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The Temporal Analysis of Light Pollution in Turkey using VIIRS data

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ABSTRACT

Artificial Light pollution (AL) in Turkey and in Turkish observatories between 2012–2020 have been studied using the archival data of Visible Infrared Imaging Radiometer Suite (VIIRS) instrument. The astroGIS database has been used in processing the data (astrogis.org) Aksaker et al. (2020a). The total energy released to space from Turkey increased by 80% in 2019 with respect to 2012. In the span of the dataset, a steady and continuous increase has been observed throughout all cities of the country. On the other hand, Dark Sky Park locations, East and Southeast Anatolian regions and mostly rural areas around the cities kept their AL level constant. Four demographic parameters have been studied and they were found to be correlated very well with AL: Population ($R \simeq 0.90$); GDP ($R \simeq 0.87$); Total Power Consumption ($R \simeq 0.66$) and Outdoor Lightening ($R \simeq 0.67$). Contrary to countries acting to prevent AL increases, Turkey seems to be at the beginning of an era where AL will arithmetically increase throughout the country and enormous amount of energy will continuously escape to space and therefore will be wasted. Therefore, a preventive legislation, especially for invaluable astronomical site locations such as TURAG, TUG, DAG and ÇAAM where each is counted as a truly dark site due to their SQM values, has to be enacted in Turkey, in very near future.

Keywords: Light Pollution

1. INTRODUCTION

Night sky is expected to be dark enough to conduct human based observations. However, there is an ongoing human activity throughout on all parts of the Earth surface which gradually prevents humanity experiencing the dark night sky. Thus, *light pollution* can simply be defined as artificial light contributing to the night sky (Cavazzani et al. 2020; Mendoza et al. 2020; Simons et al. 2020). The contribution is so large that one-third of the humanity cannot see and identify the Milky Way. The simplest reason is actually due to the world population being accumulated in or around the cities (Falchi et al. 2016). Light pollution in the night sky makes observations of astronomical objects very difficult when cumulative light above the large cities degrade

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the quality of observations especially for the observatories (Gronkowski et al. 2018). Light pollution is also an ecological problem besides its negative effect on astronomy (Navara & Nelson 2007). Note also that, when the world-wide awareness considered, UNESCO has listed **the night sky** as a universal heritage[1].

The most recent review on AL observed from space and it is interpretation for the human activity on the surface is given in Levin et al. (2020). Light pollution is monitored and studied using many different measurement techniques: Sky Quality Meter (SQM) photometers (Zamorano et al. 2016; Puschnig et al. 2019), Satellite base Defense Meteorological Satellite Program - Operational Line-Scan System (DMSP/OLS), International Space Station (ISS) nighttime light measurements (Kuffer et al. 2018) and Visible Infrared Imaging Radiometer Suite (VIIRS) (Levin et al. 2019).

Through the modern human history, populations are found to be not evenly distributed over the surface area of Earth. However, population always increases arithmetically and population density can be shown to correlate with other demographic parameters, especially human activities affecting the environment (Elvidge et al. 1999; Hara et al. 2004; Shi et al. 2014), specific to this work "the night sky" (Falchi et al. 2016). Thus, it could easily be summarized that human activity is correlated with consumed and/or with wasted energy, therefore this energy, when it is observed from the space, can also be correlated with "negative effect of human activity".

The first studies on AL pollution in Turkey[2] began under the leadership of TUBITAK National Observatory (TUG)[3] which was initiated by Zeki Aslan, earlier director of TUG. They have been using a simple photodiode based instrument, namely "Sky Quality Meter - SQM", to collect AL pollution values in the Zenith direction which can be carried out either personally or within a campaign to increase the awareness of *dark skies*. Since then, they have also been working on the legislation part of the awareness. In 2005, they documented the results of both engineering and legislative studies on AL which led the group to apply for a change in the law (see details in isikkirliligi.org).

Improper use of outdoor lighting has a negative impact on astronomical observatories in Turkey. An earlier study by Aslan (2001) noted that the background brightness level has increased by 23, from 1986 to 1999 due to increase in investments in tourism on the Mediterranean coast and use of outdoor lighting for decorative purposes. AL pollution has also been understood as an important issue in observatory site selection studies. In their site selection studies Aksaker et al. (2015) were made used DMSP/OLS (Defense Meteorological Satellite Program's Operational Linescan System) data (years 2012–2015) for AL pollution in Turkey. Another national study is carried out by Koc-San et al. (2013) and they noted AL pollution analysis for 2010 using the same satellite data but for the city Antalya only. In Ege University Observatory, Devlen (2018) reported that the sky brightness measurements in 2017 was shortened by 1.5 hours compared to 2010. Impact of AL pollution is continued to be an important issue for observatories.

In this study, we aim to find Turkey's position in terms of energy released into the space. For this purpose, the database introduced in Aksaker et al. (2020a) has been adapted for Turkey. The layering details of Artificial Light (AL) are published online in the astroGIS database [4]. A subset of the dataset has been adapted from the database and is given in Fig. 1.

2. GIS AND NIGHTTIME DATASET

Geographic Information Systems (GIS) and Remote Sensing, and their capability to capture, store, manipulate and display data, have found robust, easy to use and, time and cost efficient utility in the analyses of any spatial phenomena anywhere on/above/below the earth surface (Chang 2009). Advantages of GIS tools for spatial analysis along with progressively high precision and free-cost satellite-based remote-sensing datasets, become a key technology for environmental monitoring including human–environment interactions such

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as the economic, environmental, and social factors that influence settlement systems.

In this work, astroGIS database has been used (Aksaker et al. 2020a). In addition to GIS dataset, the demographic data for 2018 have been retrieved from the archival database of Turkish Statistical Institute[5]. Since there is no legislation enacted in the country, we aimed to find more correlations in the demographic dataset with the AL pollution. Therefore, measured national power consumption parameters reported by the Turkish government in February 2020 has been retrieved and adopted to all cities are given in Table 1 (EPDK 2020).

In constructing demographic dataset of Turkey the following information have been collected: 1) the country has 81 cities; 2) the city boundaries and total surface area were digitized from GADM dataset (see Table 1). It can be viewed in Fig. 1 (upper panel).

The Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on board SUOMI-NPP satellite in the Day Night Band (DNB) is used to acquire the nighttime data and they correspond to visible part of the spectrum. Similar data analysis methods and techniques which were applied for France (Aksaker et al. 2020b), have been adapted in this work. Overall view of the nighttime data for December 2019 is given as an example in the lower panel of Fig. 1. The resultant spatial resolution of GEOTIFF images were 463 m per pixel.

3. ANALYSIS OF THE DATA

Using astroGIS database, a monthly averaged nighttime dataset has been produced. This dataset contains 93 images. Their dates range from April 2012 to December 2019. Digitized GADM boundaries have been used, first to extract the surface area of Turkey. Afterwards, each city has been extracted from the same dataset. With respect to average light pollution value over the whole time span, above 3σ values were excluded for each pixel using a pre-filtering algorithm written in house Python code. In calculating pixel averages within each city boundary a model in Zonal Statistics tool of ArcGIS Desktop 10.4.1 has to be created to process 81 cities in total. A city-based light pollution dataset is produced using monthly nighttime data for each city. Earth Observation Group (EOG) updated VIIRS sensor calibration for Airglow (Uprety et al. 2019). Coesfeld et al. (2020) produced and published (Uprety et al. 2019) a mask for this new calibration. This airglow correction has been applied to our dataset and used through out in all stages of data manipulation.

VIIRS launched in 2012, therefore, it spans a eight-years of AL data. In this work, we aim to find AL variation over the full span of the satellite limiting to Turkey's surface area.

Accumulating this dataset for twelve month, yearly averaged data has been calculated and tabulated in Table 2. A linear regression fit applied to yearly averages (column 'L.R.') and it is given in the table along with goodness of fits (R^2). Thus, possible variation in annual AL values could then be calculated (column $\Delta(\%)$). Note that one of the main criteria in AL data is to locate and measure main AL contributing surface area or geographic locations throughout the country. Therefore, luminous flux values of cities are given in Fig. 2.

Overall view of variations were needed to visualize the effect of AL pollution through-out the country for the time span of the dataset emphasizing regional changes. This is given Fig. 3.

The Turkish observatory locations are given in Table 3. AL measurements were also carried for these locations (Table 4). They represent a single VIIRS pixel value which corresponds to 463×463m and, therefore if it can be effected from nearby luminous pixels. SQM values (in units of mag/arcsec^2 - mpsas) were calculated for each observatory location to have a good sense of site's astronomical quality. Our AL dataset for each observatory is converted to SQM values using the following equation (Sanchez de Miguel et al. 2020):

$$20.0 - 1.9\log(\mathrm{AL}) \qquad (1)$$

where AL is the VIIRS DNB value in nW cm^{-2} sr^{-1} units. The contour map of SQM for the whole county (Fig. 4), and for all observatories (Fig. 5) have also been produced to understand the effect of AL. The SQM values of the observatories are given in Table 4.

4. RESULTS AND DISCUSSIONS

We investigated the light pollution dataset for Turkey. The data runs from January 2012 to

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December 2019. The whole dataset is created from our earlier astroGIS database (Aksaker et al. 2020a). The following outcomes have been noted after the analysis of the dataset:

- The total energy released to space from Turkey increased by 80% in 2019 compared to 2012. Energy release of Turkey during 2019 is 20% higher than France Aksaker et al. (2020b).

- İstanbul, as being the most populated city, produced 12% of the total AL of the country during 2019.

- Even though there were disordered annual decreases in AL (Figure 2), trend of AL for all the cities is positive and steady.

  Note that AL variation (Fig. 3) over the whole country might give the impression of 'no improvement'. In the reality of data, accumulation of light pollution over the large cities (an increase – red colored pixels) might hide the improvements (a decrease – blue colored pixels).

- During the time span of the dataset, all cities show a steady and positive increase in AL (Table 2). The maximum and minimum AL increase were observed in İstanbul and Tunceli, respectively. R^2 of the variation during 2012–2019 stays above 0.90 for 51 cities which proves that the country's AL continuously increases.

- The following geographical "points", where they correspond to pixels in our dataset, Yusufeli/Artvin and Çorlu/Tekirdağ have the minimum (0.00) and maximum (883.6) values in VIIRS's luminous flux units, respectively. Note that these minimum and maximum values are for 2019 when the light pollution distribution over the country was considered.

- Turkish observatory locations have also been studied for AL and the following statistical outcomes have been observed: The brightest and the darkest observatory in 2019 are found to be İÖÜ (138.03) and TUG & TURAG (0.10), respectively. The largest increase and decrease in AL, between 2012–2019, are found to be in UZAYBİMER and UZAYMER, respectively. Note that, AL for İÜO shows a decreasing trend which can be easily marked as an outlier since the observatory is within the most luminous city, İstanbul, showing a saturated trend in AL.

  We present AL contour maps in Fig. 5 covering 100 km surface area centered on all observatory locations. The AL values for observatories show the same trend as the country. We would like to emphasis the importance of reducing AL especially for Turkey's most important observatories, specifically for TUG (AL increase: 56%) and DAG (AL increase: 40%). It is not uncommon to predict the future with these outcomes that without having any controlling measures wealth of society will eventually degrade and destroy the astronomical night sky especially for these invaluable scientific investments on these observatories. Note also that, as it is given in Table 4, for TURAG, TUG, DAG and ÇAAM, SQM values prove that these observatories are counted as truly dark sites.

- Aksaker et al. (2015) found two main groups of astronomical observatory sites (17 in total). Group A includes the most suitable sites where all located in Southeast Anatolia Region. Even though their dataset for AL was 2012, changes observed throughout 2012–2019 (Figure 3) show less light pollution (note dominated shades of blue) implying that the group A remained to be the most suitable site locations since all are in remote rural locations which are not effected very much from the human activities.

- Excluding two of most important astronomical parameters (elevation and cloud coverage), AL can also be used as a criteria to select specific locations, for example **Dark Sky Parks**. Turkey has dozens of such potential locations (see Fig. 4). The darkest cities among these locations are Kilis, Tunceli, Gümüşhane and Bayburt, once again confirming the main outcome: rural locations away from the human activity stayed as they are throughout 2012–2019. Note that the work with the full parameter set has been carried out and all suitable astronomical locations have been found in Aksaker et al. (2020a).

