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REMOTE SENSING OF LIGHT POLLUTION IN BOSNIA AND HERZEGOVINA

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ABSTRACT
Remote sensing of light pollution in Bosnia and Herzegovina
The study deals with the problem of light pollution in Bosnia and Herzegovina in the period 2013-2017. Remotely sensed data were obtained from the Suomi NPP satellite, which is scanning the earth's surface at night. The findings and geospatial trends of light pollution in the mentioned time period are discussed on the national and municipal levels. Some areas with very high and low levels of light pollution were exposed.

KEY WORDS
Light pollution, remote sensing, Bosnia and Herzegovina

1. Introduction

Light pollution is one of the more recent forms of environmental degradation. Since prehistoric times man has used different ways of illuminating the environment at night; however, we may say that a more intense light pollution has been out there only since the start of use of the first electric lamps. During the period between the ancient Sumerian civilization and the early 19th Century, the technology of night lighting did not change considerably. During that period, the dominant source of man-made lightning were oil lamps, which were being gradually replaced during the 19th Century first by gas lamps and then by electric lamps at the end of the 19th Century. In the 20th Century, the electric lamps were made in different forms and designs (Mizon, 2012). The problem with night lighting is not only the intensity of the lamps themselves but also their spectrum. LED lamps, which have recently been used more increasingly in this part of the world, prove to be more energy efficient; however, due to theirhigher luminescence in the blue part of the spectrum, they leave much more intensive spatial effects. According to the Raylegh law, the amount of scattering of light is inversely proportional to the fourth power of the wavelength. In other words, blue light (with the wavelength of 400 nm) is emitted in the atmosphere sixteen times more intensely than red light (with the wavelength of 800 nm) (Petkovšek and Hočevar, 1995).

With the advancement of lighting technology, with the change in housing conditions and with the urban expansion of cities – but especially since World War II – the use of lamps has become ever increasing. It was in cities in particular that the problems associated with the mass use of lamps were first brought to attention by both amateur and professional astronomers, and later by ecologists, while nowadays the warnings about negative effects that the mass use of lamps at night has on human health are also issued ever increasinglyby medical science. Exposure to artificial light interrupts the production of the hormone melatonin, thus making such persons more vulnerable to the risks of different kinds of cancers (Falchi et al. 2011; Pauley, 2004). Excessive use of lamps at night also represents an important source of excessive energy consumption.

Analyses of satellite imagery in the day and night channel show that 83% of the world population and 99% of European population live in a light-polluted night environment (sky glow exceeds 14 µcd/m2). Due to the light-polluted night sky, one third of the world population, i.e. 60% of European and 80% of North America's populations are deprived of the clear view of our galaxy (Milky Way). The most polluted countries are Singapore (100% of the population live in light-polluted night conditions), Kuwait (98%), Qatar (97%), United Arab Emirates (93%), Saudi Arabia (83%), South Korea (66%) , Israel (61%), Argentina (58%), etc. The least night-polluted areas are Greenland (0.12%), the Central African

Republic (0.29%), Somalia (1.2%) and Mauritania (1.4 %) (Falchi et al. 2016). Of course, this data canbe misleading if we are unable to interpret it and if we can manipulate with it, but they do point to the fact that economic performance of a country still does not guarantee a higher quality living environment.

Light pollution also affects ecosystems, especially nocturnal animals (insects, bats, etc.) (Bruce-White, Shardlow 2011; Huemer, Kühtreiber, Tarmann 2010). Last but not least, light pollution has reduced cultural ecosystem services in urban and suburban environments today (Hölker et al. 2010), including *inter alia* the quality of the dark sky. As a result, light unpolluted night skies could be regarded as a natural heritage asset that needs to be preserved and protected.

This paper deals with the light pollution situation and trends on the national and municipal levels. In particular, we are curious to find the answers to the following questions: (1) What is the frequency distribution of radiance in Bosnia and Herzegovina? (2) Which municipalities in Bosnia and Herzegovina have the highest and which the lowest average radiance? (3) What is the relationship between light pollution and a number of selected socio-economic indicators?

