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Light Pollution Mapping in Pécs City with the Help of SQM-L and VIIRS DNB. The Effect of Public Luminaire Replacements on the Sky Background of the Urban Sky

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Abstract
Recently light pollution has been one of the most dynamically increasing form of environmental pollution. Light, if it arrives at the wrong place, time, quantity and quality, is harmful to human health and the physical environment – not to mention that it is a mere waste of energy. The brightness of the sky above Pécs was measured by SQM-L instruments in 2011 and 2019. Maps of the different neighbourhoods with different levels of light pollution have been prepared. In addition, special VIIRS day/night band satellite images were also analysed using QGIS software. Our investigations coincided with the modernization of street lighting in the city. The impact of LED illuminators installed along main roads in Pécs was observed locally.

Keywords: light pollution mapping; SQM-L; VIIRS day/night band; QGIS; TIN; Thiessen polygon; Pécs

Introduction and Objectives
Humanity is constantly shaping its natural environment and this transformed environment affects the living creatures inhabiting it. This influence is more pronounced in areas with high population density, such as in the vicinity of large cities. The transformation of nature often leads to natural disasters involving major damage. For instance, in mountainous and hilly areas flash floods and landslides can occur due to deforestation, which inflict damage to elements of the built environment and even claim human lives (Mezősi, 2022).

A less tangible but increasingly studied form of environmental pollution is nighttime light pollution. Inadequate lighting of our environment (Artificial Light At Night - ALAN) can damage both the wildlife of the area and human health. Artificial night-time lighting is increasing worldwide by 2-6% per year. Engineers and lighting technicians are designing and

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producing more and more efficient luminaires, but this does not reduce the amount of electricity used for lighting, which results in unnecessary over-lighting in most places (Árgay, 2020).

Light pollution is defined by the social organization International Dark Sky Association (IDA) in the following way: „The inappropriate or excessive use of artificial light – known as light pollution – can have serious environmental consequences for humans, wildlife, and our climate. Components of light pollution include (Internet 1):

- Glare – excessive brightness that causes visual discomfort
- Skyglow – brightening of the night sky over inhabited areas
- Light trespass – light falling where it is not intended or needed
- Clutter – bright, confusing and excessive groupings of light sources."

The most important sources of light pollution are inadequate public lighting, street lamps, reflectors of industrial estates, decorative illumination of buildings and venues of sports and other events, and the light used for advertising at night.

The present paper is mainly concerned with light emanating from luminaires to the wrong place (skyward) and with inappropriate, excessive amounts of light. This form of light pollution is called astronomical light pollution. However, light pollution has a significant impact on the biosphere as a whole, including human health, which is called ecological light pollution (Longcore & Rich, 2004). In the majority of cases, both forms of light pollution occur simultaneously.

In addition to their impact on their immediate environment, ALAN sources contribute significantly to the brightening of the night sky and astronomical light pollution. The shining of the sky is primarily caused by the light reaching above the horizon plane from the lamps. This is expressed by the Upward Light Output Ratio (ULOR), ranging between 0-1. In the astronomical sense, we speak of a light pollution-free solution if the ULOR = 0. In the last decade, a number of mainly LED luminaires have been developed with a ULOR value of zero.

In 2014, the local government of Pécs launched a public lighting modernization program, in the frame of which, starting from 2015, the lamps along important public roads will be replaced with LED light sources. In the year 2019, marking the end of the time interval of our investigation, there were 20,238 public luminaires in the city. Of these, 7,195 were replaced with LED lights between 2015 and 2019, which is 35% of the total number (data source: Pécs City Council).

Astronomical light pollution is measured using different methods around the world, including measurements made from the surface of the earth in the direction of the sky, as well as top-down observations from outer space, possibly using aerial devices.

The light measuring devices traditionally used in lighting technology are not sensitive enough to measure the brightness of the night sky. For this purpose, the Unihedron company developed the Sky Quality Meter (SQM) instruments (Internet 2), which are widely used due to their low price. These measure the average sky brightness of a specific observation location with great accuracy (Internet 3). The temperature compensation of the SQM is therefore found to be adequate for use in the field over the range of -15°C to 35°C (Schnitt et al., 2013). The instrument was also involved into the investigation, because it is fast and efficient, i.e. it enables measurements to be taken at many measuring points within a short period.

While measurements from the surface typically provide light pollution data for a single location, measurements from satellite maps refer to large within a short time. Operational Linescan System (OLS) instruments have been installed on Defense Meteorological Satellite Program (DMSP) platforms since the 1970s. The Suomi National Polar-Orbiting Partnership (SNPP) satellite Visible Infrared Imaging Radiometer Suite (VIIRS) instrument used in this study, launched in 2011, can be considered their improved version. One of the channels of VIIRS is the day/night band (DNB), which can take low-light images at night at a wavelength of 0.5-0.9 µm. DNB is a calibrated radiometer with a spatial resolution of 742 meters and a dynamic range of 14 bits. Since 1996, the Earth Observation Group at NOAA/NGDC has been generating global annual nocturnal light composites from DMSP-OLS and VIIRS DNB data (Baugh et al., 2013; Elvidge et al., 2017).