- Examples given in Elvidge et al. (1999); Hara et al. (2004); Shi et al. (2014); Lin & Shi (2020) correlates human activity, say electric consumption, to the energy escaped to the space. Following this example as a base, our AL pollution dataset shows a strong correlation with both population (with 0.90 confidence) and GDP (with 0.87) (see Table 1 and Fig. 6).

  Even though there is a strong and obvious correlation between power consumption and AL observed in space, as it is noted in (Sánchez de Miguel et al. 2014) before coming to an immediate conclusion, the observed flux has to be assessed locally (e.g. city by city) and corrected accordingly. The aim of this work, however, was focused on whether there exists a trend of AL or not; we confirm the trend in Fig. 2. Due to free access to demographic values in Turkey, we have extended the impact of AL pollution by introducing two more consumption values (Elvidge et al. 1999; Lin & Shi 2020). Observed good correlations (i.e. confidence level) for "Total Power Consumption" and "Outdoor Lightening" are 0.66 and 0.67, respectively (see Fig. 7).

- Contrary to countries acting to prevent AL increases, Turkey, with the values presented in this work, seems to be at the beginning of an era where AL will arithmetically increase throughout the country and enormous amount of energy will continuously escape to space and therefore will be wasted. Therefore, to overcome expected worst scenario where other countries have been faced with in past decades (such as France, see Aksaker et al. 2020b) a preventive legislation has to be enacted in Turkey, in the very near future.

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Compliance with ethical standards—The authors declare that they have no potential conflict and will abide by the ethical standards of this journal.

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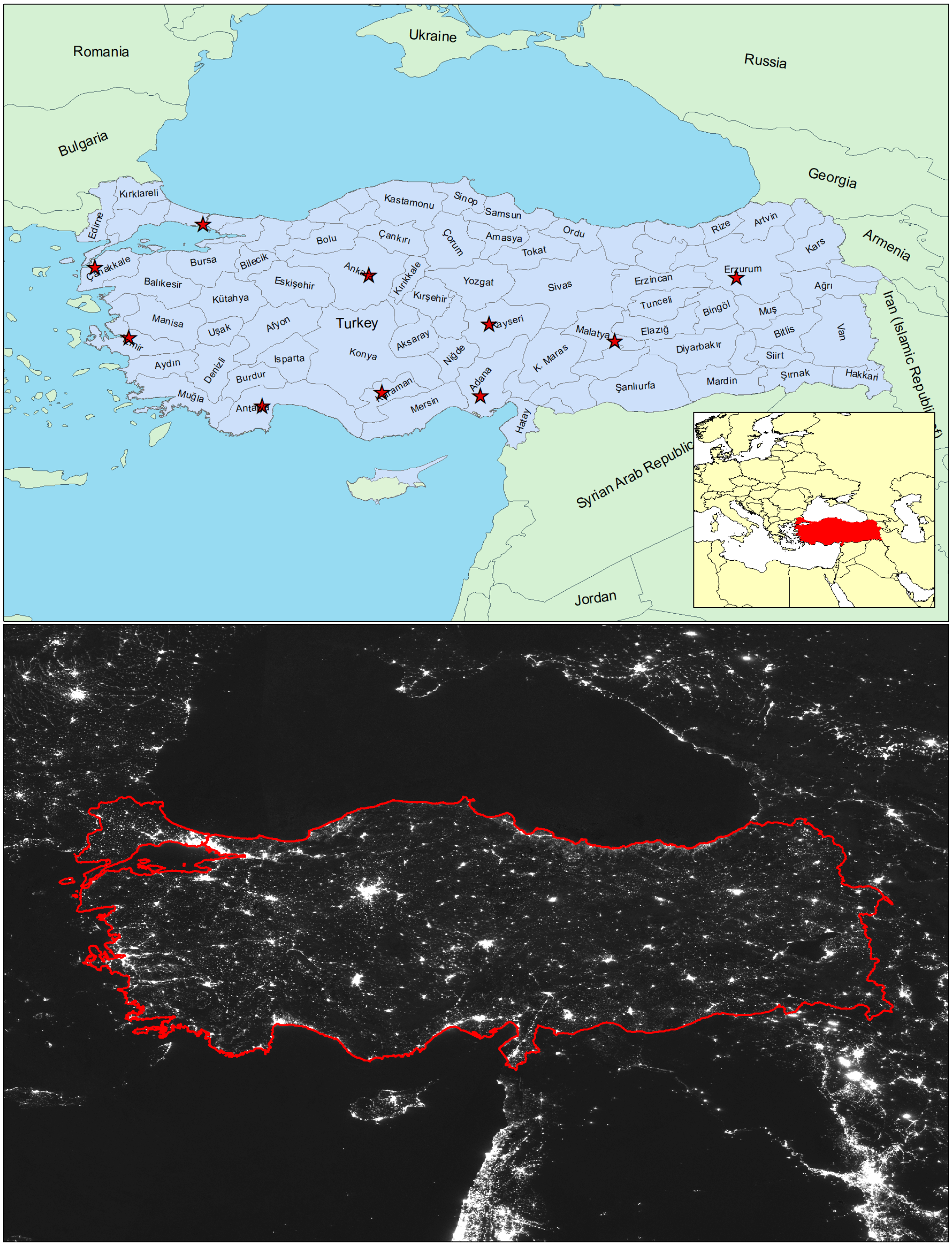

Figure 1. Upper Panel: Demographic map of Turkey showing the name and boundary of each city. Names not fitting to their boundaries are left as unnamed. Both university owned and national observatories are marked with a red star. Boundary of neighbouring countries are also drawn with no other details. Lower Panel: Artificial Light (AL) distribution of Turkey for December 2019. AL seen from space is colored as white. As expected, İstanbul and other heavily populated major cities dominate the AL distribution. Note also that geographically less populated regions, for example, rural areas, mountains, lakes etc. are colored with black.

