m x 750 m (Jensen, 2018).

The recording data is available on the website of the US Oceans and Atmosphere Agency (Network 1). Radiance values are expressed in nanowatts per steradian per square cm (nW/(sr cm^2)). One of the sensor's drawbacks is that it is a spectral light range that detects between 500 and 900 nanometers. The sensor is therefore "blind" to the extreme blue part of the visible part of the spectrum, in which most of the newer so-called "white" LED lamps, which in the last 15 years slowly replace high and low-pressure sodium lamps, which are on one hand less energy-efficient, but on the other hand they leave lower spatial effects from a spectrum perspective. Nevertheless, the Suomi NPP satellite data is currently the most high quality data in the day-night channel, both in terms of spatial and temporal resolution, as well as in terms of dynamic range of information on the state of light pollution. Data were collected at the monthly level for the period January 2019 – December 2019, and filtered for the area of Slovenia and for protected Natura 2000 sites. Most of the public infrastructure connected in one way or another to the lighting at night is the responsibility of municipalities and the values of the inhabitants of municipalities (and councillors in municipal councils) depends on what priorities they choose in maintaining and expanding public infrastructure, including public lighting as one of the most important sources of light pollution.

3. Light pollution in Slovenia in 2019 by statistical regions

The highest average radiance with 1.1864 nW/(sr cm^2) is recorded by the Osrednjeslovenska statistical region The very high average radiance can also be detected in the area of the Obalno-kraška statistical region with 1.1241 nW/(sr cm^2). In both cases, the high average values of the radiance are due to the urbanised area, but the impact of the enlightened public infrastructure should not be ignored, which is particularly pronounced in the case of Luka Koper. The lowest average radiance is in the Primorsko-Notranjska statistical region (0.3754 nW/(sr cm^2)) and the Koroška statistical region (0.4185 nW/(sr cm^2)). The lowest radiance was detected in the area of Jugovzhodna Slovenia in 2019 (Figure 1). The darkest pixel was located at 0.1425 nW/(sr cm^2) in the area of Veliki Rog in Kočevski Rog. The brightest pixel was detected in the area of Luka Koper (116.3858 nW/(sr cm^2)) (Figure 2).

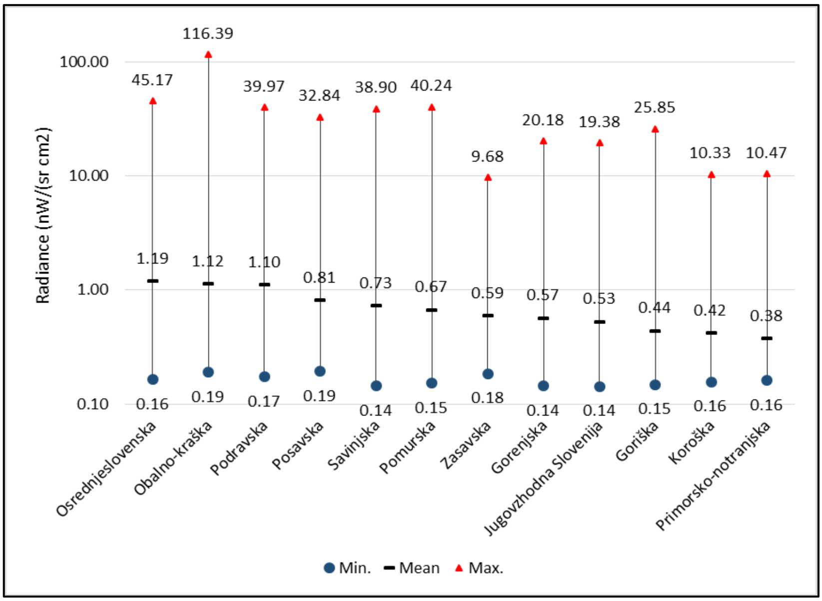

Figure 1: Minimum, average and maximum radiance by statistical regions in Slovenia in 2019.
Source: Suomi NPP; Own calculations.

