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Light pollution in the night sky of Toruń in the summer season

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Abstract. The paper presents results of research on light pollution in the night sky of Toruń. A permanent network of measuring stations has been established in the city, consisting of 24 sites representing various types of land development and land cover: single-family housing, city centre, multi-family housing, areas overgrown with vegetation and open areas. Within this network, a repeatable direct measurement of the sky brightness using an SQM photometer was carried out over a period of three consecutive months in the summer season, i.e. from June to September 2017. The measurement sessions were conducted in similar weather and astronomical conditions. Based on the obtained data, a spatial distribution of light pollution was determined, ranges of values obtained during the measurements were provided, and the results were additionally referred to the distinguished land cover categories and land development types.

Key words:
light pollution,
SQM,
land use/cover,
Toruń

Introduction

In the rapidly developing world, the environment in which we live and work is exposed to increasingly widespread and previously not analysed types of pollution. People, plants and animals are affected by the deteriorating conditions of the environment (Jechow et al. 2019). The most thoroughly researched forms of pollution, well known to most people, are mainly air pollution (e.g. particulates and ozone), water and soil pollution (e.g. pesticides and heavy metals), landscape pollution, as well as noise pollution and radioactive contamination (Wang et al. 2004; Wyszykowski and Wyszykowska 2007; Para and Para 2013; Woźny et al. 2014; Żurek et al. 2017; Quadri et al. 2019; Wani et al. 2019). Research on these forms of pollution has been continued for many years and the awareness of their prevalence and effects among average citizens is growing.

Light pollution is a form of environmental pollution that has not been previously considered in scientific research. This form has not yet been researched in a comprehensive and multifaceted way and not all factors and parameters related to its occurrence have been determined. Unlike other ecosystem contaminations, most often various physical and chemical factors, light pollution is caused by light, i.e. a factor that is not usually attributed to negative effects of human activity. Nowadays, it is increasingly often analysed as a form of environmental pollution (Hänel et al. 2017). Targeted research, along with regular monitoring, was only started at the end of the last century. In Poland, this type of research is carried out only by several academic research centres (Ściężor et al. 2010; Wojciechowska et al. 2014; Ściężor 2018). The research carried out in the summer season of 2017 in Toruń, described in this paper and based on data acquisition, was aimed at a preliminary assessment of the impact exerted by the selected elements, and additionally constituted an attempt to determine the effect of various types of cloud cover on the measurement of pollution (Fig. 1).

Phenomenon of light pollution

Along with civilizational development, a significant impact of artificial light on the natural environment has been observed. Few people, however, are aware of the phenomenon of light pollution. Light is considered to be something good, therefore we tend not to see its negative effects (Roge-Wiśniewska 2015). Approximately 80% of the world population and over 99% of the US and European population live in areas with a light-polluted sky (Falchi et al. 2011, 2016). These citizens are not able to see the numerous star constellations, not to mention the Milky Way, due to the bright glow that can be seen in the surroundings of even a small town (Fig. 2).

The excess of light causes hormonal disorders, metabolic disorders, melatonin deficiency, slow-wave sleep deprivation and the deterioration of sleep quality in humans (Jones and Francis 2003; Stevens 2009; Depledge et al. 2010; Skwarło-Sońta 2014). The adverse effects of light are also observed in plants (light affects their development) and animals that are adapted to the daily cycle (Jones and Francis 2003; Navara and Nelson 2007; Stevens 2009; Connors 2010; Depledge et al. 2010; Falchi et al. 2011; Zimoch 2017). Excessive optical radiation is also emitted into the upper part of the atmosphere, which makes the illumination costs incurred by municipalities and individuals inefficient or unnecessarily high. Consequently, areas that do not need to be or should not to be illuminated are lighted.