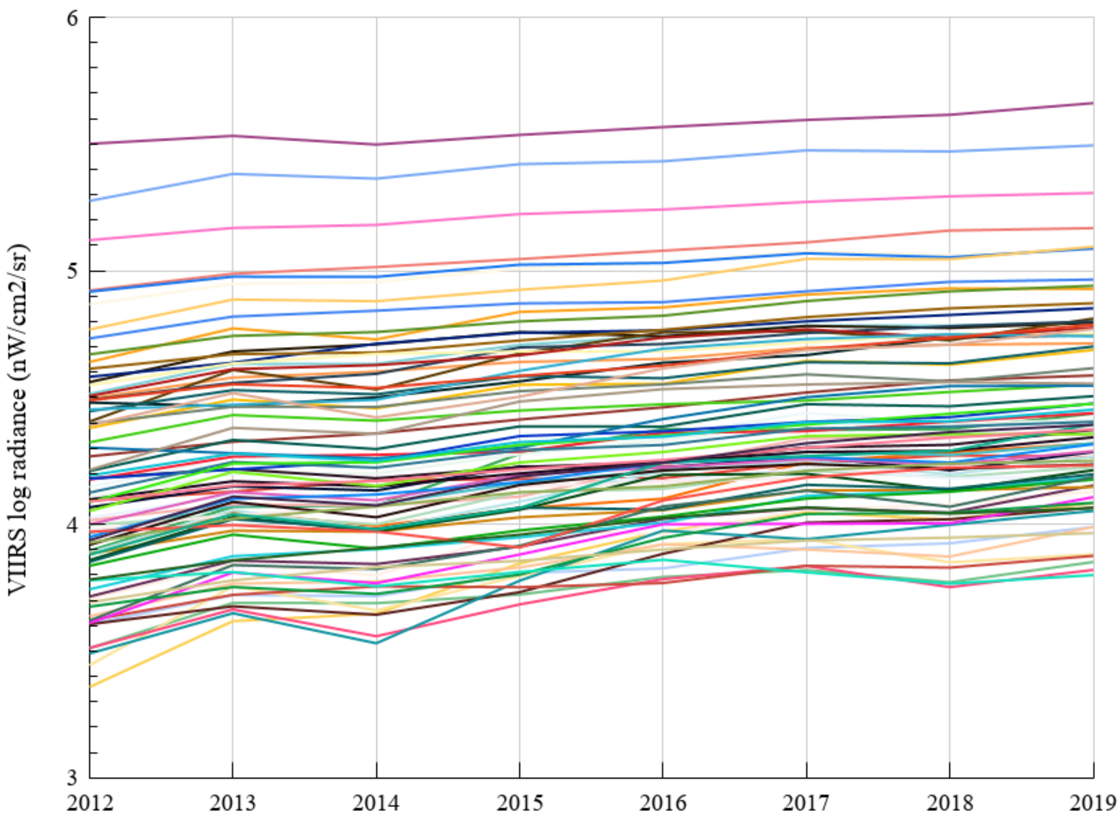

Figure 2. Artificial Light (AL) radiance averaged annually for all cities in between 2012–2019. Even though a general "ascending" trend exists in the graph, to be able to deduce a representative trend though out country, cities can easily be merged into two groups: over-luminous (>5) and luminous (≤5). Therefore AL of cities marked as "luminous" describes the general trend of the country: Variation of log values of AL in 2012: ≃3.5–5.5 and in 2019: ≃3.8–5.7.

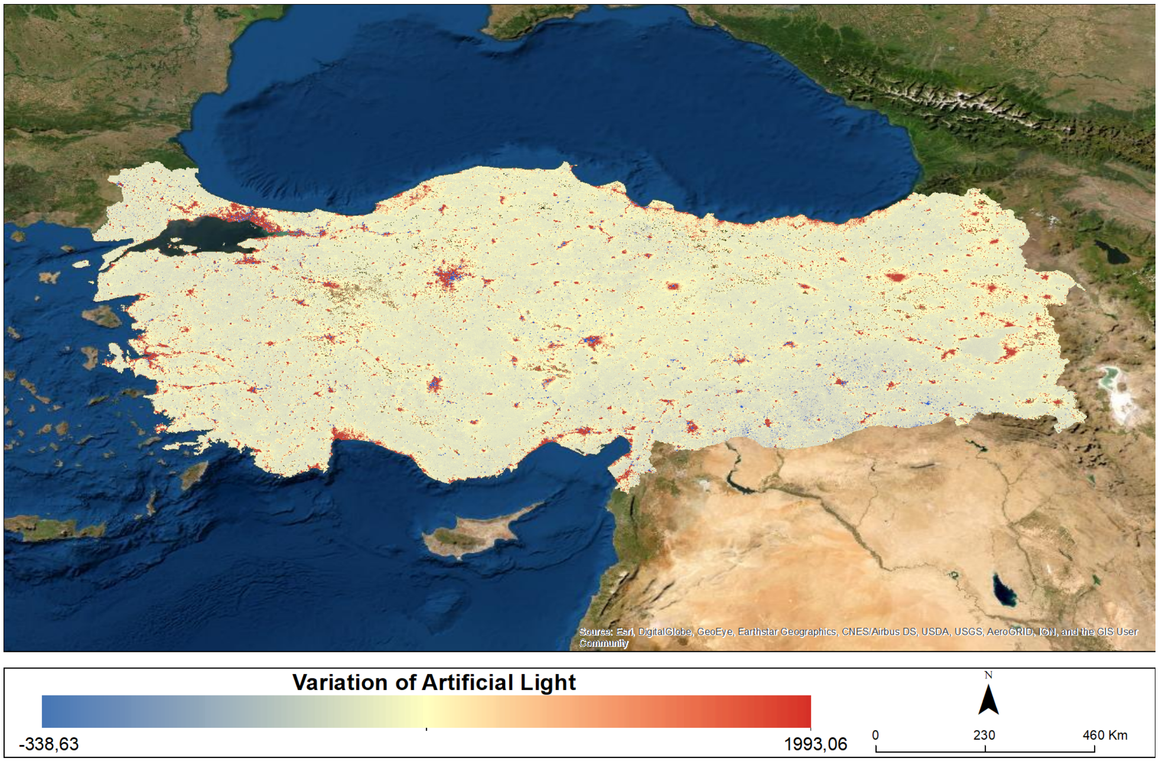

Figure 3. Variation Map of Artificial Light (AL) in Turkey between 2012 and 2019. AL's color gradient runs from blue (light pollution reduced) to red (light pollution increased). The values are in W cm^{-2} sr^{-1}. See Section 3 for detailed explanation of the variation.