2. Methodology

As an entirely new form of environmental degradation, light pollution has not yet been firmly anchored in our perception. Nevertheless, over the past ten years, the Sky Quality Meter (SQM) has been present on the market as a skyglow measurement tool manufactured by a Canadian-based company Unihedron and accepted worldwide as a standardized way of light pollution measurement. The advantage of using an SQM meter is that we get the sky brightness data for a given location immediately. The disadvantage of getting the data with SQM is that the data is represented as dots. In order to analysea light pollution situation in a wider area, it is necessary to repeat measurements in the space, which sometimes can prove to be a particularly time-consumingenterprise.

With the development of remote sensing technology for individual environmental components, we have been able to obtain such data for a wider area. In the event that the data obtained in this way is geo-referenced, it enables the spatial analyses and analyses of changes in individual environmental components over time. The number of satellites orbiting the Earth that are used for purely civilian purposes is increasing, thus expanding the range of information obtained foreach individual environmental component, which as a result constitutes a whole new source of spatial data obtained through a respective satellite imagery analysis – i.e. remote sensing.

In October 2011, the National Oceanic and Atmospheric Administration (NOAA) launched a weather satellite called the Suomi National Polar-orbiting Partnership (abbr. the Suomi NPP). The satellite is the successor to the older Defence Meteorological satellite Program or DMSP. The orbit of the Suomi NPP reaches about 824 km above the Earth's surface. The satellite's orbit is nearly polar and the satellite flies above each point twice: around 1:30 pm and 1:30 am local time. In one day it circles the Earth 14 times. Among the sensors mounted on the satellite, there is the Visible Infrared Imaging Radiometer Suite (VIIRS), which consists of a set of 22 different sensors, one of which records the surface in the day and night channel or the so-called Day/Night band or DNB. The spatial resolution represented by pixels at the nadir (a point on the Earth's surface which is situatedjust below the satellite) is about 750 m x 750 m (Jensen 2018). The recorded data is available on the official web site of the US Oceanic and Atmospheric Agency (National Geophysical Data Center, 2018). The database contains georeferenced layers of monthly averages, while eliminating the situations wherethe data about night-time light sources on the Earth'ssurface is distorted either as a result of cloudy weather, the influence of moonlight (especially at full moon) and wildfires.

The values of the light sources are featured in nanowatt per steradian per square centimetre (nW/sr cm2). One of the disadvantages of the sensor is that the spectral range of light it detects is at some point in the range between 500 and 900 nanometers. The sensor is therefore »blind« to the extreme blue band in the visible part of the spectrum. Most of the contemporary lamps, i.e. the so called »white« LED lamps, which have been in use over the past decade and which replace high and low pressure sodium lamps, have a maximum glow specifically in the blue part of the spectrum. Replacement of the orange sodium-vapour lamps with the so called »white« LED lamps is therefore detected by the sensor as a glow drop, although the situation has actually become worse since the introduction of the »white« LED lamps. According to the Rayleigh law, the installation of »white« LED lamps is causing a much more intense scattering of light at night, thus causing a more intensive light pollution, which is unfortunately not detected by the VIIRS sensor.

Nevertheless, the data of the Suomi NPP satellite is currently the highest quality data in the day-night channel, both in terms of spatial and temporal resolution, but also in terms of the dynamic range of information about the light pollution situation. Previously, the information in the day-night channel was collected with the said Defence Meteorological Satellite Program (DMSP). The data in the DMSP satellite day-night channel was collected for the period 1992-2012 and is shown in the spatial resolution of 1km x 1km, as a result of which the data values are expressed as the so-called digital numbers within the range from 0 to 63, and, as such, they show a considerably lower dynamic range compared with the Suomi NPP satellite data (Bennie et al. 2014).

