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Measurement and Determination of Light Pollution: Case Study of Malatya City

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Abstract
In this study, measurements of light pollution in and around Malatya city center were carried out by means of parcelization and mapping method with SQM (Sky quality meter) device. Measurements were carried out in the east, west, north and south directions at 5° intervals between the zenith and horizon in 7 regions in order to determine the effect of angle dependence in 84 points at the zenith references. Measurements which are taken in the lowest (bright) and highest (dark) regions measured are 16.53 mag arcsec^{-2} and 20.68 mag arcsec^{-2}, respectively (Puschnig et al. 2014). Accepting the atmosphere permeability as 73%, the total amount of light lost (escaping into space and scattered back from the atmosphere) was calculated as $\sim 3.44 \times 10^7$ lm. The angle dependence effect participated in the calculations and the luminous flux emitted towards the upper half space originating from the unnecessary use of artificial light was calculated as 4540973 lm. This value was calculated as 0.56 Mlm h (megalumen-hour) per year. In the city, street lighting, billboards, lighting on the exteriors of the buildings are considered to be active for approximately 12 hours a day and the amount spent was calculated as 441,720 kWh per month. This calculated value corresponds to 26.99% of the approximate monthly electricity amount (1 636 064.2 kWh per month) causing light pollution.

Key words: Light pollution – SQM device – Calculation of wasted energy amount

1 Introduction

One of the fastest growing and fastest spreading varieties of pollution is light pollution in the world (Chepesiuk 2009). Light pollution affects the natural environment and ecosystem globally (Pun et al. 2014). Luminous flux systems preferred in the wrong place, wrong amount, wrong direction and time constitute the most important cause of light pollution (Aslan 2018). With the enrichment of countries, increasing urbanization has increased the demand for outdoor lighting and light pollution has spread outside the urban centers to the suburbs and countryside. Light pollution causes significant energy losses and in return large material losses and visual pollution. Light pollution negatively affects astronomical observations as well as the 24-hour natural cycle processes of humans and animals, and the natural relationship between living things day and night. The unconscious rapid increase of light pollution forms a great threat to the health of living things, the economy of the states and astronomical studies. Wasted energy and exhausted natural resources mean light pollution from inefficient use of artificial light systems. The sources with the largest share of primary energy production in the world are oil, coal and natural gas, respectively. Looking at the distribution of energy sources consumed on earth, 2/3 of the consumption is provided from hydrocarbon sources. Today, the largest share in energy production is provided by fossil fuels with a rate of 87%, while the remaining 13% is provided by nuclear energy and renewable energy sources (Aksoy 2016). The majority of the energy source used for lighting systems consists of natural sources and it is important how much of the energy used in lighting is wasted and how the amount wasted can be minimized. The light pollution problem solution is a local, but global problem (Aslan 2018). In order to solve this problem, which has a local solution, the study carried out by Inönü University calculated the amount of energy wasted by measuring the brightness of the sky in Malatya city center and its environs. Results were reported and recommendations were made for local institutions to take measures to reduce wasted energy.

2 Material And Methods

As seen in Fig. 1 and 2 the SQM device detects light emitted in the direction of the device sensor within the boundary of 20°. SQM refers to the sky brightness value expressed as the read value by converting it to the "mag arcsec^{-2}" unit. The SQM device measures somewhat the amount of darkness in the night sky. SQM device calculations:

$$m = 21.58 - 5 \log 10^{1.568-(m_s/5)} - 1 \qquad (1)$$

The Eq. 1 is done by using m: mag arcsec^{-2}, m_s: limit is the value of magnitude. However, zenith-only single-band single-channel devices such as the "Sky Quality Meter" remain a viable option for long-term studies of night sky brightness and for work from a mobile platform (Hänel et al. 2018). There is no possibility to read values greater than 22.0 magnitude with the SQM device (Pravettoni et al. 2016). In our study, measurements were taken using the SQM (Sky Quality Meter).