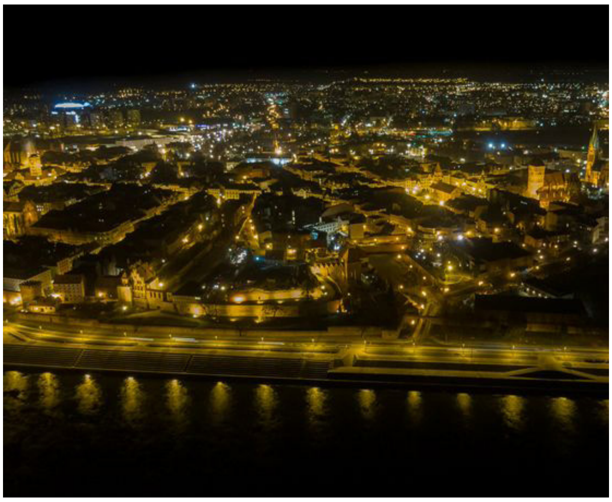

Fig. 1. View of the Toruń Old Town, source: https://farm5.static.flickr.com

Fig. 2. A photo of Orion's constellation visible, with the same setting of camera, from a place far away from the artificial light source (left) and from medium-sized agglomerations like a Toruń, source: https://pl.wikipedia.org/wiki/Zaniezyszczenie_świetlne

The amount of light emitted at night is determined by several factors, including, in addition to the technical conditions mentioned above, both the density and relative height of buildings as well as the type of land cover in the vicinity of an observation point (Kocifaj 2007; Ściężor et al. 2010).

Measurement network and methods

Light pollution can be measured in a number of ways. The methods employed can be classified into instrumental and observational. The two groups of methods are applied both by amateurs and professionals.

The method selected to achieve the objectives of the presented research was an instrumental method using a professional SQM L-version photometer

Fig. 3. SQM photometer version L from Unihedron (SQM-L), source: http://unihedron.com/projects/sqm-l/

manufactured by Unihedron, Canada (Fig. 3). Table 1 presents some of the technical parameters of the photometer. Using this type of photometer allow us to compare our results with those obtained by other research teams around the world (Kolláth 2010; Ściężor et al. 2010; Pun et al. 2013; Hänel et al. 2017; Jechow et al. 2019).

In order to achieve the objectives of this project, a permanent measurement network was established in Toruń, representing all characteristic types of land development.

The sites of the measurement network are located all over the city, forming a relatively even distribution. Each site represented a specific type of urban development. The sites were selected in such a way as to be easily accessible by road transport, while maintaining the greatest possible distance from street lamps and buildings as well as various field diaphragms that may have a significant impact on the readings. Free access to each station was conditioned by the assumptions of the project. The entire route between the sites was followed in each measurement session, moving between the measuring stations using a car. The measurement was taken at a strictly defined time depending on the position of the Sun on the horizon. In order for the measurements to be carried out correctly, each measurement had to be made at the time of the Sun's lowest position below the horizon (Fig. 4). No astronomical night occurred in the summer at the latitude corresponding to the location of the selected city, which would guarantee the least influence of the sunlight scattered in the atmosphere on the accuracy and correctness of the measurements. The route during one measurement session was 45 km and the average time of the trip was less than 2 hours.

Each station established within the measurement network was checked for compliance with the required measurement conditions, both during the day and at night. In addition, four reference sites

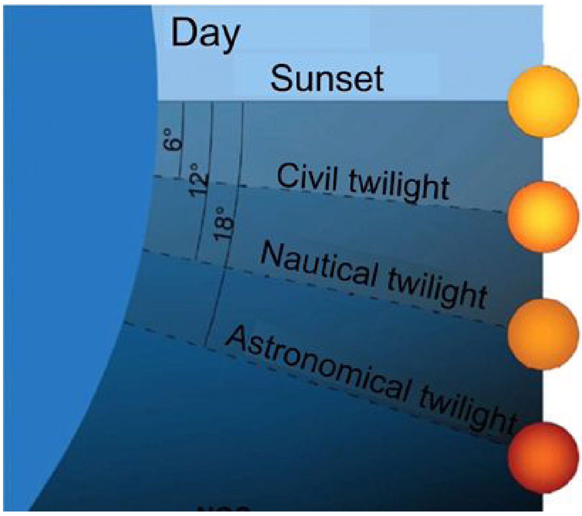

Fig. 4. Three types of twilight

Table 1. Selected technical data of the Unihedron SQM photometer

Total weight	**0.14 kg**
Dimensions	**9.2 x 6.7 x 2.8 cm**
Light sampling time	**about 8 seconds**
Maximum light sampling time	**80 seconds**
Angle of light registration	**20°**
Recorded bandwidth	**visible range (filter for infrared range)**
Temperature	**°C and °F**

source: http://unihedron.com/projects/sqm-l/

were selected outside the city limits, which served as a background for measurements in the urban area. After taking all the assumptions into account, the measurement network consisted of 24 sites (Fig. 5).