Despite the said shortcomings of the sensors in the day-night channel on the Suomi NPP satellite, we have decided to use the data from this satellite in our analysis of light pollution in the territory of Bosnia and Herzegovina. We collected the data on a monthly basis for the period January 2018-December 2018 and we processed it for the territory of Bosnia and Herzegovina. We analysed the data on multiple levels: we were interested in the situation concerning radiance in 2018 throughout Bosnia and Herzegovina (BiH) and the situation on the municipal level in Bosnia and Herzegovina. Most of the public infrastructure that in one way or another associated with night lighting is the specific responsibility of the municipalities, and it depends on the size of municipal population (and councillors in the municipal councils) what priorities they will choose in terms of maintaining and expanding the public infrastructure, including public lighting as one of the most important sources of light pollution.

3. Results and discussion

For the sake of easier understanding of the light pollution situation in Bosnia and Herzegovina in the broader context, we will first make a comparison with a number of European countries. As far as the average radiance is concerned, Bosnia and Herzegovina has recorded the average value of 0.59 nW/sr cm^2, thus occupying 37th place out of the total 52 European countries. The highest average radiance is recorded in a number of smaller densely populated urban countries, such as: Monaco (112.21 nW/sr cm^2), Vatican (87.10 nW/sr cm^2), Gibraltar (29.11 nW/sr cm^2), followed by Malta (14.98 nW/sr cm^2), San Marino (8.46 nW/sr cm^2) and the Netherlands (4.64 nW/sr cm^2). The lowest radiance values are recorded in Iceland (0.39 nW/sr cm^2) and Belarus, Svalbard and Latvia (0.36 nW/sr cm^2). In terms of maximum radiance (the brightest pixel value in the country),the highest value is recorded in the Russian Federation (12964.42 nW/sr cm^2), which is followed by the Netherlands (8314.49 nW/sr cm^2), Ukraine (6648.79 nW/sr cm^2), Finland (4291.42 nW/sr cm^2) and France (2785.76 nW/sr cm^2). BiH occupies the 43rd place with only 70.06 nW/sr cm^2. The lowest maximum radiance is recorded in Liechenstein (16.65 nW/sr cm^2), Guersney (8.39 nW/sr cm^2) and Svalbard (1.54 nW/sr cm^2). In terms of the country's share of the surface area with radiance above 1.00 nW/sr cm^2, Gibraltar, Monaco and Vatican occupy the top position (100%), while BiH has 8.40% thus occupying 33rd place (Internet 1; the authors' own calculation, 2019).

In BiH, the areas with radiance ranging between 0.50 and 1.00 nW/sr cm^2 cover 10.31% of the country's surface, the areas with radiance ranging between 0.25 and 0.50 nW/sr cm^2 occupy 34.93% of the surface, the areas with radiance ranging between 0.10 and 0.25 nW/sr cm^2 occupy 46.36% of the surface, while the areas with radiance below 0.10 are not found in BiH (Figure 1).

In BiH the situation is also favourable in comparison with the other former SFRY republics. Serbia has the highest average radiance (1.08 nW/sr cm^2), followed by Croatia (1.00 nW/sr cm^2) and Slovenia (0.79 nW/sr cm^2). BiH occupies the last place. The maximum radiance is highest in the Northern Macedonia (Skopje-280.46 nW/sr cm^2), followed by Serbia (Belgrade-214.99 nW/sr cm2), Slovenia (Luka Koper-117.95 nW/sr cm2) and Croatia (Zagreb-110.36 nW/sr cm^2). BiH occupies the last place also in terms of maximum radiance (National Geophysical Data Center, 2018; the authors' own calculation, 2019).