For measurements, Malatya city center and its surroundings were divided into approximately 2×2 km^2 grid within the target area with a length of 19 km along the east-west directions and 17 km along the north-south directions. The midpoint of each rectangular grid was determined and the coordinates (latitude and longitude) of these points were recorded. The recorded latitude and longitude values were used to reach the target destination point desired by entering GPS instruments. Measurements were repeated at least 5 times with intervals

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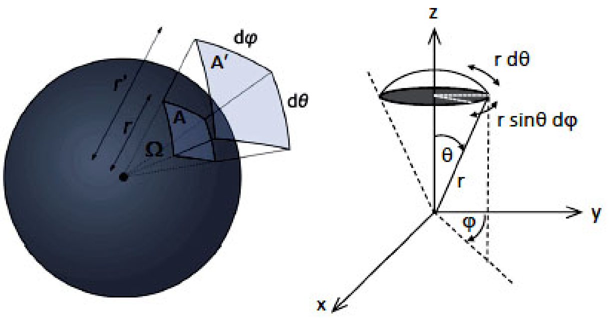

Figure 1. Definition of angle in spherical coordinate system and solid angle (Aslan 2018).

of at least 3 sec in the direction of the zenith at 84 points consisting of the target points or close ones determined as far as by land conditions and lighting systems allow. Of the repeated measurement values, the most repeated (mod) or averages were assigned as the sky brightness (light pollution) value of each region. The measurements results are shown in Table 1. The measurements taken in the lowest (luminous) and highest (dark) regions measured are 16.53 mag arcsec^{-2} and 20.68 mag arcsec^{-2}, respectively. As seen in Fig. 3, the values measured in the field and recorded together with their coordinates have been processed on the numerical map on the Geographic Information Systems (GIS) software database. In order to better evaluate the differences between the values, the number values representing the darkest and brightest values were divided into 0.1 digit values by an algorithm registered in the Surfer 15 Program database and the colorization was done and the equivalent brightness curves were obtained and shown in Fig. 4.

SQM device measures the amount of light mag arcsec^{-2} in the area within the cone boundaries whose peak angle is $A = 20°$ in

$$L = 10.8 \times 10^4 \cdot 10^{-0.4m} \tag{2}$$

L: Luminous Intensity per unit area in cd m^{-2}, m: sky brightness read from SQM in mag arcsec^{-2}

The Enlightenment corresponding to the value of m read; the amount of luminous flux per unit area.

$$L\Omega = 10.8 \times 10^4 \cdot 10^{-0.4m} \iint \sin\theta \, d\theta \, d\varphi \tag{3}$$

It was calculated by Eq. 3 where E: Enlightenment (luminous flux per unit area) in lm m^{-2} and

$$\Omega = \iint \sin\theta \, d\theta \, d\varphi = \int_{\varphi 1}^{\varphi 2} \int_{\theta 1}^{\theta 2} \sin\theta \, d\theta \, d\varphi \tag{4}$$

The Ω given in Eq. 4 represents the solid angle at which the field of view of the given SQM instrument corresponds. The angles where θ and φ angles match in spherical coordinates are indicated in Fig. 1.

$$\Omega = \int_0^{2\pi} d\varphi \int_0^{\pi/2} \sin\theta \, d\theta = 2\pi \tag{5}$$

The luminous flux per unit area from the entire hemisphere will be $E_0 = 2\pi L$.

If the light pollution values are considered to be constant in all directions and angles, the solid angle will be a hemispherical with homogeneous light distribution in the enlightenment calculations. If the luminous flux is calculated according to angles from the zenith values (as you move from zenith to horizon, the value read in SQM will decrease), the smallest value of light pollution will be calculated (Aslan 2017). The unit of flux (lm m^{-2}) values given in Eq. 3 were multiplied by the area of the measured in for main directions. Luminous flux in lumen unit for each surface area;

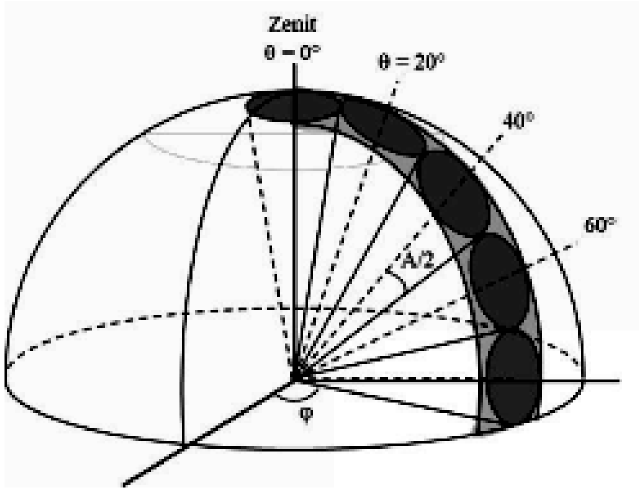

Figure 2. Solid angle diagram used in calculations for areas of sky brightness measurement Aslan (2018).

$$\phi_{0i} = E_{0i} A_i \tag{6}$$

A_i is the surface area of the i^{th} section. E_{0i} is the corresponding minimum luminous flux per unit area derived from SQM readings.