Table 2 give locations of selected measurement stations. The type of land development surrounding a specific measurement station was marked with appropriate colours (see the legend under the Table 2).

Results of the conducted measurements

Repeatable measurement sessions of the sky brightness were started when all the stations were established in accordance with the project assumptions. In the described summer season, a total of nine measurement sessions were carried out, including three sessions with mostly cloudy sky and six sessions with a cloudless sky.

Spatial analysis of the summer sky brightness

Spatial distribution of light pollution in Toruń was determined based on average values obtained during the summer season. Data interpolation was carried out using the kriging method in the ArcGIS (Esri) environment, which enables multifaceted spatial analysis. The obtained interpolation result for the data concerning the average value of sky brightness for the summer season is presented in Figure 6.

The obtained spatial distribution shows that we can distinguish three areas in the city with significantly higher brightness of the night sky (marked with yellow and red colour) compared to other areas. They include the city centre, where Toruń Old Town with its compact development is located, Rubinkowo – a large housing estate with tall multi-family buildings and Wrzosy – a single-family housing estate located in the north-western part of the city. The darkest areas, marked in blue and navy blue, are the zones located far from the functional and geometric centre of the city.

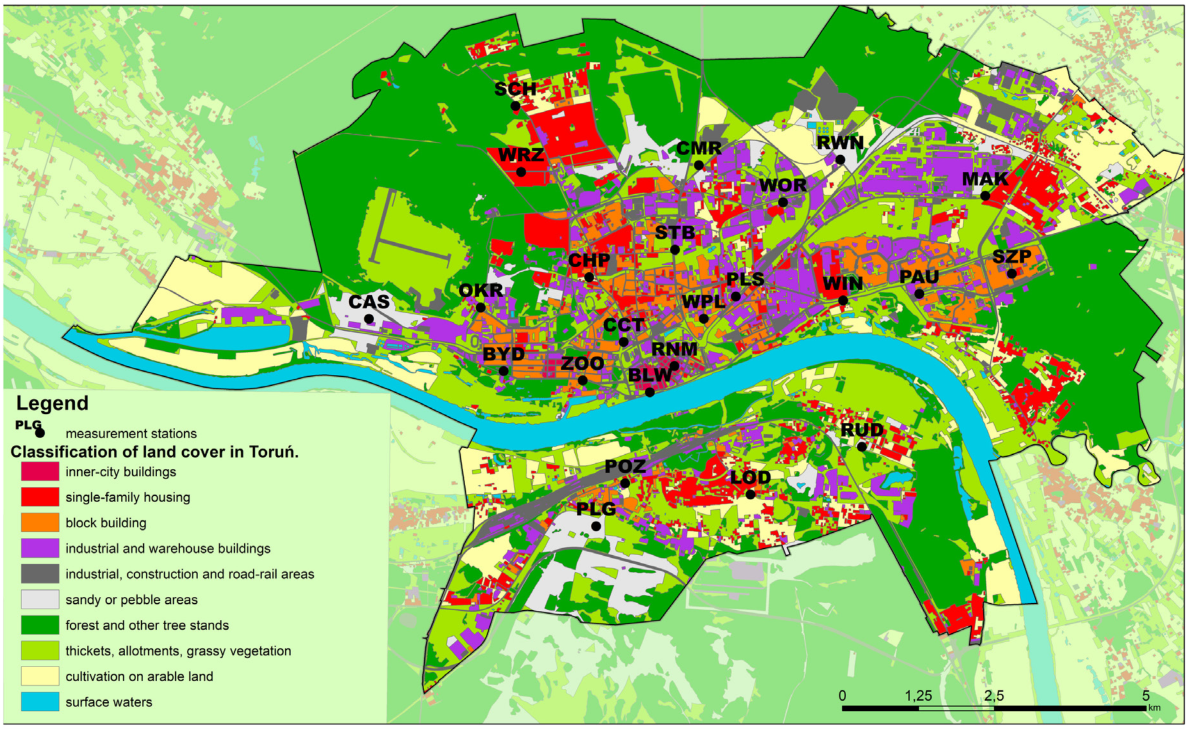