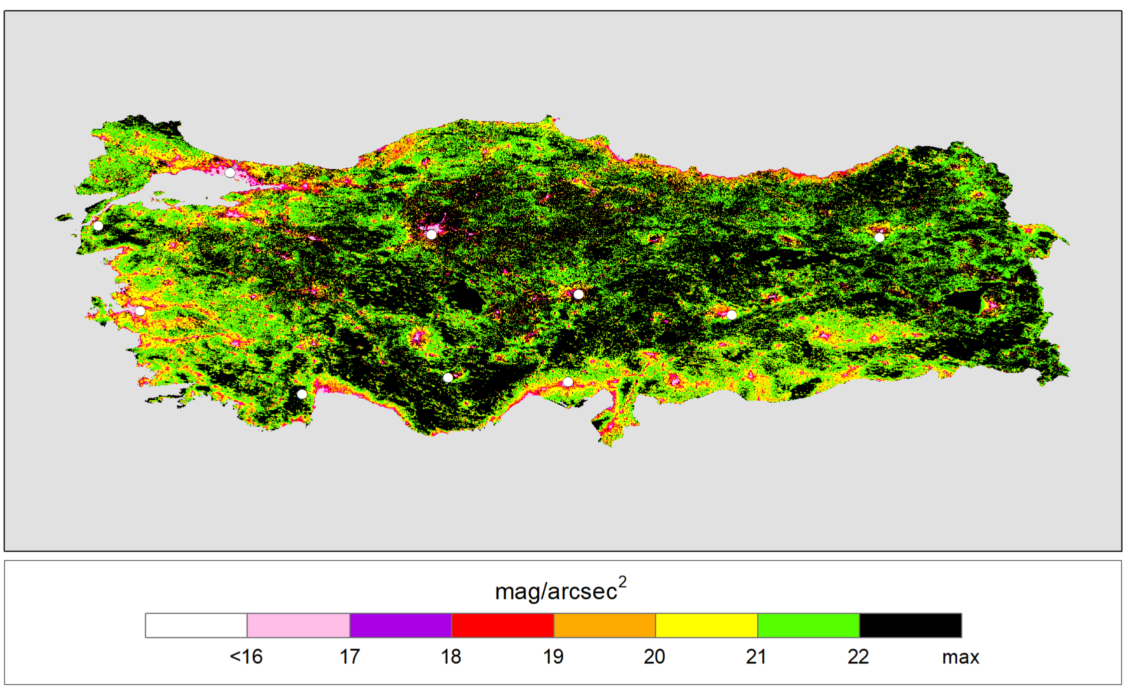

Figure 4. Ten observatories of Turkey (white filled circles) overlaid on to the annual (2019) Artificial Light (AL) of the country. The colors represents AL in unit of mag/arcsec^2. Note that most of the observatories are severely effected from the AL. However, dark regions (AL > 22) still occupy a larger part of the country's surface area.