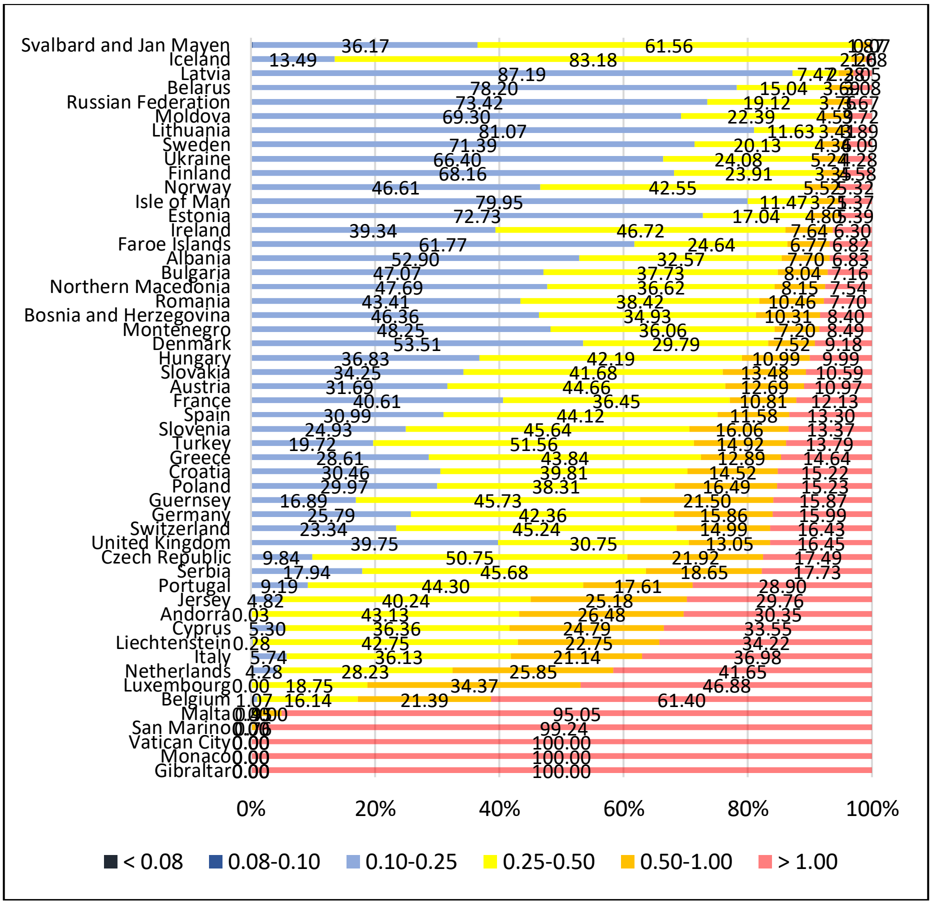

Figure 1: Radiance share in nW/sr cm^2 across selected countries in Europe, 2018. Source: the authors' own calculations, 2019.

Light pollution in Bosnia and Herzegovina in 2018 is highest in major urban areas and their suburban hinterland (Sarajevo, Banja Luka, Mostar, Tuzla, Zenica, Livno, Bijeljina, Bosanski Brod, Brčko, Pale, Bosanska Gradiška, Doboj, Bihac, Trebinje).

Larger areas with lower radiance are found mainly in the Dinaric Highlands in western Bosnia and more fragmented in southeastern and eastern Bosnia, where population density is lower (Figure 2). The brightest pixel in the territory of BiH in 2018 was located in the municipality of Lukavac (70.06 nW/sr cm^2 in the area of Global Ispat Coking Plant Industry " ltd. Lukavac). The second brightest pixel in 2018 was located in Sarajevo, in the area between Zmaj od Bosne Street and the Woodrow Wilson's Promenade alley, in the vicinity of the BiH Parliament Building area (65.48 nW/sr cm^2).

In the City of Sarajevo, the area at the site of EUFOR's Military Camp in Butmir (62.50 nW/sr cm^2) is also heavily polluted. The third most light-polluted area in BiH was recorded in the City of Mostar in 2018; specifically, between Dr. Ante Starcevic Street in the north and east, King Tomislav Street in the west and King Zvonimir Street in the south (62.55 nW/sr cm^2). In the City of Banja Luka, the area that stands out in terms of light pollutionas the most polluted area is the one between Tržnica (Marketplace), King Petar Karadjordjevic Street and Ban Dr. Todor Lazarevic Street (60.43 nW/sr cm^2)