Fig. 5. Map of land use/cover of Toruń based on 1:10,000 scale database

Table 2. List of measuring stations in the area of Toruń

No.	CODE	Location of measuring stations (street names)	Coordinates PUWG 1992		Altitude [m a.s.l.]
			X	Y	H
1	SCH	Pawia	576187.00	471317.00	69.0
2	WRZ	Antoniego/Jastrzębia	575100.00	471409.00	68.5
3	CHP	Józefa Wybickiego/Kurpiowska	573364.00	472532.00	65.0
4	OKR	Szosa Okrężna/ul. Bielańska	572866.00	470743.00	49.5
5	CAS	Szosa Bydgoska	572679.00	468902.00	42.0
6	BYD	Szosa Bydgoska	571819.00	471121.00	49.5
7	ZOO	Bydgoska/Jana Matejki	571665.00	472424.00	50.0
8	BLW	Bulwar Filadelfijski	571471.00	473531.00	39.5
9	RNM	Rynek Nowomiejski	571902.00	473936.00	49.0
10	CCT	Aleja 700-lecia Torunia/ Konstantego Ildefonsa Gałczyńskiego	572300.00	473100.00	50.5
11	POZ	Poznańska/Marii i Jana Prüfferów	569971.00	473123.00	47.5
12	PLG	Generała Andersa	569264.00	472646.00	55.5
13	LOD	Łódzka	569786.00	475189.00	50.0
14	RUD	Rypińska	570570.00	477027.00	47.0
15	WIN	Winnica	572982.00	476717.00	60.0
16	PAU	Konstytucji 3-go Maja	573092.00	477972.00	67.5
17	SZP	Kosynierów Kościuszkowskich	573424.00	479497.00	64.5
18	MAK	Józefa Chrzanowskiego/Barwna	574707.00	479057.00	66.5
19	RWN	Polna/Równinna	575302.00	476669.00	66.5
20	WOR	Polna/Kanałowa	574601.00	475726.00	65.0
21	PLS	Bolesława Chrobrego	573049.00	474948.00	60.5
22	WPL	Wojska Polskiego	572682.00	474418.00	60.0
23	STB	Grudziądzka	573820.00	473946.00	62.0
24	CMR	Celnicza	575211.00	474340.00	62.5

single-family housing
industrial, construction and road-rail areas
high-rise building
city centre buildings
industrial and warehouse buildings
thickets, allotments, grassy vegetation
forests and other tree stands
sandy or gravelly areas