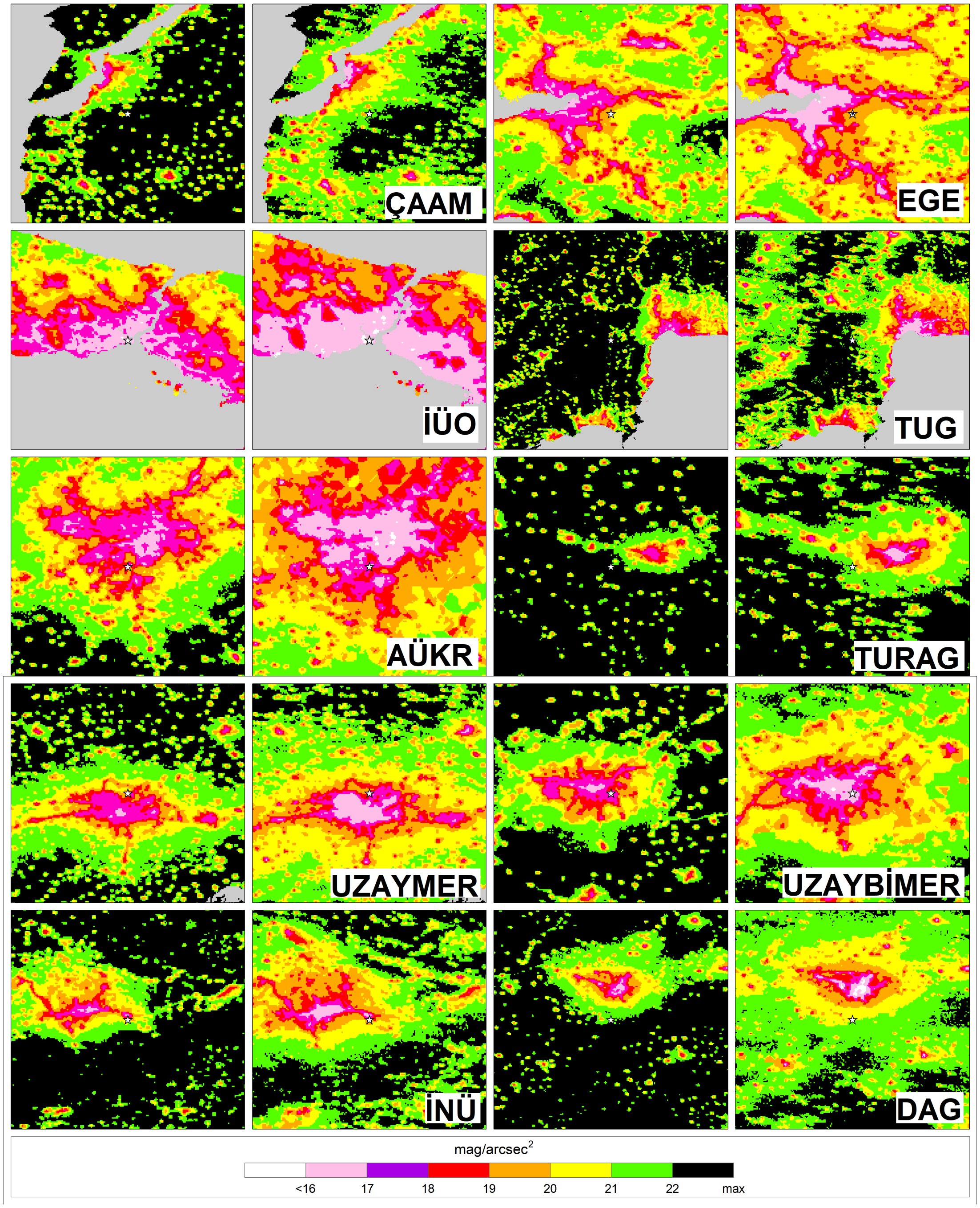

Figure 5. Observatories of Turkey (white filled stars) overlaid on to the annual Artificial Light (AL) of the country for start and end of the dataset (left inset: 2012, right inset: 2019). Observatories are listed according to longitude from left to right and north is up. The scale is the same as Fig. 4. AL for all observatories show the same trend as the country.

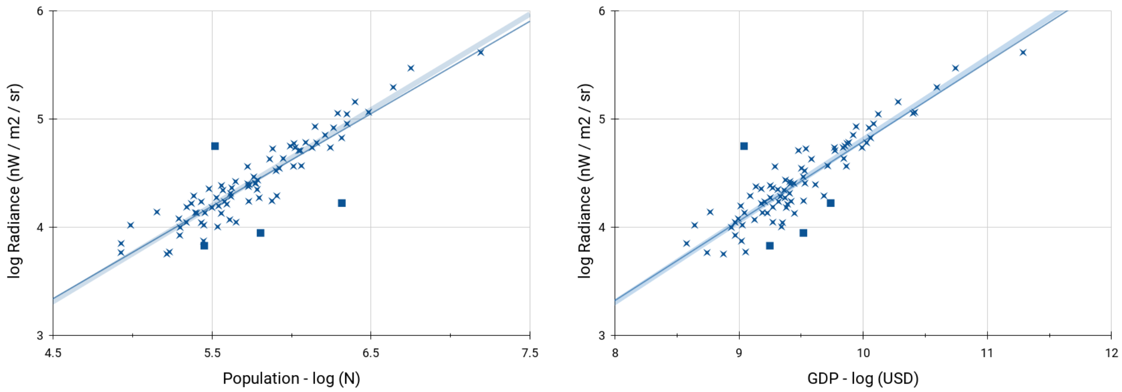

Figure 6. Total radiance as measured by the satellite versus population (Left Panel) and GDP (Right Panel) for 2018 are plotted in logarithmic scales. Thick solid lines represent the linear regressions for Population ($y = 0.886x - 0.674, R^2 \sim 0.90$) and GDP ($y = 0.752x - 2.71, R^2 \sim 0.87$). Note that, both demographic values show good correlations with the radiance and when it is combined with Fig. 2 the country is continuously polluting the sky. The cities marked with rectangles (Kilis, Siirt, Sivas and Şanlıurfa) became as outliers due to their AL values staying low or high (namely Siirt) with respect to their VIIRS pixels corresponding to their unit surface area.