The SQM and the VIIRS DNB have different spectral sensitivities. While the SQM is sensitive in the whole province of visible light (Internet 3), the VIIRS DNB is not sensitive in the visible blue province (Chen et al., 2021). This latter fact also influences the perception of LED lamps (Sanchez de Miguel et al., 2020).

The objective of the present research was to create as detailed an astronomical light pollution map of the city of Pécs as possible. To this end, surface and space measurements and data taken both from the surface and from outer space were used to reveal in light pollution for the city of Pécs between 2011 and 2019. What effect the LED lamps installed as part of the public lighting modernization program since 2015 had on the astronomical light pollution conditions of the city?

In the literature the measurement of urban light pollution using the SQM method is amply treated but measurements are restricted to few points and, thus, unsuitable for mapping. In most of the cases, permanent measurement stations at fixed locations are used to monitor light pollution in the centre of an individual city possibly with one or two permanent stations in the outskirts (Faid et al., 2016; Pavlić & Željko, 2020; Pun et al., 2014; Puschnig et al., 2022). In contrast, in the present study during the two measurement campaign light pollution in Pécs was surveyed in detail, employing numerous measurement points and mapped. The purpose was to compare the maps made at different dates.

There are light pollution studies where the SQM (or similar) measurements survey to calibrate the VIIRS DNB (or similar) data for light pollution mapping (Duriscoe et al., 2018; Katz & Levin, 2016; Nisar et al., 2022). In this paper, however, the two data series are treated separately and two independent methods are applied to detect the changes in the spatial pattern of light pollution in Pécs. The results are not affected by the spectral sensitivity of the instruments, they supplement each other.

Study Area

Pécs is a city in southwestern Hungary, with an area of 163 km^2 and a population of 140,000 (Figure 1.A). It lies on the southern slopes of the Mecsek Mountains and in the Pécs Basin. As a result of its basin character, the light pollution from the neighbouring settlements is eliminated by the ranges of the Mecsek Mountains and the Baranya Hills. The closest major town, Komló (population: 22,000) is located on the opposite side of the Mecsek, at 13 km distance, in valley. The two small villages in the Pécs Basin, in the immediate vicinity of Pécs (Pellérd & Keszü) are insignificant in this respect and did not disturb the measurements.

The neighborhoods of Pécs are listed in Figure 1.B shown with numbers. Inhabited since Roman times, the inner city (16) is located on the border of the two landscapes. The most important public and railway transport routes run here in east-west direction, along which the city has been expanding with mixed construction for centuries. Typically, the largest industrial and commercial establishments are also located along this axis (2, 13, 22, 23). Only in the second half of the 20th century did the city expand to the southern side of the once swampy basin, where the cityscape is mostly dominated by housing estates with blocks of flats (30). The hillslopes used to be vineyards (1, 4, 5, 7, 8, 9, 10, 17, 18), but in the 20th century it is increasingly occupied by residential areas and family homes and some villages were also added to the city (11, 27, 32, 33, 36).

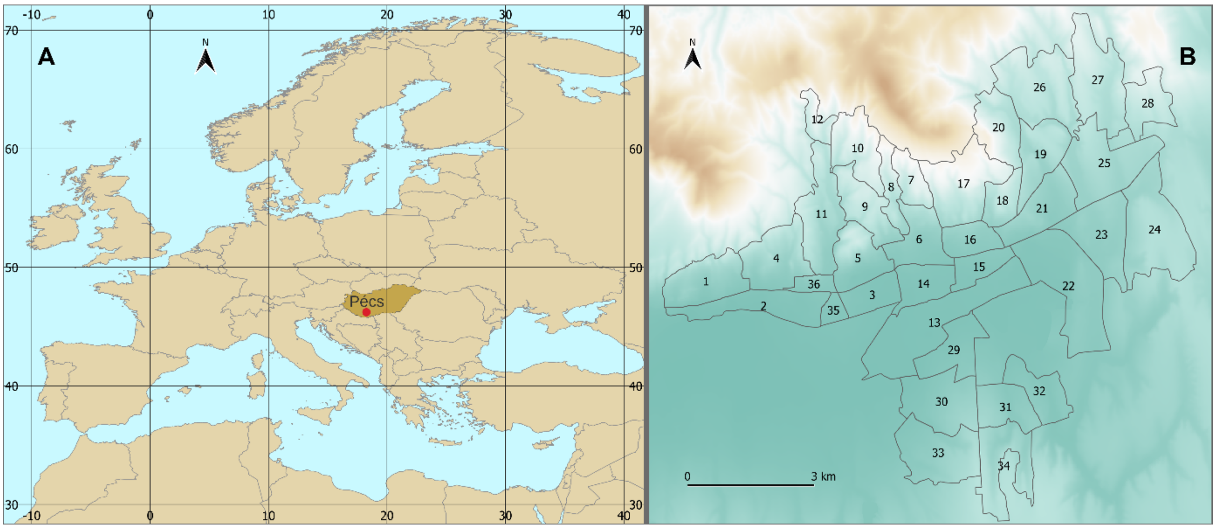

Figure 1. Location of Pécs in Europe (A) and its neighbourhoods (B)