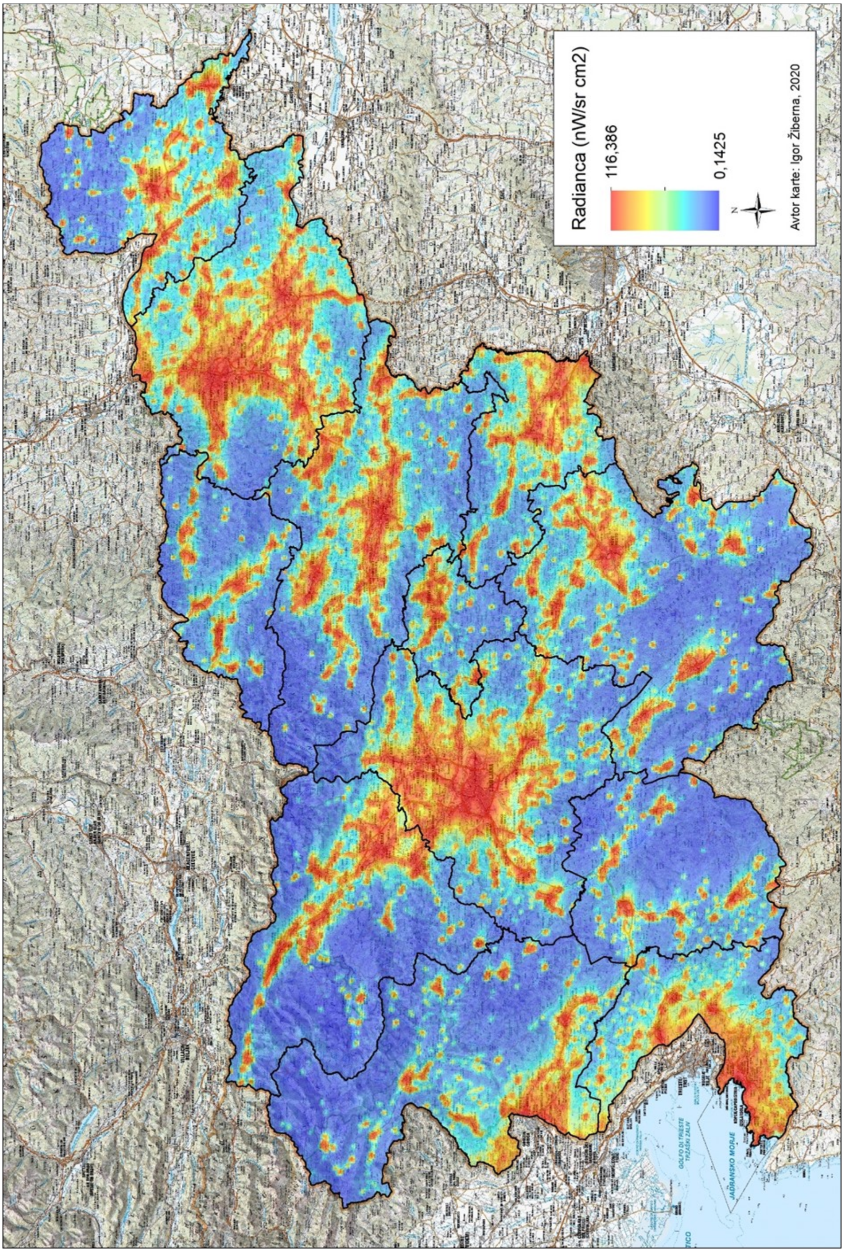

Figure 2: Radiance in Slovenia in 2019.
Source: Suomi NPP; Own calculations.

Cumulative radiance (the sum of radiance of all pixels in the statistical region) is the highest in the Osrednjeslovenska statistical region (18,545.20 nW/sr cm^2), Podravska (16,128.06 nW/(sr cm^2)) and Savinjska statistical region (11,229.49 nW/(sr(cm^2)), but it should be taken into account, that the value depends on the area of the statistical region.

4. Light pollution in Slovenia in 2019 by municipalities

The sources of light pollution are usually very much impacted by the local community or municipalities through the management of public infrastructure and the planning of its development, so we have extended our analysis to the level of municipalities. In doing so, we analysed the average radiance by municipalities and the share of the surface in each municipality in different radiance classes.