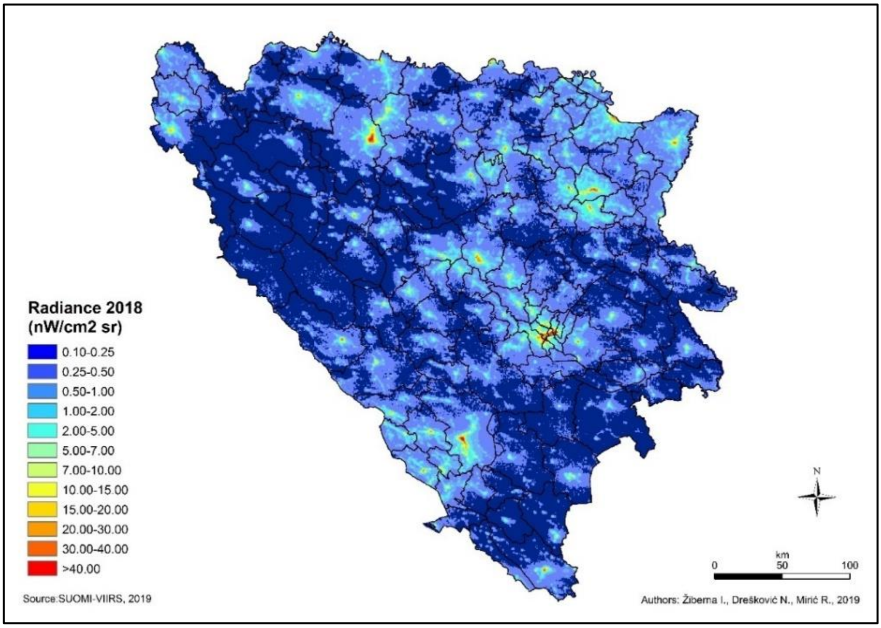

Figure 2: Radiance (v nW/sr cm^2) in Bosnia and Herzegovina recorded in 2018. Source: Suomi VIIRS, 2019, the authors' own calculations, 2019.

Within 143 of the analysed municipalities in BiH, the differences were found to be quite significant. The average radiance is highest in the municipalities of Novo Sarajevo (21.33 nW/sr cm^2), Novi Grad Sarajevo (8.01 nW/sr cm^2), Istočna Ilidža (8.01 nW/sr cm^2), Centar (5.75 nW/sr cm^2), Istočno Novo Sarajevo (4.35 nW/sr cm^2), Ilidža (4.03 nW/sr cm^2), Stari Grad (2.77 nW/sr cm^2), and the cities of Tuzla (2.77 nW/sr cm^2), Doboj South (2.55 nW/sr cm^2) and Vogošća (2.43 nW/sr cm^2) (Figure 3). Out of the 143 municipalities, as many as 72 of them (50.3%) have an average radiance of less than 0.50 nW/sr cm^2, but only 7 (4.9%) of them have less than 0.25 nW/sr cm^2. Generally speaking, large differences can be observed in terms of the distribution of light pollution: the radiance of the brightest pixel recorded in as many as 16 municipalities was found to be lower than the radiance of the darkest pixel recorded in the Novo Sarajevo municipality.