Data and Methods

For the research, we also used both data collected by authors during field work and satellite remote sensing data. To collect field data, car drives around the city were used to measure the background brightness of the sky in places without direct lighting with Sky Quality Meter L equipment (SQM-L), and also recorded the GPS coordinates of the measurement points (Figures 2.A. and 2.B). On 2-7 May 2011 for four nights at 236 places, and in 21-25 October and on 23-24 November 2019 the background brightness of the night sky at 261 locations over five nights was measured. In both cases, this meant driving around 300 km in and around Pécs. In all cases, the measurement sites were free from direct lighting. If there was a street lamp nearby, we covered its direct light with some object. Measurements were made observing IDA instructions (Internet 4).

The measurements were carried out under excellent bright skies after a cold front. We started the measurements after the end of astronomical twilight, making sure that the Moon was not above the horizon. We calibrated the results measured on different days since the atmospheric parameters (e.g. humidity, see Table 1) changed slightly from night to night. For this purpose, we designated three control measurement points along the road north of the city, 250-350 high above the city centre, at 4-5 km distance from there, on the slopes beyond the crest of the Mecsek Mountains, where urban light pollution is limited to a narrow section of the sky around the zenith, where the SQM-L data are collected. We started the measurements there every evening.

Table 1. Meteorological data for the days of measurement at midnight (meteorological station of the University of Pécs, 46°04'40.4"N, 18°12'22.3"E, elevation: 174 m)

Date and Time (CET)	**Temperature (°C)**	**Relative Humidity (%)**
02. 05. 2011 24:00	14.5	72.2
04. 05. 2011 24:00	5.7	70.0
05. 05. 2011 24:00	7.2	54.4
06. 05. 2011 24:00	8.4	57.7
21. 10. 2019 24:00	17.6	79.0
22. 10. 2019 24:00	17.8	66.0
23. 10. 2019 24:00	14.9	72.0
24. 10. 2019 24:00	13.3	85.0

23. 11. 2019 24:00	6.6	77.0

We used a SQM-L device for the measurement (Internet 5). It measures the average brightness of the sky above the observer in units of magnitude/square second (m/arcsec^2), so they provide a single numerical data for each observation. SQM-L only works in the range of visible light, its measurement accuracy is ±0.10 m/arcsec^2.

The L type SQM instrument has a much smaller field of view than previous SQM instruments. Approximately 90% of the light is collected from a 38° wide field of view (Internet 6), which is extremely beneficial in urban conditions because it is not disturbed by lights close to the horizon.

Recently, the issue of aging of the SQM devices has been raised (Bará et al., 2021; Puschnig et al., 2021). This only affects permanent stations exposed to weather in open spaces. The device used in the present study, however, is stored in climatized rooms, in drawer, packed in plastic bag with silica gel between two campaigns.

It is worth noting that the magnitude used in astronomy is a roughly logarithmic scale in reverse direction, therefore the higher values in the figures and tables represent the darker sky, the lower values the brighter.

Three measurements were taken at each location, and the data were averaged. The measurements of several consecutive nights were calibrated with the data of the three control points. The sky brightness values measured at the control points were averaged. The control values of each measurement day differed slightly from the average. All the measurement data from that day were modified accordingly.

The 2011 and 2019 locations overlapped to a significant extent, but not completely. Although we visited all 2011 measurement points in 2019, there were sites which were no longer suitable for repeated measurements because their environment had changed. In 2019, we also added new locations for future investigations. Between the measurement periods of 2011 and 2019, we had 155 shared, overlapping locations. Two measurement points were considered identical if there was a maximum distance of 150 meters between the two data collection locations. The 155 common measurement points were used to analyze changes over time (Figure 2.C).

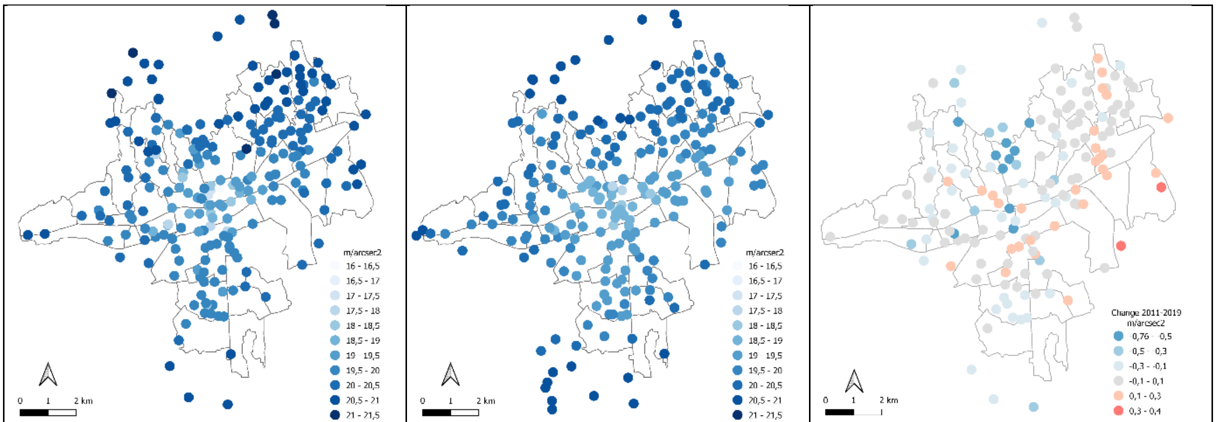

Fig. 2.A. Sites and values of measurements in 2011	**Fig. 2.B.** Sites and values of measurements in 2019	**Fig. 2.C.** Common locations and changes in their background brightness between 2011-2019