The highest recorded average radiance in 2019 was recorded in the municipality of Ankaran at 7.30 nW/(sr cm^2). It is highly likely that the source of such high values is not located in the area of the municipality, but in the nearby Luka Koper, from which light pollution also spreads to neighbouring municipalities, especially Ankaran. Average radiance is also high in Ljubljana (4.90 nW/(sr cm^2)) and Maribor (4.39 nW/(sr cm^2)), in fourth place is municipality Celje (3.67 nW/(sr cm^2)) on the fifth, the slightly unexpected municipality Šempeter-Vrtojba (3.53 nW/(sr cm^2)), where high values can be explained by the brightly lit infrastructure (for example border crossing and service activities) at the end of the highway through the Vipava valley, immediately before the border crossing at the border with Italy (Figure 3). Municipalities with higher value of average radiance in 2019 also include Trzin (2.68), Izola (2.40), Ptuj (2.35) and Murska Sobota (2.29). At the other end of the frequency range are the municipalities Solčava and Jezersko (both only 0.20 nW/(sr cm^2)). Perhaps in this group, the municipalities Bovec and Bohinj, which, despite the tourist infrastructure, have managed to maintain a low level of radiance, are somewhat surprising, but it is true that the municipality of Bohinj is located within the area of the Triglav National Park.

Minimal radiance indicates in which municipalities the least light-polluted areas occur. This is the lowest in areas coinciding with lower population density and less infrastructure. Forested mountainous and hilly areas such as Julijske and Kamniško-Savinjske Alpe, Karavanke, high karst plateaus, wider area of Kočevski Rog, forrested areas on Dolenjska and on Goričko can be mentioned here (Figure 4). The lowest minimum radiance was recorded in the municipality of Kočevje (0.1425 nW/(sr cm^2)), Solčava (0.1433 nW/(sr cm^2)), Bohinj (0.1428 nW/(sr cm^2)), Tržič (0.1467 nW/(sr cm^2)), Gorje (0.1483 nW/(sr cm^2)) and Bovec (0.1483 nW/(sr cm^2)) (Figure 4).

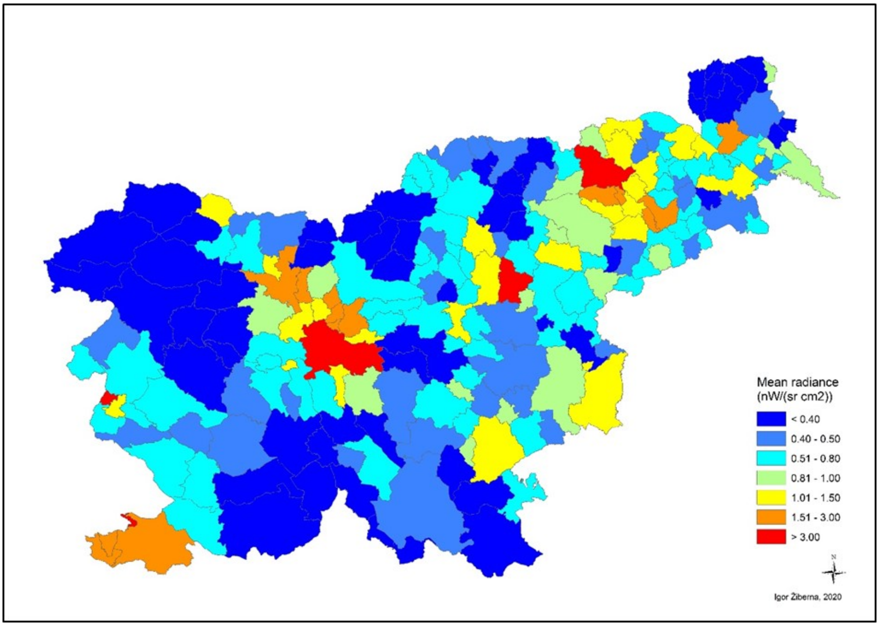

Figure 3: Mean radiance by municipalities in Slovenia in 2019.
Source: Suomi NPP; Own calculations.