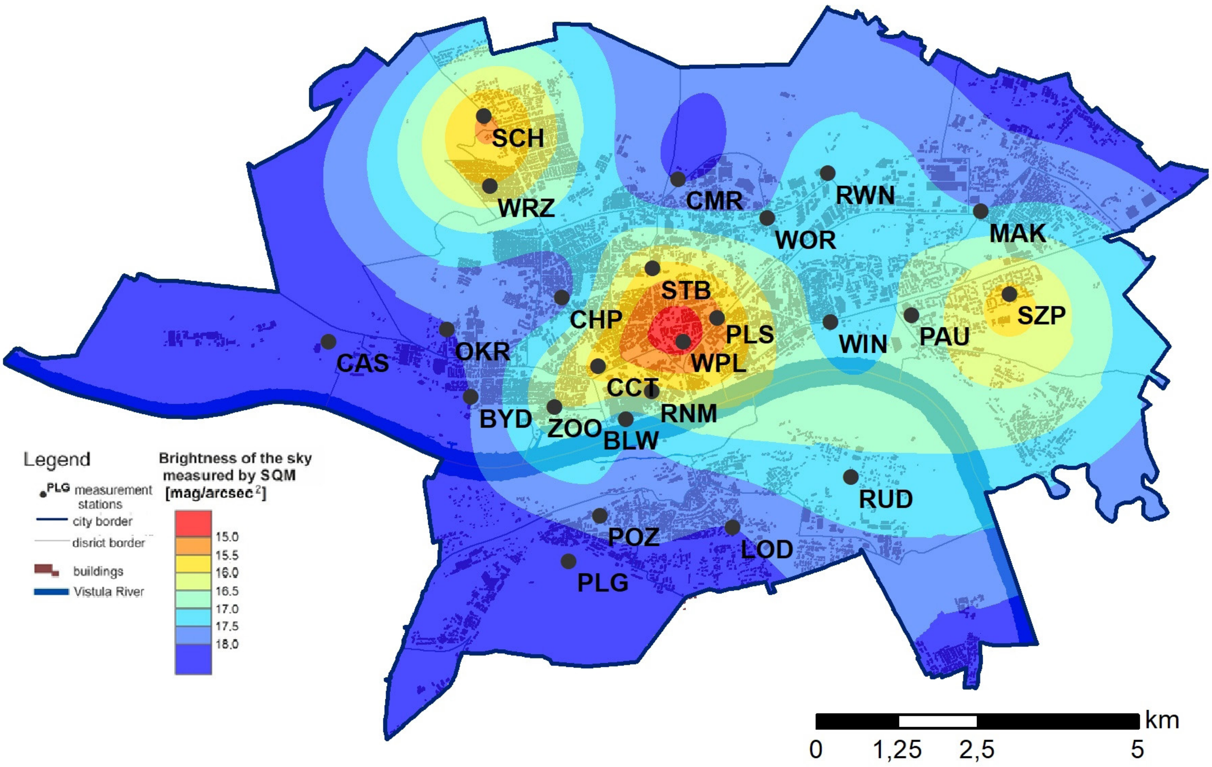

Fig. 6. Spatial distribution of the light pollution in summer; interpolation – empirical Bayesian kriging

Analysis of sky brightness in relation to the type of land development

The analysis of light pollution of the night sky in relation to the type of land development was performed based on the existing classification of the land cover (Kunz et al. 2012) (Fig. 5). The sites were assigned to the corresponding land cover classes created by the integration of available spatial databases on a scale of 1:10,000. For each category of land cover, the average sky brightness was calculated from the summer measurements and broken down into the degree of cloudiness (Table 3).

The highest sky brightness was observed in areas with single-family housing and high-rise buildings and in the city centre; its average value was about 16 mag/arcsec^2. The darkest sky was observed in sandy and gravelly areas, where average brightness reached 18 mag/arcsec^2. The difference between the brightest area and the darkest one is about 2 mag/arcsec^2, which means over six times brighter sky. There are differences between the brightness of a mostly cloudy and slightly cloudy sky. It is worth noting that for high-density housing, the brightness of the sky during mostly cloudy nights is higher compared to cloudless nights. The difference is about 1 mag/arcsec^2, which corresponds to a 2.5 times brighter sky. Another conclusion is the observation that the smallest difference occurs in areas with dense land development, where the sky is so bright that the cloud cover does not have a great impact on the observed brightness of the sky, as shown in the diagram below (Fig. 7). The opposite is true in areas far from built-up areas, where the difference is greater than in densely built-up areas.

Figure 8 shows the relationships between the brightness of the night sky and the type of land development surrounding a measurement station.

On this visual juxtaposition, the sites are ranked on the basis of the distance from the illuminated road and the existing buildings. The visualization according to this criterion shows the tendency of the measured night sky brightness to decrease with the distance from the traffic routes and buildings illuminated at night. In the first part of the figure we can see the dominance of sites classified as single-family and multi-family housing, while on the right side – open land sites.