In addition to surface measurements, we also downloaded and analyzed the raster files created by the VIIRS DNB instrument as well as the latest WGS 84 projection GeoTIF layers released on 07/08/2022 from eogdata.mines.edu (Internet 7). Unfortunately, the SNPP probe only carried out measurements for the first time in 2012, there are no data for 2011. The downloaded GIS layers contain average values of the lights observed on the night side of the Earth for the years 2012 and 2019. They are masked and free from disturbing effects (e.g. moonlight). The area around Pécs was cut out from the global GIS layer. The pixel size of the already pre-processed stands in the examined area is 463×324 m (0.00416666° × 0.00416666°). Calibrated VIIRS DNB data are expressed in W cm^{-2} sr^{-1}.

The analyses and maps were prepared using QGIS software versions 3.16 and 3.22.

Results and Discussion

Individual light pollution sources were assessed separately and represented on a map (Figure 3). Light pollution in Pécs is basically caused by public lighting in built-up areas. Despite the improvements, the majority of luminaires currently do not meet the ULOR = 0 condition. Especially high-power lights were placed along the main traffic arteries with heavy traffic and the more important first and second order roads.

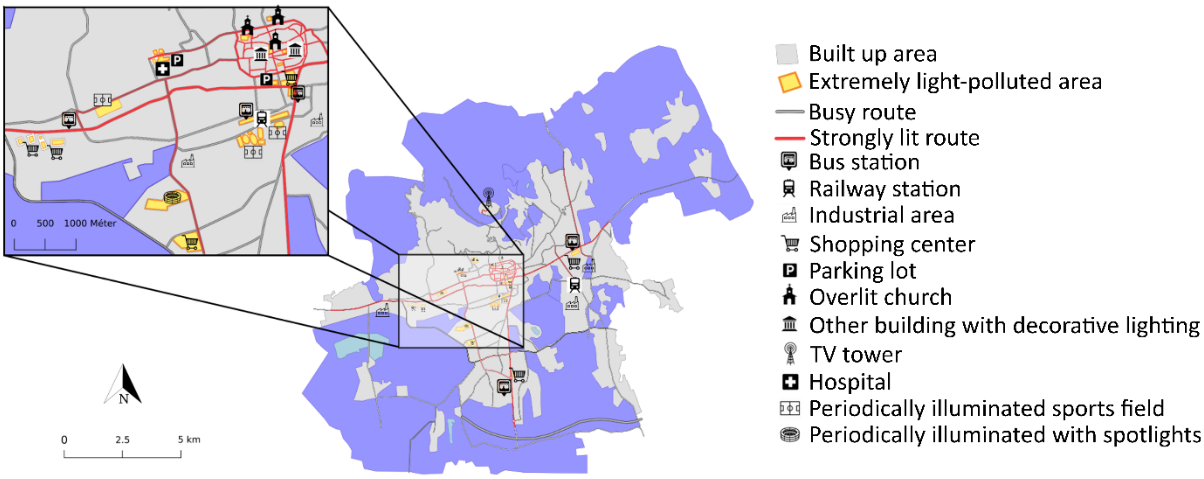

Figure 3. Major sources of light pollution in Pécs and environs

The brightest area is the inner city (downtown) and its surroundings, where many buildings are illuminated, car parks are amply lit, and street lighting is also denser. Due to their design and brightness, the decorative lighting of the downtown church on the main square (Figure 4.A), the City Hall (Figure 4.B), the Pécs National Theatre, the Pécs Basilica and the Pécs Calvary Chapel are extremely light polluting. The nocturnal lights of the Árkád shopping center south of the city center and the surrounding parking lots, the long-distance bus station, the railway station and the nearby sports fields appear as bright spots on the map. In the western part of the city, the lights of the Clinic's building and parking lots, and further away the lights of shopping centers and industrial estates form light pollution hotspots. In the south, next to Pécs Plaza and other shopping centers, the reflectors of the local bus station can be highlighted. In the eastern part, the main pollution sources are the thermal power plant and other industrial facilities, as well as the parking lots of shopping centers. The PMFC football stadium holds training sessions on a daily basis, but also matches on a monthly basis, which then makes the football field the biggest source of light pollution in the city (Figure 4.C). The Expo Center in Pécs is also brightly lit on a few occasions in a year. The color-changing decorative lighting of the TV tower above the city, on the top of the Misina mountain, disturbs the nocturnal rhythm of the living world as a powerful source of light.