These calculations were repeated and collected for each region and the total luminous flux in each direction was calculated, as shown in Eq. 7.

$$\phi_{\text{total, minimum}} = \phi_0 = \sum_{i=1}^{n} E_{0i} A_i \tag{7}$$

The minimum value of total flux calculated for Malatya city center and its surroundings was calculated at 9.31×10^6 lm. Values measured with SQM are the amount of light directed towards the earth by scattering the molecules in the atmosphere Aslan (2018). The atmospheric permeability was considered to be 73% so the total amount of Light lost (escaping into space and scattering back from the atmosphere) is approximately 3.7 times the calculated value of 9.31×10^6 lm. That is, the sum total was calculated to be 3.44×10^7 lm. The effect of direction and angle concepts must also be taken into account to achieve the true value of light pollution. In order to determine the direction and angle effect the SQM values and calculations read from 7 different locations in different directions and angles are shown in Table 2. The data measured with the SQM device varies depending on the region (position), direction (φ) and angle (θ) in which it is measured. The value of m in Eq. 1 measured by the SQM instrument is a function dependent on θ and φ; $m = m(\theta, \varphi)$. If θ and φ are added to the previously obtained luminous flux equation, the resulting luminous flux

Table 1. SQM values read in 85 different locations. m: SQM Value (mag arcsec^{-2}), L: Brightness (cd m^2), A: Surface Area (m^2), I: Light Intensity (lm), E: Luminous Flux per Area (lm m^2), Φ: Luminous Flux (lm). $A_{total} = 30102836.40$. $I_{total} = 1481398.7000$. $\Phi_{total} = 9307902.5640$.