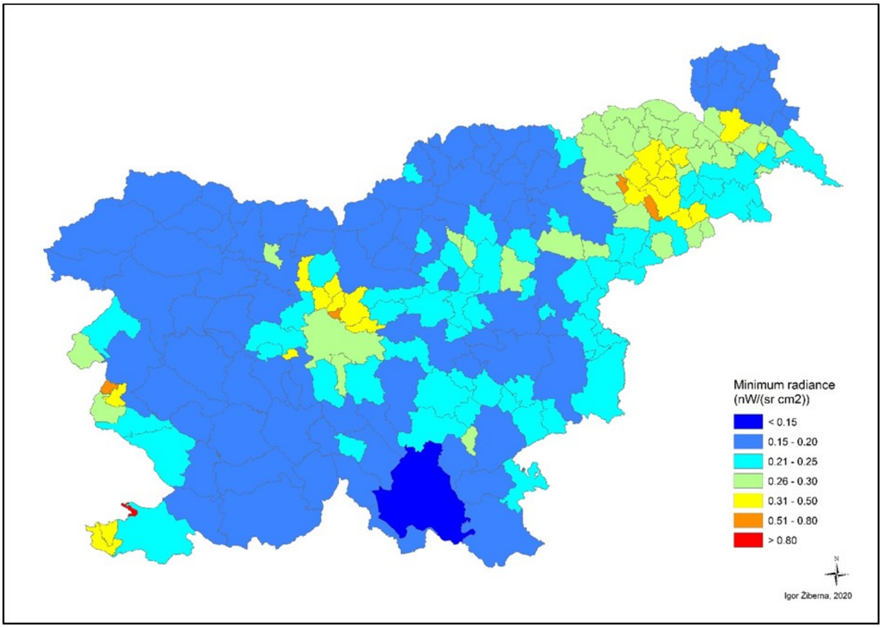

Figure 4: Minimum radiance by municipalities in Slovenia in 2019.
Source: Suomi NPP; Own calculations.

The highest minimum radiance is recorded by the municipalities of Ankaran (1.25 nW/(sr cm^2)), Šempeter-Vrtojba (0.79 nW/(sr cm^2)), Trzin (0.57 nW/(sr cm2)), Miklavž na Dravskem polje (0.57 nW/(sr cm^2)) and Hajdina (0.54 nW/(sr cm^2)). If the municipality of Ankaran is some kind of "collateral damage" near Luka Koper, in some other municipalities, above-average light pollution is due to a higher concentration of service activities whose infrastructure is above average illuminated at night.

Areas with maximum radiance are connected to areas with higher population density with more public infrastructure, and in some other municipalities, above-average light pollution is due to an very intensive illuminated infrastructure at night specific activity. The highest maximum radiance is recordedwithin the municipality of Koper (116.38 nW/(sr cm^2)), which is the result of the aforementioned intensive night lighting in the area of Luka Koper. Far behind it are the municipalities of Ljubljana (45.17 nW/(sr cm^2)), Ankaran (41.31 nW/(sr cm^2)) and Ljutomer (40.24 nW/(sr cm^2)). The municipality of Ankaran records a disproportionately high maximum radiance as a result of the location near Luka Koper (Figure 5).

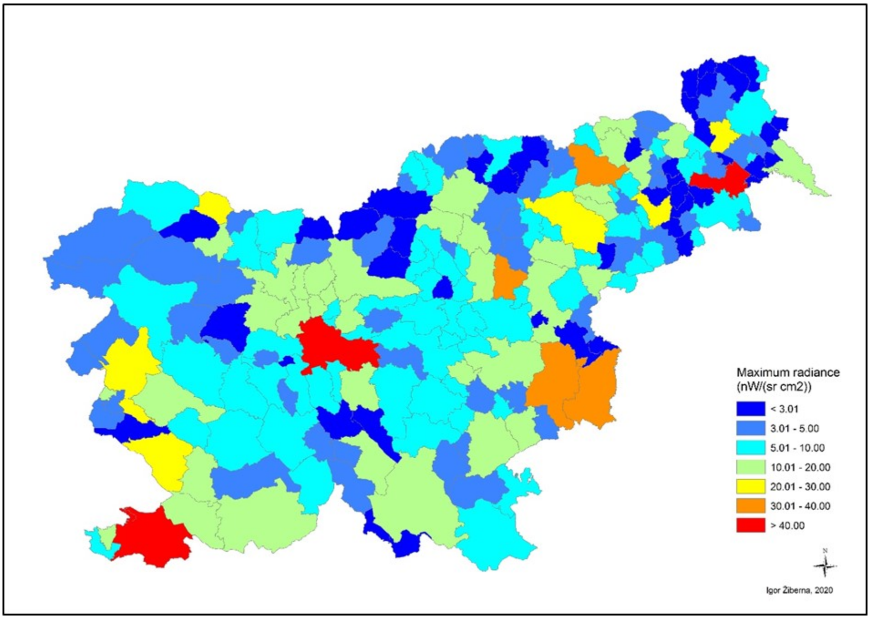

Figure 5: Maximum radiance by municipalities in Slovenia in 2019.
Source: Suomi NPP; Own calculations.