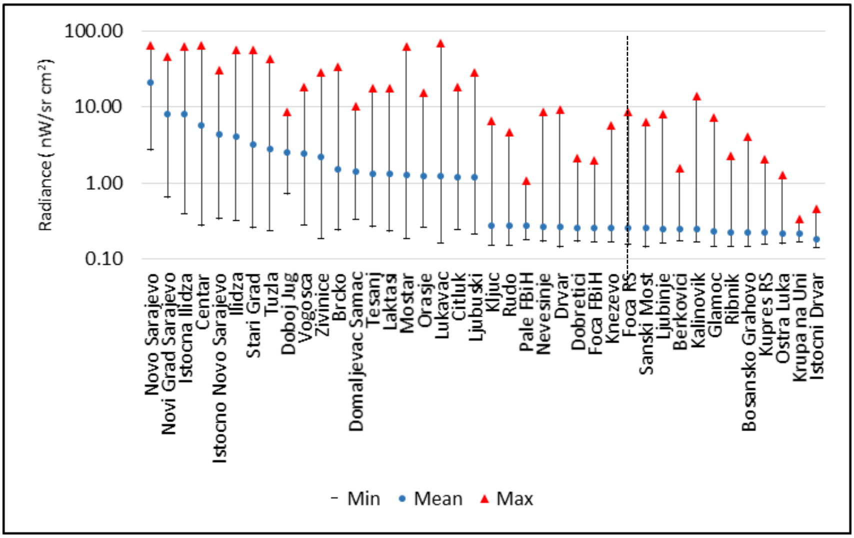

Figure 3: Average maximum and minimum radiances (in nW/sr cm^2) in the most light-polluted (left) and least-light polluted (right) municipalities in Bosnia and Herzegovina in 2018.
Source: Suomi VIIRS, 2019, the authors' own calculations, 2019.

The main source of light pollution is public lighting that is in function along the public roads and in public areas, both of which depend on the population size, population density and economic power. To this end, we have also analysed the dependence of radiance on the population size, population density and GDP by municipality, while relying on the data collected in 2013 and 2014. It turns out that there is an evident correlation between the population size and the maximum radiance across municipalities, since 47% of the differences in the maximum radiance can be explained by the differences in the population size (Figure 4). Only 9% of the differences in the average radiances can be explained by the differences in the population size.

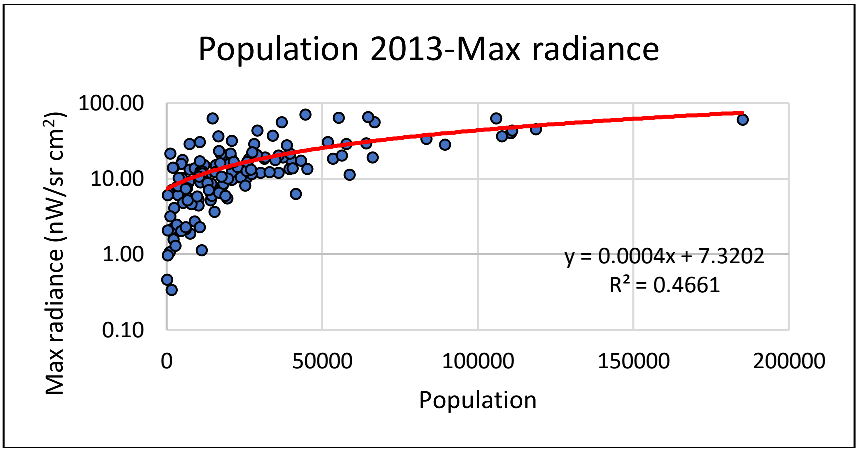

Figure 4: Dependence of the maximum radiance on the population size by municipality in BiH in 2013
Source: Agency for Statistics of BiH, 2019; the authors' own calculations 2019.

Population density by municipality also affects light pollution. In this case we can speak about a correlation between the average radiance and the population density in a given year, since as much as 90% of the differences in the average radiance can be explained by the differences in the population density (Figure 5). The determination coefficient between the maximum radiance and the population density by municipality in 2013 is only 0.2032.