Table 3. Mean values of summer measurements in relation to land cover

CODE of measuring station	Classification of land cover	Average light pollution in summer [mag/arcsec^2]		
		general average	average in days with high cloudiness	average in days with little cloudiness
SCH WRZ	single-family housing	15.67	15.14	15.93
CCT	industrial, construction and road-rail areas	15.67	15.17	15.92
CHP ZOO PAU SZP WPL	high-rise building	16.32	15.69	16.63
BLW RNM	city centre buildings	16.80	15.86	17.27
OKR POZ RWN WOR PLS STB	industrial and warehouse buildings	16.66	16.16	16.91
WIN MAK CMR LOD	thickets, allotments, grassy vegetation	17.72	16.80	18.17
BYD	forests and other tree stands	18.01	16.96	18.53
CAS PLG RUD	sandy or gravelly areas	18.04	17.28	18.43

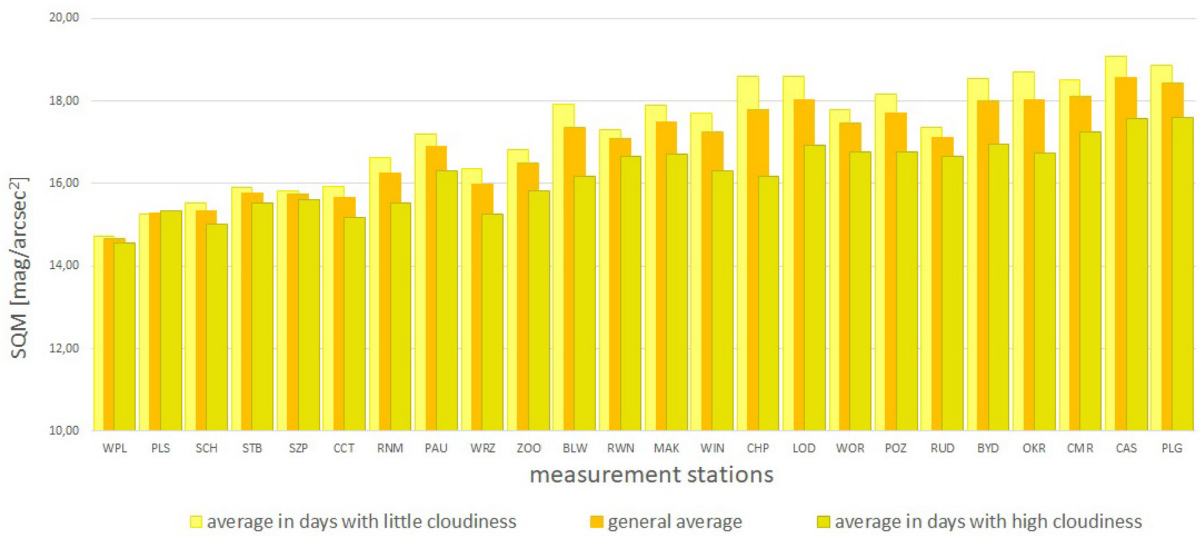

Fig. 7. Average values of the sky brightness measured with the SQM photometer in the summer