The cause of the high maximum radiance in the municipality of the Ljutomer are the illuminated greenhouses at night in the western part of the Ljutomer. High maximum radiance is also found in municipalities with larger municipal centres and suburbanized surroundings (Maribor, Celje), but also in municipalities with specific infrastructure (for example nuclear power plant in Krško, international border crossing in Brežice municipality).

By logic, public road lighting should be one of the most important sources of light pollution. That maximum radiance in municipalities depends also on other sources, such as illuminated buildings, advertising pane or parking lots, shows Figure 6. Only 28% of differences in maximum radiance can be explained by differences in the length of public roads (Figure 6).

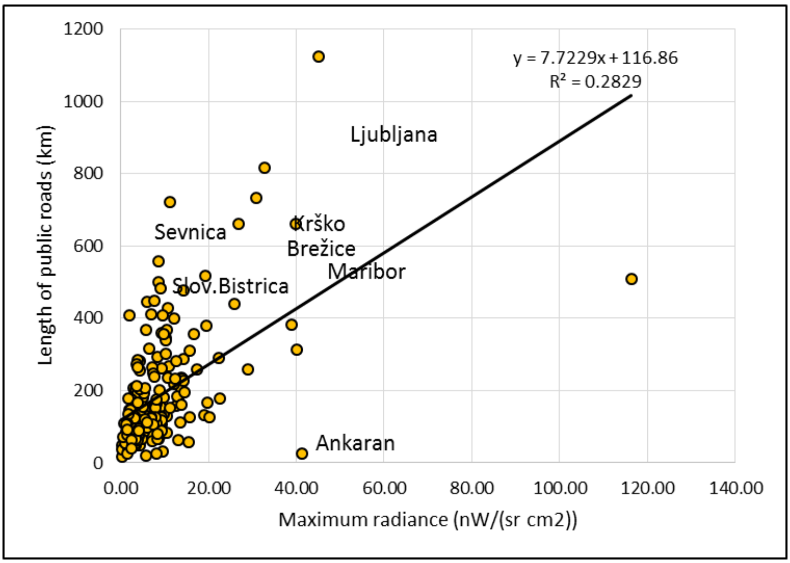

Figure 6: Maximum radiance and length of public roads by municipalities in Slovenia in 2019.
Source: Suomi NPP; Network 2; Own calculations.

5. Light pollution in Slovenia in 2019 in Natura 2000 areas

Natura 2000 is a European network of special protection areas declared in the Member States of the European Union with the basic objective of preserving biodiversity for future generations. Special protection areas are therefore intended for the conservation of animal and plant species and habitats that are rare or at European level threatened by human activity.

Natura 2000 sites are designated on the basis of the Birds Directive and the Habitats Directive. The Government established Natura 2000 sites by the Regulation on Special Protection Areas, Natura 2000 Sites, (Uredba o posebnih varstvenih območjih... 2004). There are 355 sites defined, of which 324 are designated under the Habitats Directive and 31 under the Birds Directive. The total area in Natura 2000 areas is 7,684 km^2, of which 7,678 km^2 are on land and 6 km^2 at sea. The Natura 2000 area therefore covers 37% of the total surface of Slovenia.

However, despite clearly defined restrictive measures in Natura 2000 sites, some environmental impacts (such as noise or light) spread without restriction within these protected areas. In other words, despite the fact that Natura 2000 sites do not have significant sources of light pollution, they are degraded in all terms due to impacts from areas outside Natura 2000.