(m)	(L)	(A)	(I)	(E)	(Φ)	(m)	(L)	(A)	(I)	(E)	(Φ)
18.13	0.00604538	3526286.42	21317.7488	0.037984256	133943.3660	17.96	0.00707007	4165987.64	29453.8271	0.044422564	185063.8535
18.99	0.00273794	3625287.33	9925.8153	0.017202978	62365.7367	16.53	0.02638905	3495612.10	92245.8824	0.165807291	579597.9728
19.43	0.00182568	4065874.39	7422.9701	0.011471062	46639.8969	17.58	0.01003284	3541121.40	35527.4937	0.063038174	223225.8266
19.33	0.00200181	3498995.52	7004.3388	0.012577769	44009.5584	17.83	0.00796937	3225149.40	25702.3950	0.050073001	161492.9104
20.05	0.00103139	3488974.40	3598.5003	0.006480427	22610.0440	18.58	0.00399414	3489455.50	13937.3889	0.025095949	87571.1974
19.78	0.00132259	3654758.14	4833.7301	0.008310050	30371.2220	18.64	0.00377941	3516154.26	13288.9808	0.023746720	83497.1292
18.26	0.00536320	3598994.60	19302.1173	0.033697961	121278.7798	18.14	0.00598996	3521146.70	21091.5198	0.037636014	132521.9272
18.76	0.00338395	3496657.32	11832.5086	0.021261976	74345.8441	17.45	0.01130899	3533454.57	39959.7965	0.071056469	251074.8060
19.20	0.00225644	3425045.66	7728.4094	0.014177630	48559.0285	17.51	0.01070099	3687452.20	39459.3707	0.067236272	247930.5382
20.00	0.00108000	3689846.64	3985.0344	0.006785840	25038.7094	18.10	0.00621475	3512179.40	21827.3216	0.039048434	137145.1062
18.91	0.00294730	3478854.60	10253.2143	0.018518407	64422.8452	17.78	0.00834495	3498786.79	29197.2019	0.052432869	183451.4302
18.89	0.00300209	3566458.45	10706.8304	0.018862690	67272.9996	17.32	0.01274746	2987652.21	38084.9856	0.080094671	239295.0219
19.34	0.00198346	2998745.44	5947.8959	0.012462456	37371.7319	18.26	0.00536320	3549487.50	19036.6010	0.033697961	119610.4915
19.16	0.00234112	3556512.67	8326.2245	0.014709694	52315.2113	18.33	0.00502833	3568546.50	17943.8287	0.031593928	112744.4011
18.91	0.00294730	3515146.63	10360.1776	0.018518407	65094.9158	20.68	0.00057733	4036894.84	2330.61851	0.003627468	14643.7080
18.91	0.00294730	3468875.36	10223.8025	0.018518407	64238.0456	18.64	0.00377941	3502015.60	13235.5451	0.023746720	83161.3824
17.85	0.00782391	3458567.25	27059.5133	0.049159066	170019.9361	18.03	0.00662863	3778956.40	25049.3025	0.041648908	157389.4092
18.87	0.00305790	3499456.48	10700.9997	0.019213373	67236.3642	20.00	0.00108000	3587456.22	3874.45272	0.006785840	24343.9044
20.03	0.00105057	3589874.52	3771.4037	0.006600907	23696.4284	18.17	0.00582672	3516178.62	20487.7697	0.036610328	128728.4538
20.14	0.00094934	3854624.50	3659.3659	0.005964906	22992.4739	18.73	0.00347875	3475855.60	12091.6476	0.021857658	75974.0625
19.49	0.00172752	3445896.42	5952.8642	0.010854345	37402.9488	18.17	0.00582672	3501026.48	20399.4825	0.036610328	128173.7290
18.24	0.00546291	3465627.55	18932.3987	0.034324453	118955.7696	18.71	0.00354343	3475485.45	12315.1365	0.022264022	77378.2848
18.92	0.00292028	3589896.24	10483.4844	0.018348629	65869.6749	18.30	0.00516921	3625149.46	18739.1407	0.032479073	117741.4935
18.94	0.00286697	3845498.65	11024.9447	0.018013729	69271.7704	19.17	0.00231966	3526568.54	8180.4291	0.014574834	51399.1519
17.83	0.00796937	3186476.85	25394.1993	0.050073001	159556.4597	18.88	0.00302987	2989685.40	9058.3531	0.019037224	56915.3112
17.68	0.00915006	3512457.32	32139.1814	0.057491498	201936.4326	18.68	0.00364270	3556545.82	12955.4399	0.022887778	81401.4296
17.75	0.00857875	3489965.17	29939.5210	0.053901844	188115.5586	19.13	0.00240671	3658864.80	8805.8264	0.015121805	55328.6388
19.82	0.00127475	3398475.44	4332.1940	0.008009467	27219.9774	18.04	0.00656786	3645467.30	23942.9116	0.041267069	150437.7505
19.88	0.00120621	3798854.32	4582.2248	0.007578855	28790.9678	18.90	0.00297457	3468645.11	10317.7173	0.018689756	64828.1296
20.57	0.00063889	4154864.25	2654.4870	0.004014243	16678.6334	19.11	0.00245145	3358486.72	8233.1758	0.015402940	51730.5695
18.42	0.00462832	3389454.40	15687.4932	0.029080617	98567.4269	18.61	0.00388529	3506056.78	13622.0572	0.024412015	85589.9099
17.98	0.00694103	3507895.63	24348.3995	0.043611761	152985.5060	18.25	0.00541282	3498563.20	18937.1003	0.034009764	118985.3103
17.50	0.01080000	3287941.65	35509.7698	0.067858401	223114.4640	17.96	0.00707007	3507895.78	24801.0711	0.044422564	155829.7256
17.92	0.00733540	3765643.10	27622.4955	0.046089673	173557.2579	18.91	0.00294730	3499756.41	10314.8181	0.018518407	64809.9135
18.26	0.00536320	3499865.25	18770.4671	0.033697961	117938.3228	18.26	0.00536320	3596625.96	19289.4138	0.033697961	121198.9615
17.99	0.00687739	3612145.40	24842.1385	0.043211926	156087.7598	18.05	0.00650764	3504516.80	22806.1461	0.040888730	143295.2420
18.40	0.00471437	3498964.21	16495.4154	0.029621267	103643.7514	19.35	0.00196528	2875646.45	5651.4416	0.012348199	35509.0550
17.72	0.00881909	3521148.14	31053.3210	0.055411974	195113.7701	18.93	0.00289350	3542564.32	10250.4162	0.018180408	64405.2645
20.08	0.00100328	3798546.22	3811.0195	0.006303817	23945.3417	19.33	0.00200181	3945764.45	7898.6871	0.012577769	49628.9149
17.95	0.00713549	3389945.30	24188.9182	0.044833601	151983.4555	18.05	0.00650764	3501214.63	22784.6567	0.040888730	143160.2204
17.58	0.01003284	3747856.50	37601.6333	0.063038174	236258.0297	17.79	0.00826844	3028249.50	25038.9095	0.051952162	157324.1080
17.96	0.00707007	3522747.90	24906.0766	0.044422564	156489.4948	18.89	0.00300209	4025564.50	12085.1083	0.018862690	75932.9746
18.67	0.00367641	3512146.88	12912.0865	0.023099556	81129.0320						