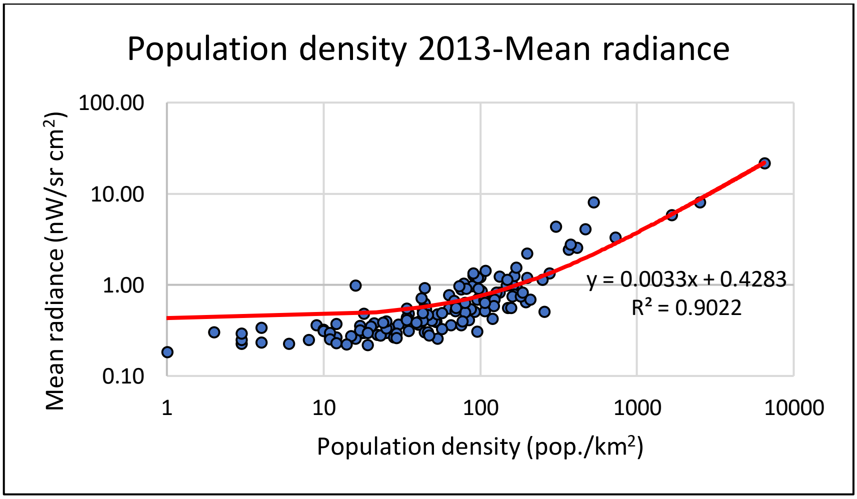

Figure 5: Dependence of the mean radiance on population density by municipality in BiH in 2013.
Source: Agency for Statistics of BiH, 2019; The authors' own calculations 2019.

The correlation between GDP by municipality and the radiance is less pronounced: the determination coefficient between the average radiance and GDP per capita in 2014 by municipality is 0.2545, whereas the correlation between the maximum radiance and GDP per capita in 2014 by municipality is 0.3035 (Figure 6).

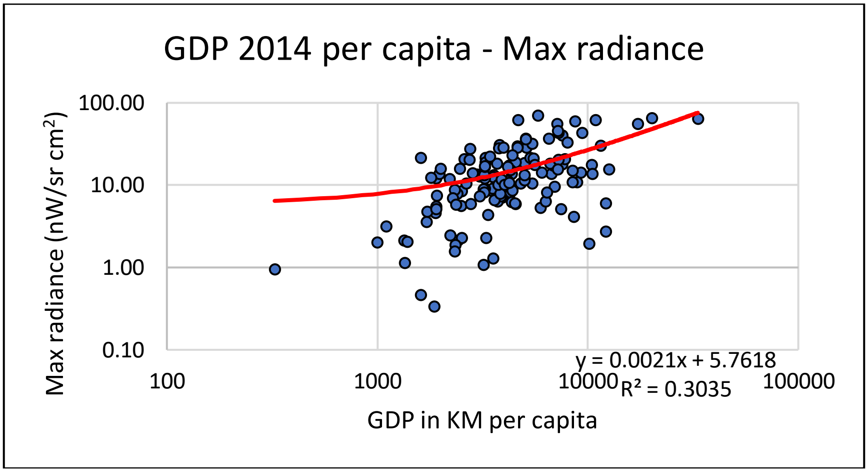

Figure 6: Dependence of the maximum radiance on GDP in KM per capita by municipality in BiH in 2014.
Source: Agency for Statistics of BiH, 2019; the authors' own calculations 2019.

4. Conclusion

This study represents only an introduction to abroader study of light pollution in the territory of BiH through remote sensing. The results show that there are large differences recorded in BiH among individual parts of the country, which are largely due to their population density. On average, BiH is (for the time being) one of the less polluted areas in Europe, which is the reason why primarily the areas that are not yet highly light-polluted would need to be preserved as the so-called »Dark parks«, as is the case in some more environmentally conscious countries.

The conditions conducive to such preservation certainly exist in some of its areas. In urban areas, BiH will necessarily have to start with renovation of public lighting, and in doing it this country should try to avoid repeating mistakes made by other countries, including its neighbouring countries, which have taken into account some primarily economic, but less environmental concerns, in the process of renovation of public lighting and thus began with a large scale mounting of the so-called »white« LED lamps, which are otherwise more energy efficient but have nonetheless had catastrophic spatial effects due to an excessive level of radiation in the blue spectrum, which is why light pollution in these countries has only increased.

Another measure that BiH should start to consider immediately is the adoption of appropriate legislation that would introduce limits with regard to light pollution, since otherwise the light pollution situation in a number of primarily major urban areas of BiH will deteriorate significantly in the coming years.

In the public sector, but particularly in primary and secondary schools, the topic of light pollution should also be introduced to young individuals among a range of other environmental topics as a new form of environmental degradation. Thus, among the younger population we would start developing somewhat different values, which would include their increased awareness of the fact that more intense night lighting does not in any way mean a higher quality of living environment.

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