The average radance in Natura 2000 areas is 0.7129 nW/(sr cm^2), which is only slightly less than the average for the whole of Slovenia (0.7959 nW/(sr cm^2)). 142 Slovene municipalities (or 66.6%) has a lower radiance than the average radiance in the Natura 2000 site. The maximum radiance in the Natura 2000 site is 28.93 nW/(sr cm^2) (in the area of the whole of Slovenia this is 116.3858 nW/(sr cm^2)). The brightest pixel in Natura 2000 sites is located in the area of the Drava Nature Park at the very edge of the municipal centre Ptuj, as evidenced by the thesis that if we really want to protect protected areas, it is necessary to create special buffer zones in a given zone outside the protected areas, which is especially true for noise, light and airborne pollution. This is even more explicit in Figure 7.

The most light-polluted Natura 2000 sites lie in the immediate vicinity of more densely urbanised areas. Examples include Ljubljansko Barje, Rašica and Šmarna gora near Ljubljana, The Vipava Valley (neighbourhood of Nova Gorica and Ajdovščina), the Karst (in the hinterland of Trst and Koper), The Slovenian Istria and the Sečoveljske soline (in the hinterland of Piran, Portorož, Izola and Koper), Kum (where the influences of Trbovlja are detected), Pohorje (influences of Maribor and the suburbanized Dravsko polje), Drava (influences of the suburbanized Dravsko polje, Duplek, Hajdina and Ptuj), to name only the most pronounced examples. The highest average radiance is in the areas of Škocjanski zatok (13.39 nW/(sr cm^2)), Slovenske Konjice (7.86 nW/(sr cm^2)) and Voglajna at the outflow into the Savinja (6.69 nW/(sr cm^2)). The areas with the lowest radiance within Natura 2000 are located in the Julijske Alpe, Kamniško-Savinjske Alpe the high karst plateaus, Snežnik, Kočevsko western part of Pohorje and Goričko.