equation (Aslan 2017, 2018):

$$E = \iint L(\theta,\varphi)\,\Omega(\theta,\varphi) = 10.8\times 10^4 \cdot 10^{-0.4m} \iint \sin\theta\,d\theta\,d\varphi \quad (8)$$

obtained. As seen in Fig. 2, when measurement is taken from the zenith to the horizon (where the angle θ remains constant) without changing the direction (unchanged angle) of the SQM instrument, an arc is formed between the zenith and the horizon, indicated by rings scanned in dark tones. The step size in the zenith angle defined by the SQM device used for measurement is 20°(Sánchez de Miguel et al. 2017; Cinzano 2007). The total luminous flux per unit area over the entire hemisphere:

$$E(\varphi) = L(0,\varphi)\,\Omega_0 + L(20,\varphi)\,\delta\Omega_{20} + L(40,\varphi)\,\delta\Omega_{40} + L(60,\varphi)\,\delta\Omega_{60} + L(80,\varphi)\,\delta\Omega_{80} \quad (9)$$

This effect was considered a coefficient so as to observe how an effect occurs when the angle is changed in studies. In the positions shown in Fig. 5, the entire 90° angle extending from the zenith to the horizon was scanned with a 5° angle measurement for each of the north, south, east and west directions. k values were calculated by comparing the results to the measured value at the zenith. With this perspective

$$E_\phi = kE_{0i} \quad (10)$$

Table 2. SQM (m), Brightness (L) and Luminous flux per area (E) values read from four main directions in seven different locations to determine the angle dependence.

SQM values (m)

		1#	2#	3#	4#	5#	6#	7#
North	Min	15.84	15.81	15.41	15.40	17.15	19.75	16.15
	Mid	18.02	17.81	17.83	17.74	18.82	20.08	18.32
	Max	18.74	18.55	19.37	19.41	19.89	20.90	19.50
East	Min	16.95	15.7	18.4	19.36	15.96	18.57	18.52
	Mid	18.03	17.50	18.88	19.61	18.32	19.61	19.22
	Max	18.67	18.39	19.32	19.73	19.41	19.80	19.80
South	Min	16.37	15.27	19.2	19.27	18.13	16.77	18.23
	Mid	17.99	17.47	19.46	19.38	19.12	18.51	19.09
	Max	18.8	18.55	19.65	19.45	19.96	19.84	19.79
West	Min	15.4	16.44	16.24	15.64	18.90	16.17	17.39
	Mid	17.82	17.75	18.17	18.03	19.61	18.60	19.08
	Max	18.81	18.54	19.34	19.40	20.05	19.49	19.74

Brightness values (L)