The astronomical light pollution of the new LED lamps is visibly much lower than that of previous lamps. Most of their light emission is directed downwards (Figure 4.D).

Figure 4. Negative and positive examples of lighting in Pécs (2019). The photos were taken in fog. Ornamental lighting and the reflectors of the stadium are largely directed above the horizon (A, B, C), while the new LED lamps fully below the horizon (D)

In the SQM-L measurements, the darkest average sky brightness value (21.05 m/arcsec^2) was measured NE of the city, on the crest of the Mecsek Mountains. The clearest average sky brightness value (17.85 m/arcsec^2) was recorded in the inner city. The maximum value of VIIRS DNB was 50.46 W cm^{-2} sr^{-1}/pixel in the inner city of Pécs (the minimum is 0 in areas further away from the city).

The difference between the 2011/12 and 2019 data was calculated for both vector and raster layers. For the 155 common points, the largest background brightness increase was found in a newly built part of the Újhegy (24) neighbourhood (+0.40 m/arcsec^2). The highest degree of darkening of the sky background was observed south of the railway station (-0.76 m/arcsec^2) (Figure 2.C).

In the VIIRS DNB images taken between 2012 and 2019, brightness increased most in the eastern part of the city, in an industrial area (+8 W cm^{-2} sr^{-1}/pixel), while brightness dropped most (-12 W cm^{-2} sr^{-1}/pixel)in the central part of Megyeri kertváros (30) (Figure 5.C.3).

The satellite image as a tessellation model can be interpreted as point measurements in a regular grid network extended into a surface. Similarly, a raster GIS layer can be created from surface measurements through conservative methods, Thiessen polygon (THI) and Triangulated Irregular Network (TIN) calculations (with a pixel size of 20×20 meters) to present light pollution and its fluctuations as a continuous surface. However, resolution is spatially variable, since the spatial distribution of the SQM-L measurement locations does not form a unidistance network either. Unfortunately, the number of common ground measurement points is only 155, compared to the number of pixels in the satellite image, of which 407 are located in the interior of Pécs. The interpolation results are shown in Figures 5.A.1-2. and 5.B.1-2. Along with the satellite images, a raster file was also prepared for the raster file showing the difference between the 2011/12 and 2019 data (Figures 5.A.3, 5.B.3).

Average change for the 155 common points between 2011-2019: -0.05 mg/arcsec^2.

Average change for Thiessen polygon surfaces: -0.02 m/arcsec^2; for TIN surfaces: -0.03 m/arcsec^2; for VIIRS DNB layers: -1.77 W cm^{-2} sr^{-1}/pixel.

For the entire area of the city, a very weak light pollution reduction trend can be observed in all cases (although within the measurement error limits).

Data reading at the neighbourhood level allowed the comparison of the raster surface data obtained by different methods and their verification. Using the Zonal Statistics module of the QGIS software, average light pollution values were extracted from the polygons of each city neighburhoods, which were ranked. In Table 2, in the case of the rankings obtained from all three raster surfaces, the 5 darkest neighbourhoods with the clearest sky are marked in blue and the 5 neighbourhoods with the brightest skies are marked in yellow. These show a fairly good match for the raster surfaces generated from two types of data collection, but actually created utilizing three approaches. In Figures 6.A. and 6.B., for both 2011/12 and 2019 it is visible which neighbourhoods were in the first or last 5 places on the list obtained by at least one method. The most light-polluted parts of the city are typically around the inner city, and the parts with the darkest skies are located on the edge (hillslopes with family homes). Between the two dates, it can be observed that Megyeri kertváros (30), which is characterized by blocks of flats and heavy-traffic roads, was excluded from among the most light-polluted neighbourhoods, but Északmegyer and Vágóhíd (13), which have industrial estates and sports fields modernized during the investigation, were included in this group. Szabolcs (27) and Nagyárpád (32) on the outskirts were the least light-polluted neighborhoods.

The above picture is differentiated through the assessment of the neighbourhoods which showed the largest average change in light pollution during the study period. In this case, too, the 5-5 neighbourhoods with the largest average increase or decrease from all three raster layers were identified. In the centre only the light pollution of the inner city (16) increased, while it decreased in the adjacent areas otherwise highly light-polluted compared to 2011. In the east, presumably due to the industrial park, average light pollution in the Balokány and Basamalom neighbourhoods (22) increased. Light pollution increased in the neighborhoods on the edge of the city, with otherwise lower pollution. These are mostly single-family residential areas, where the light pollution may have been caused by large-scale housing construction and the subsequent infrastructure developments that were significantly supported by the government in the last decade. The situation of the city neighbourhoods with the largest average reduction in light pollution is well suited to the alignment of the routes with heavy traffic. In our opinion, the decrease can be largely explained by the fact that the most powerful luminaires were replaced with LED ones as part of the lighting modernization program which started in 2015.