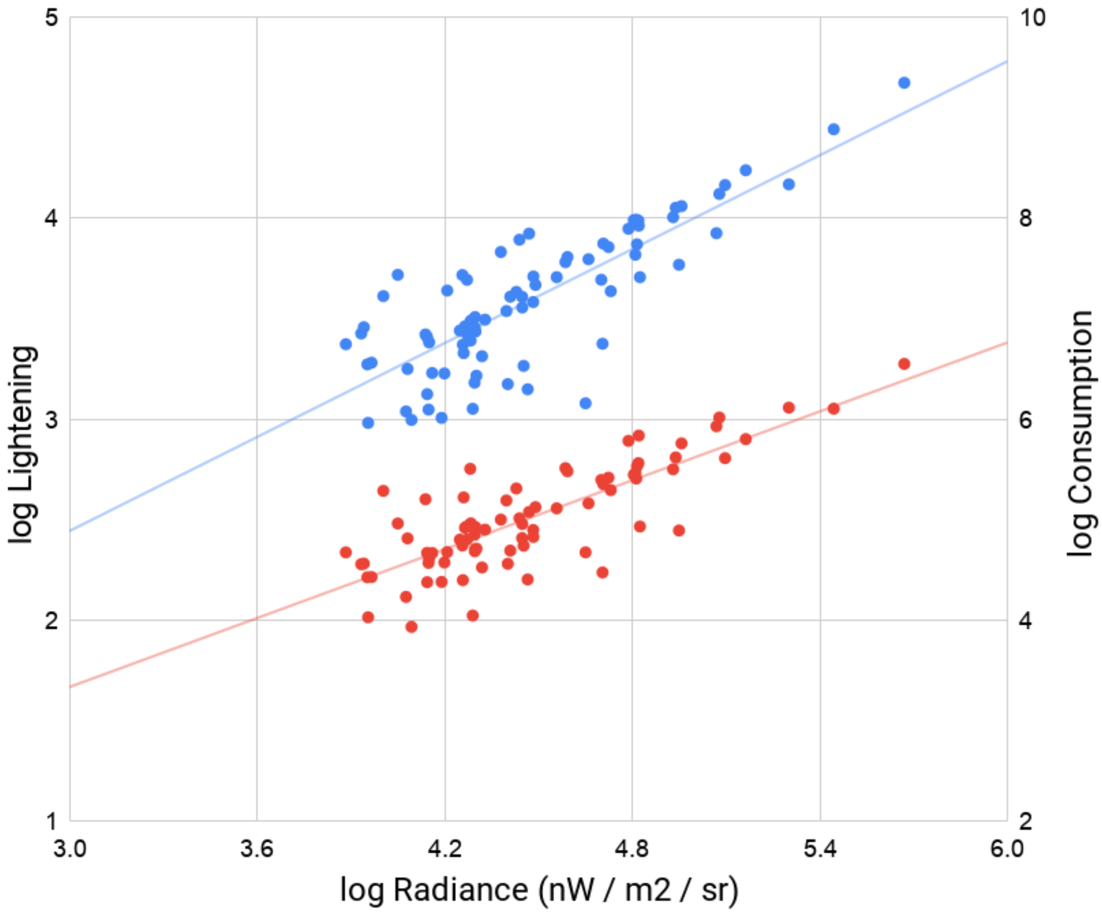

Figure 7. Additional correlations between total radiance and two demographic values for each city are given with their linear fits for February 2019: Outdoor Lightening (left y-axis, in blue color) and Total Power Consumption (right y-axis, in blue color). All three parameters are in logarithmic scale. Thick solid lines represent the linear regressions for Power Consumption ($y = 1.14x - 0.09, R^2 \sim 0.66$) and Lightening ($y = 0.78x + 0.11, R^2 \sim 0.67$). Lower part of the "luminous" cities (< 4) show large variations around the fit, therefore decreases R^2. However, the correlation for both values still exist with these outliers.

Table 1. Five demographic values for all cities in Turkey. Area is in square km. GDP is in billions US dollars and population is for 2018. GDP data is taken from TÜİK in units of thousands of Turkish Lira and an exchange rate of December 31st, 2019 is applied to obtain GDP in US dollars. L_{out} and ΣP_{cons} represent the values of *Outdoor Lightening* and *Total Power Consumption* for February 2020, respectively. See section 2 for the discussion.

City	Area	Pop.	GDP	L_{out}	ΣP_{cons}	City	Area	Pop.	GDP	L_{out}	ΣP_{cons}
Adana	15843	2237940	12.1	11469	572566	K.Maraş	14586	2232374	5.2	6401	302219
Adıyaman	7455	626465	2.3	3088	91657	Karabük	3314	579257	1.5	2560	46580
Afyon	14752	729483	3.8	6241	144753	Karaman	8334	800165	1.7	1695	46483
Ağrı	10491	536199	1.4	1492	36262	Kars	10529	1440611	1.1	1407	25332
Aksaray	7626	337800	2.2	2755	63123	Kastamonu	13459	1154102	2.1	4931	85427
Amasya	6216	5639076	1.8	2858	48362	Kayseri	15953	838778	8.8	10106	316369
Ankara	25731	2511700	55.4	27665	1268170	Kilis	1428	983142	1.8	2357	47128
Antalya	21184	170875	19.1	17297	631273	Kırıkkale	4671	408809	2.8	2636	159177
Ardahan	4863	1110972	0.4	1125	11078	Kırklareli	6387	303010	1.2	2054	33347
Artvin	7868	1228620	1.1	2864	36451	Kırşehir	6780	362861	0.6	1115	37032
Aydın	8038	219427	5.9	7465	225340	Kocaeli	4044	754198	25.2	8410	848109
Balıkesir	14773	279812	7.7	9778	278824	Konya	40893	343212	13.2	14608	407950
Bartın	2583	348115	0.9	2665	35955	Kütahya	12217	1029650	3.3	4651	132832
Batman	4401	316126	2.1	1517	70481	Malatya	11544	1348542	3.4	5082	129279
Bayburt	3421	270796	0.4	990	8551	Manisa	13267	330280	10.7	7407	339163
Bilecik	4649	3056120	1.9	2129	166094	Mardin	10659	218243	3.2	1839	54939
Bingöl	8217	542157	1.0	1330	23799	Mersin	15213	638956	11.2	11253	415279
Bitlis	8805	195789	1.0	2346	24932	Muğla	12875	1055412	7.2	7177	260722
Bolu	8266	530864	2.4	2458	89022	Muş	8243	612747	1.3	1907	26778
Burdur	7261	1037208	1.6	2648	63407	Nevşehir	5137	808974	1.5	3216	50482
Bursa	10886	1756353	26.1	13188	1036221	Niğde	7187	84660	1.8	3124	79238
Çanakkale	9838	413903	4.1	4293	203743	Ordu	5929	2073614	3.3	6782	99933
Çankırı	7915	591098	1.0	2407	41435	Osmaniye	3077	370509	2.6	3037	319829
Çorum	12309	234747	2.6	4057	65379	Rize	3678	1136757	2.2	4359	47403
Denizli	10915	762062	7.4	6572	290005	Sakarya	4701	421200	7.3	6038	324691
Diyarbakır	14952	887475	5.9	4327	196251	Samsun	9529	596053	6.9	9821	255865
Düzce	2388	2069364	2.5	2891	82948	Şanlıurfa	19750	283017	5.4	1686	37383
Edirne	6166	448400	2.5	2725	84080	Siirt	5059	416367	1.1	2370	29735
Elazığ	9350	164521	2.8	3590	90339	Sinop	6010	84843	0.9	5221	91340
Erzincan	11616	280991	1.5	1643	51315	Sivas	28427	253279	3.3	4091	192925
Erzurum	24656	1628894	3.5	5859	77754	Şırnak	8018	608659	1.9	1198	47164
Eskişehir	14058	444914	7.0	4935	247879	Tekirdağ	6641	529615	9.8	8848	606927
Gaziantep	7172	1840425	11.5	9168	684888	Tokat	9853	198249	2.4	5124	67142
Giresun	6841	15519267	1.9	5209	55142	Trabzon	5069	97319	4.8	8372	118941
Gümüşhane	6658	4367251	0.7	1871	26633	Tunceli	8105	199442	0.6	957	10649
Hakkari	6331	285410	1.1	1013	23949	Uşak	4927	270976	2.3	3447	154947
Hatay	5794	379405	8.3	9708	364341	Van	21545	248458	3.0	5082	85245
Iğdır	4012	1407409	0.9	1091	16992	Yalova	651	142490	2.2	1776	64922
Isparta	8879	361836	2.6	3821	78671	Yozgat	13160	538759	1.9	4063	49076
İstanbul	4767	242938	194.2	47129	3540493	Zonguldak	3058	392166	3.4	7807	102832
İzmir	12435	1953035	39.3	14716	1298341						

Table 2. Annual Artificial Light (AL) for all cities of Turkey. Light pollution values are in units of in nW cm^{-2} sr^{-1}. Two different values are given for AL: Ave-All, Ave-19 representing average of annual AL values in between 2012–2019, for 2019, respectively. L.R. and R^2 columns are the slope of linear regression and its correlation coefficient of the regression, respectively for annual AL values in between whole data range. See section 2 for the discussion on the trend of the change.