		1#	2#	3#	4#	5#	6#	7#
East	Min	0.003676	0.004758	0.00202	0.001385	0.00186	0.001298	0.001298
	Mid	0.007560	0.014698	0.003174	0.00155	0.008311	0.001642	0.002356
	Max	0.017924	0.056679	0.004714	0.001947	0.044609	0.004031	0.004221
West	Min	0.003232	0.004144	0.001983	0.001877	0.001031	0.001728	0.001372
	Mid	0.016852	0.010210	0.008374	0.013435	0.001664	0.006451	0.003213
	Max	0.074718	0.028670	0.034469	0.059900	0.002975	0.036764	0.011952
North	Min	0.011103	0.000740	0.002096	0.000621	0.005075	0.011733	0.001398
	Mid	0.030127	0.001756	0.007120	0.000921	0.011800	0.028907	0.004051
	Max	0.077522	0.003779	0.030579	0.001385	0.033529	0.094934	0.012174
South	Min	0.001263	0.020769	0.002407	0.001665	0.001121	0.001251	0.001310
	Mid	0.003757	0.050245	0.112758	0.016904	0.002863	0.005911	0.002797
	Max	0.007541	0.096699	0.512181	0.179235	0.006045	0.021156	0.005513

Luminous flux per area values (E)

		1#	2#	3#	4#	5#	6#	7#
East	Min	4.44E-05	0.000908	6.06E-05	0.000271	5.44E-05	1.4E-05	7.22E-05
	Mid	0.374646	0.635892	1.740249	0.572347	0.671949	0.813653	2.558130
	Max	3.206542	1.916574	6.712225	2.486749	4.246300	7.189703	10.14858
	Total	2.510400	2.392336	3.480499	1.144694	1.343897	1.627305	5.116259
West	Min	1.76E-05	0.000532	0.000105	0.000624	2.74E-06	2.77E-05	8.44E-05
	Mid	0.102979	1.911838	1.259362	2.362929	0.238362	0.616872	2.455365
	Max	1.073659	9.375851	6.421433	9.162764	1.836584	9.180504	7.323369
	Total	1.956599	1.816247	2.392789	4.489566	4.528881	1.172056	4.665194
North	Min	0.000116	0.000109	0.000110	0.000206	0.000105	0.000104	0.000133
	Mid	1.220298	3.113982	1.923242	2.376487	1.522028	0.883599	2.141639
	Max	8.913267	9.863396	6.964124	9.353819	8.550878	7.668509	7.391132
	Total	2.371796	1.370685	4.264180	7.021260	2.734760	1.947462	3.352067
South	Min	2.46E-05	0.002716	0.000134	0.000208	3.13E-05	1.47E-05	9.34E-05
	Mid	0.823220	2.168287	2.402866	1.654270	0.428665	0.083974	2.536906
	Max	7.459521	6.900277	10.30643	9.638528	2.558649	0.880463	7.769717
	Total	2.309146	1.227598	3.132411	3.359674	2.355723	5.549968	1.571222

The equation was defined as shown in Eq. 10. E is the enlightenment with angle effect E_0 is the corresponding minimum luminous flux per unit area driven from zenith SQM readings and k is the coefficient of the angle effect. In Eq. 6, if the effect of angle dependence is added to the luminous flux in the lumen unit for each field

$$\phi_i = k_i \phi_{0i} = k_i E_{0i} A_i \qquad (11)$$

The Eq. 11 occurs. By taking these k values into consideration in the calculations, a different k multiplier was calculated

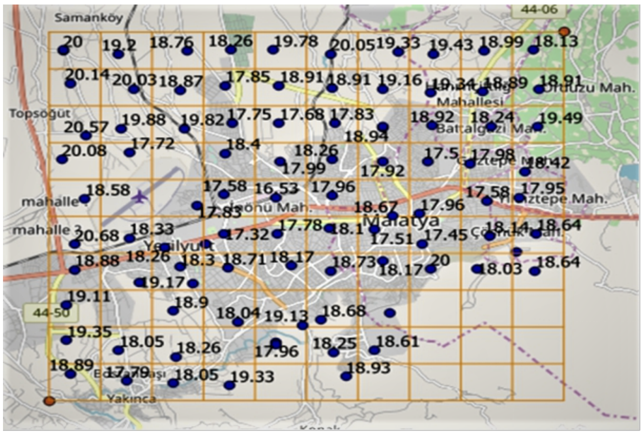

Figure 3. Light pollution measurement points taken and recorded SQM measurements.