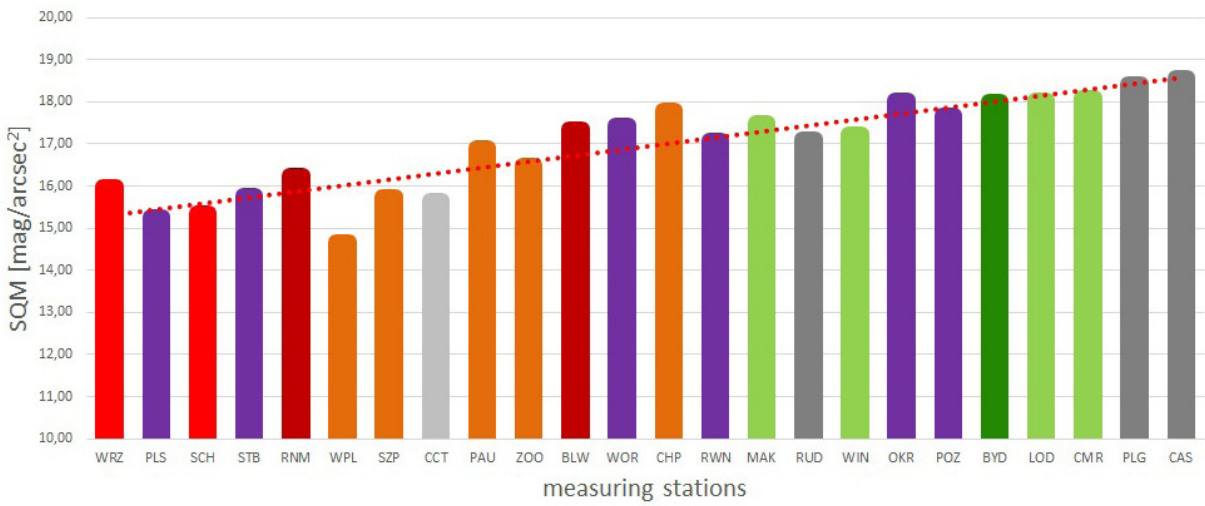

Fig. 8. Average sky brightness measured in summer with the SQM photometer. Measuring stations arranged in terms of distance from the road and buildings

Conclusions

Light pollution as a relatively new issue is currently under intensive research and scientists from various institutions are increasingly interested in this issue, both in terms of understanding the causes and determining its effects. The problem of excessive light emission at night is becoming more and more common and is becoming a phenomenon subject to observations and systematic monitoring. The applied research methods and visualizations of collected measurement data are varied.

Light pollution is affected by a number of factors, including the scale of the cloud cover and the type of land cover close to observation points. Based on the conducted research, it can be concluded that the brightest values are characteristic for densely built-up areas, representing large concentrations of single-family and multi-family housing and city centre buildings. The increase in the brightness of the sky in these areas is caused by the large number of street lamps and the presence of illuminated billboards and neon lights, the number of which is constantly increasing. On the other hand, the darkest places are open areas, located far from densely built-up areas and adjacent industrial areas. Observations of the dark sky is also facilitated by a long distance to illuminated traffic routes and buildings. At the sites with high light pollution, it has been observed that the degree of cloudiness has no significant impact on the measurement of sky brightness. This factors, on the other hand, affect the measurements of this phenomenon in areas with a dark sky.

The obtained results are interesting to the extent that the measurement of the night sky brightness will be carried out within the established network over a longer period of time, taking all seasons of the year into account. Research on the sky brightness is an interdisciplinary topic and it is necessary to determine its limitations and impact on the elements associated with our lives.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author Contributions

Study design: D.K., M.K.; data collection D.K., M.K.; statistical analysis D.K., M.K.; interpretation of results D.K., M.K.; preparation of manuscript D.K., M.K.; literature review: D.K., M.K.

References

CONNORS BM, 2010, Effect of artificial light on marine invertebrate and fish abundance in an area of salmon farming. *Marine Ecology Progress Series* 419: 147–156.

DEPLEDGE M, GODARD-CODDING CAJ and BOWEN R, 2010, Light pollution in the sea. *Marine Pollution Bulletin* 60(9): 1383–1385.

FALCHI F, CINZANO P, ELVIDGE C, KEITH D and HAIM A, 2011, The expanding use of light at night is due to the fact that humans are diurnal animals that are trying to extend activities into the usually dark hours. *Journal of Environmental Management* 92: 2714–2722.

FALCHI F, CINZANO P, DURISCOE D, KYBA CCM, ELVIDGE C, BAUGH K, PORTNOV B, RYBNIKOVA N and FURGONI R, 2016, The new world atlas of artificial night sky brightness, *Science Advances* 2: 1–25.

HÄNEL A, POSCH T, RIBAS SJ, AUBÉ M, DURISCOE D, JECHOW A, KOLLÁTH Z, LOLKEMA DE, MOORE C, SCHMIDT N, SPOELSTRA H, WUCHTERL G and KYBA CCM, 2017, Measuring night sky brightness: methods and challenges. *Journal of Quantitative Spectroscopy and Radiative Transfer* 205: 278–290.

JECHOW A. RIBAS SJ, CANAL-DOMINGO R, HÖLKER F, KOLLÁTH Z and KYBA CCM, 2019, Tracking the dynamics of skyglow with differential photometry using a digital camera with fisheye lens. *Journal of Quantitative Spectroscopy and Radiative Transfer* 209: 212–223.