Neighbourhood-level data were also used to check the information from the three raster layers. Since they were obtained from data collection with two different instruments and the dimensions of the measured data are also different (m/arcsec^2 and W cm^{-2} sr^{-1}). Therefore, Spearmann's rank correlation was used based on the average light pollution order of the neighbourhoods from the three data sets (Table 1 THI_R, TIN_R, VIIRS_R The correlation between the THI_R and TIN_R rankings from the same data source is obviously extremely strong (2011: 0.966; 2019: 0.978), but also very strong between rankings of different origins. Between THI_R and VIIRS_R it is 0.893 for 2011 and 0.929 for 2019, while between TIN_R and VIIRS_R 0.905 for 2011 and 0.937 for 2019. The correctness of the research results is confirmed by the rank correlation indicators, that the data from different data collection methods show very similar results.

The raster surfaces derived from our the SQM-L measurements by authors and the VIIRS DNB satellite images are in principle also suitable for mapping light pollution changes below neighbourhood level. Since data collection and data processing methods can be loaded with uncertainty and errors, it is better to highlight only the clear trends through the visual interpretation of these layers. Most of the details are provided by the VIIRS DNB surveys and their difference map (Figure 5.C.1-3). Our previous findings are confirmed by the fact that in both the 2012 and 2019 records, the area around the city center is the most light-polluted, and pollution decreases towards the edges. Compared to the neighbourhood-level studies, the decrease in light pollution along the east-west and north-south axes of the city are better detectable from the VIIRS DNB pixel-level difference map. This reduction, in our opinion, was mainly due to the replacement of lamps along main roads and at bus stations. On the VIIRS DNB difference map, the average light pollution of Megyeri Kertváros (30) has decreased extremely, and an extreme brightening can be observed in the eastern industrial park. However, by our own SQM-L measurements these changes are judged to be of lesser extent. The contradictions partly result from the different spectral sensitivities of devices.

Conclusions

Light pollution changes in Pécs from 2011 to 2019 was mapped based on field measurements and satellite image analyses. The need for the investigation was also justified by the modernization of public lighting in the city since 2015. It was found that average astronomical light pollution, projected over the entire built-up area, probably decreased to a minimal extent, but this reduction is within measurement (uncertainty) limits. The findings are in accordance with other studies (Kolláth et al., 2016). The neighbourhood level study showed that the most light-polluted area of Pécs is the inner city and its vicinity, while the least light-polluted are the regions with family homes on the slopes of the Mecsek Mountains.

Both neighbourhood-level investigations and interpretations of the raster layer with a better spatial resolution showed that along the east-west and north-south axes of the city, astronomical light pollution within the city decreased slightly. In our opinion, this is most likely due to the replacement of luminaires along the main roads. It is sensible installing LED lamps that meet the ULOR = 0 condition, not only to save electricity, but also to reduce astronomical light pollution.