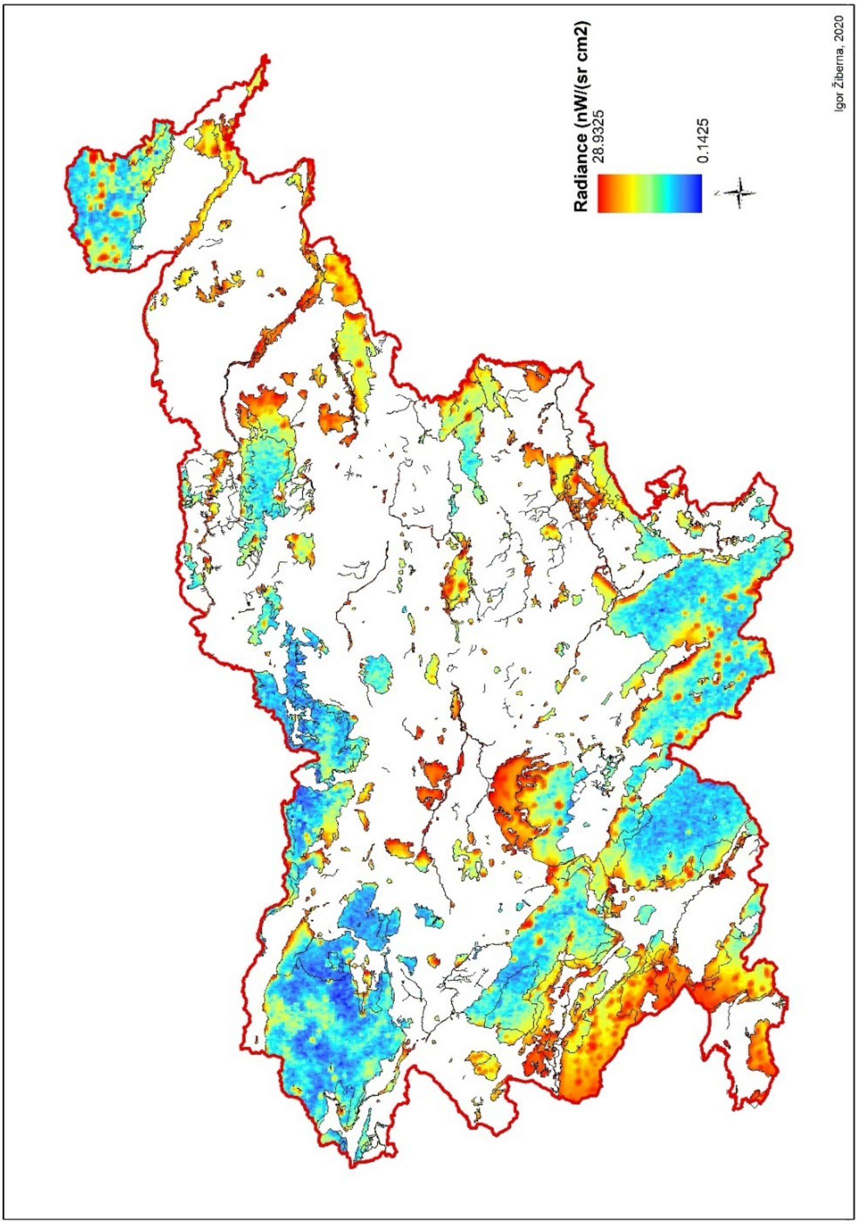

Figure 7: Radiance in Natura 2000 areas in Slovenia in 2019.
Source: Suomi NPP; Medmrežje 3; Own calculations.

6. Conclusion

Slovenia is one of the few countries that has adopted legal regulations on the limitation of light pollution. However, the situation does not improve with the desired dynamics. Within Slovenia there are large differences in the level of light pollution, with the main sources illuminated at night by public infrastructure in urbanised and suburbanised areas and some economic activities (for instance Luka Koper). Despite the fact that 37% of Slovenia's surface is protected by the Natura 2000 Regulation, the spread of light does not stop in its areas. In particular, protected areas in the vicinity of major urbanised areas are heavily polluted. In order to improve the quality of natural conditions within protected areas, measures should also be considered in transitional areas outside Natura 2000.

7. References

Petkovšek, Z., Hočevar, A. 1995: Meteorologija. Osnove in nekatere aplikacije. Biotehniška fakulteta. Oddelek za gozdarstvo. Ljubljana.

Bruce-White, C., Shardlow, M. 2011: Review of the impact of artificial light on invertebrates.Buglife—The Invertebrate Conservation Trust, Peterborough.

Falchi, F., Cinzano, P., Elvidge, C.D., Keith, D.M., Haim, A. 2011: Limiting the impact of light pollution on human health, environment and stellar visibility. Journal of Environmental Management. Volume 92, Issue 10. Elsevier.

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C., Elvidge, C., Baugh, K., Portnov, B., Rybnikova, N., Furgon R., 2016: The new world atlas of artificial night sky brightness. June 2016. Science Advances 2(6):e1600377-e1600377. DOI: 10.1126/sciadv.1600377

Huemer, P., Kühtreiber, H., Tarmann, G. 2010: Anlockwirkung moderner Leuchtmittel auf nachtaktive Insekten. (www.hellenot.org).

Hölker, F., Wolter, C., Perken, E.K., Tockner, K. 2010. Light pollution as a biodiversity threat. Trends in Ecology & Evolution. DOI:https://doi.org/10.1016/j.tree.2010.09.007.

Jensen, J.R., 2018: Introductory Digital Image Processing. A Remote Sensing Perspective. 4th Edition. Pearson. Hoboken, New Jersey, ZDA.

Mizon, B. 2012: Light Pollution. Responses and remedies. Springer. London.

Pauley, S.M. 2011: Lighting for the human circadian clock: recent research indicates that lighting has become a public health issue. Medical Hypotheses. Volume 63, Issue 4. Elsevier.

Uredba o posebnih varstvenih območjih (območjih Natura 2000). Uradni list 49/2004

Žiberna, I., Ivajnšič, D., 2018: Daljinsko zaznavanje svetlobne onesnaženosti v Sloveniji. Revija za geografijo. 13-1, 2018. Oddelek za geografijo, Filozofska fakulteta, Univerza v Mariboru.

Network 1: https://www.ngdc.noaa.gov/eog/viirs/download_dnb_composites.html (10.5.2020)
Network 2: https://podatki.gov.si/dataset/dolzine-javnih-cest-po-obcinah-od-leta-2002 (16.8.2020)
Network 3: https://gis.arso.gov.si/geoportal/catalog/main/home.page (22.8.2020)