JONES J and FRANCIS CM, 2003, The effects of light characteristics on avian mortality at lighthouses. *Journal of Avian Biology* 34: 328–333.

KOCIFAJ M, 2007, Light pollution model for cloudy and cloudless night skies with ground-based light sources. *Applied Optics* 46(15): 3013–3022.

KOLLÁTH Z, 2010, Measuring and modelling light pollution at the Zselic Starry Sky Park. *Journal of Physics Conference Series* 218(1): 012001.

NAVARA KJ and NELSON RJ, 2007, The dark side of light at night: physiological, epidemiological, and ecological consequences. *Journal of Pineal Research* 43(3): 215–224.

PARA A and PARA A, 2013, Świadomość skażenia otoczenia człowieka radonem. *Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska* 59: 88–97.

PUN CSJ, SO CW, LEUNG WY and WONG CF, 2013, Contributions of artificial lighting sources on light pollution in Hong Kong measured through a night sky brightness monitoring network. *Journal of Quantitative Spectroscopy and Radiative Transfer* 139: 90–108. doi: http://doi.org/10.1016/j.jqsrt.2013.12.014

QADRI R and FAIQ MA, 2019, Freshwater Pollution: Effects on Aquatic Life and Human Health. *Fresh Water Pollution Dynamics and Remediation*. Springer Press, Singapore.

ROGE-WIŚNIEWSKA M, 2015, Światło – Dobrodziejstwo czy problem? [In:] *Przejdź na ciemną stronę nocy. Środowiskowe i społeczne skutki zanieczyszczenia światłem*, (eds) Roge-Wiśniewska M, Tomasik K, Wyd. Uniwersytetu Warszawskiego, Warszawa.

ŚCIĘŻOR T, KUBALA M, KASZOWSKI W and DWORAK TZ, 2010, *Zanieczyszczenie świetlne nocnego nieba w obszarze aglomeracji krakowskiej. Analiza pomiarów sztucznej poświaty niebieskiej*, Wyd. Politechniki Krakowskiej, Kraków.

ŚCIĘŻOR T, 2018, *Naturalne i antropogeniczne czynniki łuny świetlnej nocnego nieba*. Monografie Politechniki Krakowskiej, Kraków.

SKWARŁO-SOŃTA K, 2014, Melatonina: hormon snu czy hormon ciemności? *Kosmos, Problemy Nauk Biologicznych* 63(2): 223–231.

STEVENS RG, 2009, Light-at-night, circadian disruption and breast cancer: assessment of existing evidence. *International Journal of Epidemiology* 1–8.

WANG LK, PEREIRA NC and HUNG YT, 2004, Air Pollution Control Engineering. *Humana Press Inc*., Springer Science+Business Media New York.

WANI KA, MANZOOR J, DAR AA, SHUAB R and LONE R, 2019, Heavy Metal Intrusion and Accumulation in Aquatic Ecosystems. *Fresh Water Pollution Dynamics and Remediation*. Springer Press, Singapore.

WOJCIECHOWSKA A, WIŚNIEWSKA A and BARCIKOWSKI A, 2014, Zanieczyszczenie światłem – ekologiczny problem współczesnego miasta. *Prace i Studia Geograficzne* 53: 109–128.

WOŹNY A, DOBOSZ M and PACANA A, 2014, Wpływ hałasu na jakość pracy. *Humanities and Social Sciences*, 19(2): 251–258.

WYSZKOWSKI M and WYSZKOWSKA J, 2007, Zanieczyszczenie gleby kadmem a zawartość makropierwiastków w roślinach. *Ochrona Środowiska i Zasobów Naturalnych* 31: 231–235.

ZIMOCH J, 2017, Sztuczne światło przeszkadza nocnym owadom w zapylaniu kwiatów, http://wyborcza.pl/7,75400,22233046,sztuczne-swiatlo-przeszkadza-nocnym-owadom-w-zapylaniu-kwiatow.html (02.06.2018).

ŻUREK ZH, JASIŃSKI T, GLINKA T and SOBOTA J, 2017, Pole magnetyczne wokół transformatorów energetycznych. *Przegląd Elektrotechniczny* 1(11): 54–56.

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