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2011/12	2019	Change 2011-2019
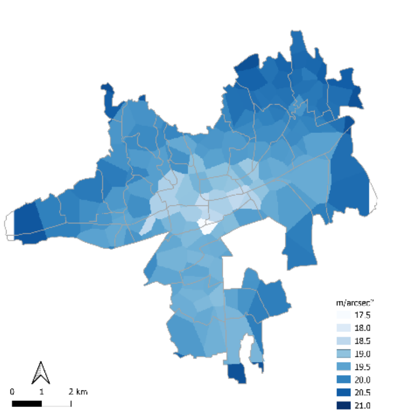	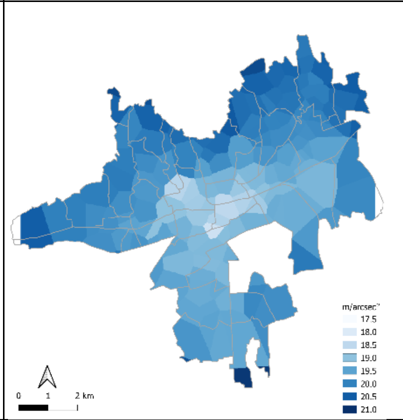	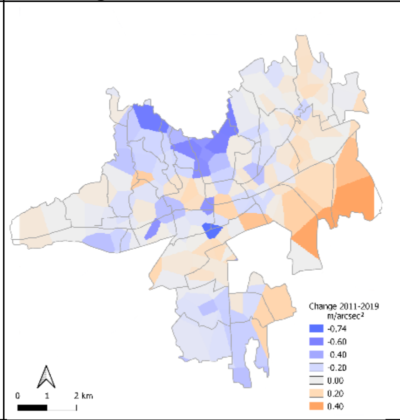
Fig. 5.A.1. Thiessen polygon surface created from the SQM-L measurements in 2011	**Fig. 5.A.2.** Thiessen polygon surface created from the SQM-L measurements in 2019	**Fig. 5.A.3.** Difference of Thiessen polygon surfaces created from the SQM-L measurements in 2011 and 2019
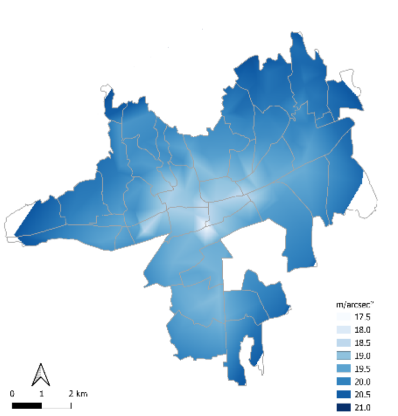	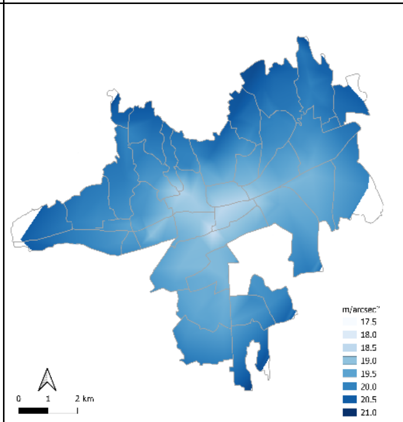	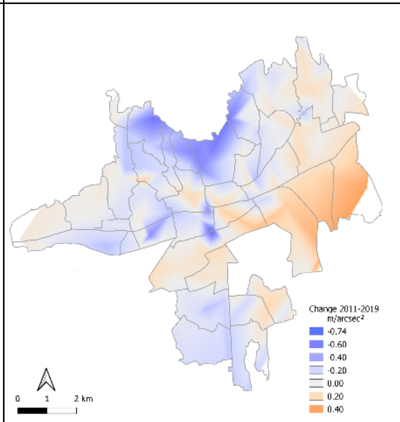
Fig. 5.B.1. TIN surface created from the SQM-L measurements in 2011	**Fig. 5.B.2.** TIN surface created from the SQM-L measurements in 2019	**Fig. 5.B.3.** Difference of the TIN surfaces created in 2011 and 2019
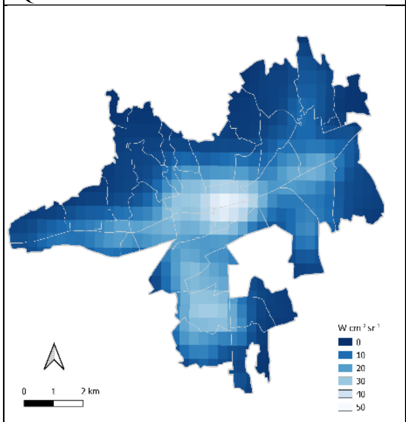	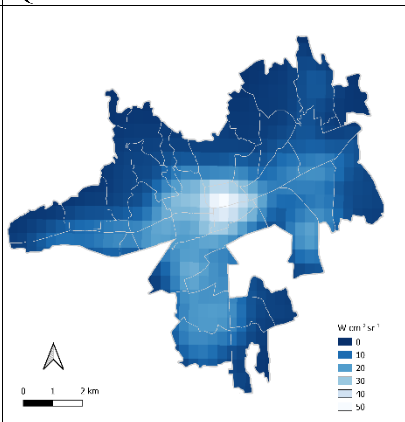	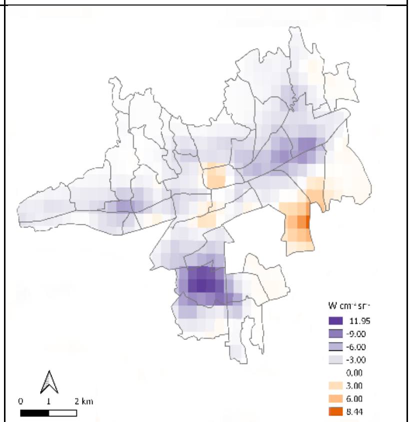
Fig. 5.C.1. Annual average intensity from VIIRS DNB data (2012)	**Fig. 5.C.2.** Annual average intensity from VIIRS DNB data (2019)	**Fig. 5.C.3.** Difference between annual average intensities from VIIRS DNB data between 2012 and 2019

Table 2. Average values and rankings for the neighbourhoods interpreted from raster layers

CQ_ID	2011/2012						2019					
	THI	THI_R	TIN	TIN_R	VIIRS	VIIRS_R	THI	THI_R	TIN	TIN_R	VIIRS	VIIRS_R
1	20,30	3	20,35	3	4,98	8	20,26	4	20,31	4	3,09	6
2	19,88	10	19,86	13	13,29	21	19,98	9	20,00	12	11,25	21
3	19,20	32	19,16	32	21,09	30	19,33	29	19,32	30	20,23	32
4	19,98	8	20,03	10	7,34	13	19,97	11	20,02	9	5,46	12
5	19,50	24	19,45	26	14,54	24	19,56	24	19,54	24	12,10	23
6	18,98	33	18,98	33	26,82	33	19,02	33	19,04	33	24,70	34