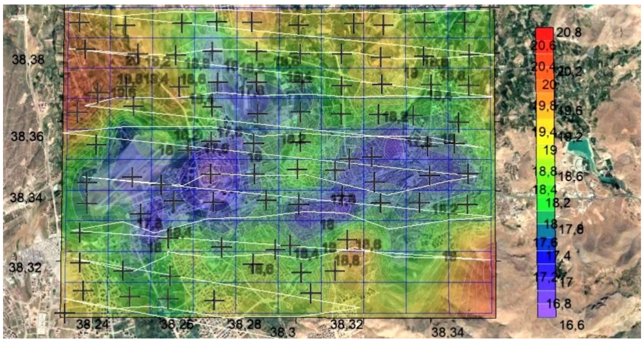

Figure 4. Co-brightness curves drawn using the reading measurements. The minimum (luminous) measurement was 16.53 mag arcsec^{-2} and the highest (dark) measurement was 20.68 mag arcsec^{-2}, dividing the range by 0.10 digits.

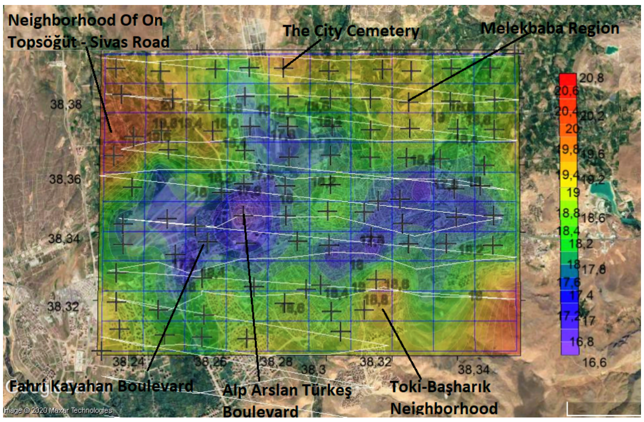

Figure 5. Measurement of light pollution in Malatya province center and its environs co-brightness curves. The measurement locations are marked and the light pollution scatter map is displayed with 30% transparency so that the measurement points can be observed more clearly.

Table 3. K coefficients and luminous flux classified according to the values read. R: SQM Range (mag arcsec^{-2}), A: Area (km^2), L: Luminous Flux (Mlm), k: Average Coefficient.

Location	R	A	L	k	L × k
#7, #4	<18	76.7	4.55	4.03	18.33
#3, #5	18—19	144.9	3.28	3.28	13.08
#2, #6	19—20	49.2	2.35	2.35	1.38
#1	>20	30.3	2.17	2.17	0.36
	Total	301.1	12.35		33.17

for each region in 7 different regions within the entire region measured and the results were reached using these calculated k values.

Classification and calculated k values and luminous flux magnitudes according to measured values from SQM instrument are given in Table 3 (Aslan 2017). In line with the values in Table 3. The wasted luminous flux (emitted back from the atmosphere) by the effect of angle dependence was calculated to be 122.72 Mlm (megalumens). If the contribution of atmospheric permeability is also taken into account, considering the atmospheric permeability effect, the luminous flux escaping into space caused by wrong lighting is calculated Total luminous flux from all directions ($\phi_{\text{total}} = \sum_1^{85} E_{0i}\ A_i$) as 4.54 Mlm (4 540 973 lm). As of the end of 2019, Malatya province has a population of 800 165 people according to TUIK address based population data. In the light of these data, the amount lost instantly per capita was calculated as 154 lm and when calculated on a year basis this value becomes 0.56 Mlmh (megalumens-hour). Today, only the energy used for street lighting in the cities is 4% to 6% of the total energy consumed by the city. With the addition of advertising lighting and building facade lighting to this value, it is seen that the rate will increase to 10% (Çetin et al. 2004). If the efficiency values of the lamps used in street lighting are considered to be 100 lm W^{-1} on average, the instantaneous value of the total luminous flux (122.7 Mlm) that causes light pollution is equal to 1 227 kW of power. Exterior (outdoor) lighting was considered to be active for approximately 12 hours in a day, and the amount wasted was calculated to be 441 720 kWh per month. This calculated value is 26.99% of the estimated monthly amount of electricity (1 636 064.2 kWh per month) that causes light pollution. And this value corresponds to about 27%. If the average electricity expenditure per household is considered 160 kWh, it means that the energy consumed by 2 760 households in one month is wasted. The equivalent of electricity expenditures in money is 0.6769 TL per kWh for July 2019. If we round this value as 0.68 TL per kWh, the material equivalent of the total amount of lost light is calculated as (441 720 kWh per month × 12 months per year × 0.68 TL per kWh) = 3 604 435 TL per year.

3 Results And Discussion

As seen in Fig. 5, the areas located in the east of the city, Mehmet Buyruk street and the neighbourhoods around it, in the western part of the city, Alp Arslan Türkeş boulevard and Fahri Kayahan boulevard are seen as the brightest areas and the smallest values in Turgut Özal, Karakavak and Barguzu neighbourhoods around these regions measured; that is, a large level of lightness has been observed. As seen in Fig. 5:

- The gap between Topsöğüt in the north-west of the province, Toki Başharık in the South-East, the city cemetery and its surroundings in the north-east, and Melekbaba neighbourhood in the north-east of the province shows itself as dark spots.
- The sky is bright with the naked eye along the ring road starting from the eastern entrance of the city to the western exit. While these light values are increasing in and around the center of the city, in the East, Buhara Street is evident until the 2nd organized industry in the West.
- It is observed as a "hot spot" in the middle, near the city center, around Atatürk Street and the surrounding neighbourhoods, around the city hall, in the areas where the Tecde neighbourhood is located in the south.
- Beydağları, which runs along the south of the province, causes the region to increase its level of darkness.
- The regions where the sky's dark values are measured highest (> 20.50 mag arcsec^{-2}) are located in the north-west of the province, neighborhood of on Topsöğüt - Sivas road.

The amount of light wasted due to inefficient use of artificial light: 0.56 Mlmh per year $\Longrightarrow$ 122.7 Mlm per year $\Longrightarrow$ 441 720 kWh per month $\Longrightarrow$ 5 300 640 kWh per year. If approximately 27% of the consumption spent on external (outdoor) lighting was calculated to be 3.6 million TL per year, equal to the total electricity consumption of 33 130 households each year.

4 Precautions Against Artificial Light Pollution

- It can be said that light pollution increases proportionally with the population, because human is the main source of light pollution like all pollution.
- The province of Malatya receive a migration due to its developing industry and agricultural activities, especially the economic conditions that apricot production provides for people. The unconscious lighting in new residential areas formed with population growth increases light pollution rapidly.
- Lighting systems that comply with regional requirements and international standards should be preferred (Aslan & Onaygil 1999).
- In accordance with the conditions, monochrome light skis should be preferred for street or outdoor lighting (Çetegen & Batman 2005). Sodium vapour lamps should be the primary choice.
- The use of LED lights that are rich in blue wavelength should be avoided. Using motion and time sensor lighting according to the need will reduce electricity consumption (Aksoy & Söğüt 2008).
- Sufficient amount of time should be reduced within the boundaries of the region to be illuminated (Çetegen & Batman 2005).
- In the open spaces (site gardens, squares, parks, children playgrounds etc.) lighting systems that send light to the upper half space in the form of a sphere should be avoided in lighting systems should be preferred full-screen lighting systems should be preferred (Aslan & Onaygil 1999; Çetin et al. 2004).
- The settlement near observatories should be avoided or, if it can not be, low pressure sodium lamps should be used in residential centers close to observatories that can be filtered by astronomers (Çetegen & Batman 2005).
- The led lighting used in the exterior decoration of the building and the use of materials with more reflective properties in the roof and surface coatings of the building should be avoided.
- The exterior lighting of the building and the lighting on the walls of structures with historical texture such as historical ruins, mosques and visits should be oriented from top to bottom. The most valuable of the precautions to be taken to prevent the spread of light pollution is to inform people about the damages of light pollution.
- In the later hours of the night, the contribution to light pollution and energy expenditure will be reduced in proportion to the reduction of the lighting intensity of lamps or the number of lamps burning which will not compromise the safety measures (Karımı Ansarı 2013).
- The waste of energy used in street lighting is a major burden for the economies of the country. Reducing wasted energy in street lighting is important in terms of depletion of natural resources and not damaging the economies of the country.

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Teşekkür: Makalemize yaptıkları değerli öneri ve katkılardan dolayı hakemlere teşekkür ediyoruz.

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