7	19,66	17	19,65	19	8,98	15	20,04	8	20,01	10	6,87	14
8	19,54	22	19,60	23	9,21	16	19,75	17	19,82	16	7,97	16
9	19,57	20	19,57	24	7,42	14	19,68	21	19,69	23	7,10	15
10	19,80	14	19,90	12	2,29	4	20,17	6	20,22	6	2,10	5
11	19,85	12	19,91	11	4,40	7	19,98	10	20,00	11	3,53	8
12	20,32	2	20,41	1	1,06	1	20,35	2	20,44	1	0,92	1
13	19,26	31	19,26	31	18,73	27	19,22	32	19,21	32	17,27	29
14	18,84	35	18,84	35	26,66	32	18,99	34	18,98	34	24,48	33
15	18,58	36	18,76	36	36,48	35	18,59	36	18,71	36	35,71	35
16	18,89	34	18,91	34	39,26	36	18,93	35	18,91	35	40,49	36
17	19,52	23	19,53	25	9,96	17	19,86	14	19,86	15	8,28	18
18	19,34	28	19,36	27	14,33	23	19,40	27	19,42	27	10,33	20
19	19,85	11	19,85	15	6,45	12	19,89	12	19,88	14	4,00	9
20	20,10	7	20,07	7	2,06	3	20,23	5	20,28	5	1,62	3
21	19,37	27	19,36	28	19,18	28	19,35	28	19,36	29	13,95	26
22	19,68	15	19,69	17	11,11	19	19,52	25	19,53	25	12,37	24
23	19,48	26	19,62	20	16,16	26	19,28	30	19,38	28	14,29	28
24	20,21	6	20,07	6	5,40	9	19,87	13	19,78	19	5,76	13
25	19,80	13	19,86	14	12,08	20	19,74	18	19,78	18	8,09	17
26	20,29	4	20,29	4	3,48	6	20,31	3	20,32	3	2,08	4
27	20,23	5	20,24	5	6,11	11	20,17	7	20,19	7	4,98	11
28	20,39	1	20,40	2	1,38	2	20,36	1	20,35	2	1,55	2
29	19,34	29	19,33	29	21,99	31	19,25	31	19,26	31	17,60	30
30	19,28	30	19,32	30	28,07	34	19,42	26	19,44	26	18,57	31
31	19,68	16	19,71	16	11,08	18	19,69	19	19,73	20	8,50	19
32	19,96	9	20,04	9	3,04	5	19,81	16	19,96	13	3,48	7
33	19,49	25	19,66	18	13,54	22	19,60	23	19,80	17	11,28	22
34	19,65	18	20,05	8	5,74	10	19,81	15	20,16	8	4,50	10
35	19,55	21	19,61	21	15,41	25	19,67	22	19,72	21	12,70	25
36	19,61	19	19,60	22	20,44	29	19,69	20	19,69	22	14,16	27

CQ_ID = number of neighbourhood (see Fig.1); VIIRS = average pixel values (W cm^{-2} sr^{-1}) from VIIRS DNB surveys of neighbourhoods; VIIRS_R = rankings of pixel values for neighbourhoods from VIIRS DNB surveys; THI = background sky brightness interpreted from the Thiessen polygon surface; THI_R = ranking of average sky brightness of the neighbourhoods interpreted from the Thiessen polygon surface; TIN = value of average background sky brightness interpreted from the TIN surface; TIN_R = average background sky brightness interpreted from the TIN surface

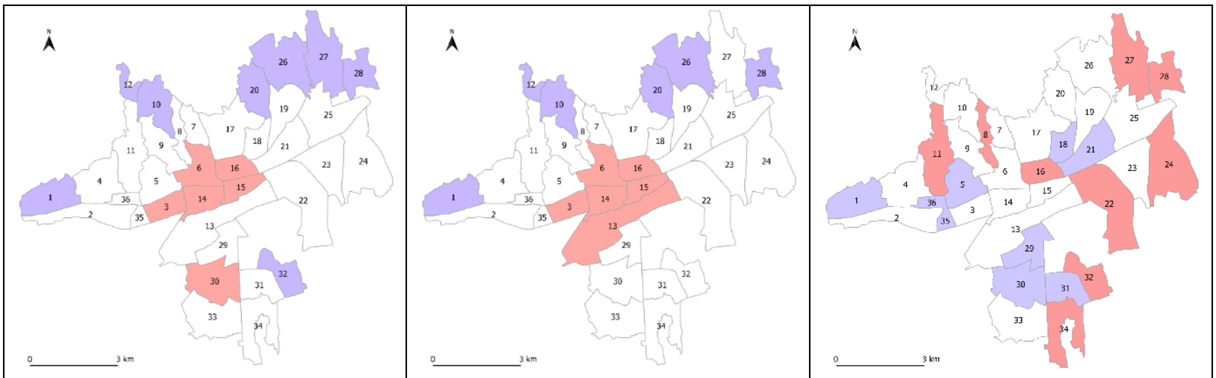

Fig. 6.A. Neighbourhoods with the lowest (blue) and highest level of astronomical light pollution based on THI_R, TIN_R, and VIIRS_R in 2011/12	**Fig. 6.B.** Neighbourhoods with the lowest (blue) and highest level of astronomical light pollution based on THI_R, TIN_R, and VIIRS_R in 2019	**Fig. 6.C.** Neighbourhoods with the lowest (blue) and highest change in astronomical light pollution between 2011/12 and 2019

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