City	Ave-All	Ave-19	L.R.	R^2	City	Ave-All	Ave-19	L.R.	R^2
Adana	75661.0	92369.2	0.51	0.96	K. Maras	28267.1	38666.2	0.30	0.99
Adıyaman	15714.4	18490.8	0.09	0.94	Karabük	11220.9	14038.9	0.09	0.95
Afyon	36326.0	48749.7	0.33	0.93	Karaman	10233.5	15320.2	0.14	0.97
Ağrı	18604.6	27348.1	0.28	0.92	Kars	12523.4	16359.9	0.12	0.78
Aksaray	13824.7	20837.6	0.19	0.91	Kastamonu	15388.0	19453.0	0.12	0.90
Amasya	15369.1	20886.4	0.17	0.97	Kayseri	68485.9	84816.9	0.60	0.92
Ankara	262707.9	312326.8	1.60	0.91	Kilis	5973.6	7511.4	0.04	0.92
Antalya	117113.9	147358.0	0.91	0.99	Kırıkkale	10659.7	15008.0	0.11	0.94
Ardahan	7620.3	12112.6	0.15	0.95	Kırklareli	16969.1	22042.6	0.13	0.96
Artvin	5517.9	7104.9	0.05	0.84	Kırşehir	11767.5	15746.1	0.11	0.90
Aydın	43808.9	51746.7	0.28	0.95	Kocaeli	104777.1	122444.0	0.52	0.93
Balıkesir	51165.4	62837.4	0.43	0.94	Konya	91805.9	124538.6	0.89	0.96
Bartın	6737.0	9765.1	0.08	0.97	Kütahya	24657.0	32040.4	0.21	0.93
Batman	16369.0	22646.5	0.20	0.91	Malatya	28910.2	35651.4	0.18	0.93
Bayburt	6388.6	7614.3	0.07	0.65	Manisa	48519.9	63196.2	0.48	0.97
Bilecik	13312.5	16823.2	0.11	0.89	Mardin	25684.5	35221.4	0.28	0.85
Bingöl	7050.5	9763.3	0.06	0.85	Mersin	66947.3	87291.0	0.57	0.98
Bitlis	13654.8	18505.9	0.15	0.85	Muğla	48314.4	56420.4	0.27	0.91
Bolu	14158.9	15359.3	0.07	0.65	Muş	9802.8	15372.0	0.15	0.91
Burdur	14018.3	18886.4	0.13	0.98	Nevşehir	18262.5	22723.1	0.17	0.90
Bursa	102608.8	121942.3	0.67	0.93	Niğde	20178.5	25379.2	0.17	0.95
Çanakkale	20093.5	25955.5	0.20	0.96	Ordu	15431.2	20707.3	0.15	0.93
Çankırı	9221.6	13460.1	0.12	0.95	Osmaniye	13712.8	17825.3	0.14	0.98
Çorum	21636.7	27685.4	0.19	0.91	Rize	8369.0	12799.1	0.11	0.93
Denizli	53840.5	62375.7	0.31	0.82	Sakarya	33663.1	41319.0	0.22	0.93
Diyarbakır	41004.7	55799.3	0.42	0.95	Samsun	48676.5	59663.0	0.38	0.90
Düzce	15901.6	19319.1	0.09	0.80	Şanlıurfa	42984.3	55148.2	0.47	0.92
Edirne	18198.1	23596.3	0.11	0.87	Siirt	8143.0	12162.9	0.12	0.93
Elazığ	21352.2	27436.9	0.17	0.96	Sinop	7448.3	9236.9	0.06	0.97
Erzincan	14115.8	17225.3	0.13	0.84	Sivas	12290.2	17093.6	0.13	0.79
Erzurum	47536.9	64825.1	0.50	0.84	Şırnak	29471.3	35903.9	0.29	0.87
Eskişehir	38450.8	50304.5	0.28	0.93	Tekirdağ	43323.0	61303.2	0.42	0.94
Gaziantep	56220.0	71179.5	0.46	0.98	Tokat	21508.0	29875.7	0.23	0.98
Giresun	9376.0	14240.2	0.12	0.94	Trabzon	15022.6	24818.1	0.23	0.92
Gümüşhane	5190.2	6610.6	0.05	0.75	Tunceli	6316.4	6308.7	0.00	0.01
Hakkari	7313.8	11643.6	0.12	0.92	Uşak	17681.7	23676.8	0.16	0.99
Hatay	57326.0	74518.1	0.49	0.98	Van	39477.1	58893.6	0.49	0.90
Iğdır	7048.8	11293.2	0.12	0.90	Yalova	9416.6	11586.2	0.08	0.92
Isparta	22095.5	29978.3	0.21	0.98	Yozgat	16876.3	24698.2	0.23	0.97
İstanbul	368785.7	458720.4	1.92	0.88	Zonguldak	21851.1	28349.2	0.17	0.95
İzmir	169984.4	202726.1	1.01	0.99					

Table 3. Turkish observatories listed in alphabetical order with their acronyms. Their geographical locations and elevations were taken from (Aksaker et al. 2015).

Observatory Acronym & Observatory Organisation		City	λ	ϕ	Elevation
AÜKR	Ankara University Kreiken Observatory	Ankara	32.78	39.84	1254
ÇAAM	Çanakkale Astrophysics Research Center	Çanakkale	26.48	40.01	373
DAG	Doğu Anadolu Gözlemevi	Erzurum	41.23	39.78	3102
EGE	Ege University Observatory	İzmir	27.27	38.40	622
İNÜ	İnönü University Observatory	Malatya	38.44	38.32	1021
İÜO	İstanbul University Göz. Uyg. Arş.Mrk.	İstanbul	28.96	41.01	55
TUG	TÜBİTAK National Observatory	Antalya	30.34	36.82	2436
TURAG	Turkish National Radio Astronomy Obs. Site	Karaman	33.09	37.14	1062
UZAYBİMER	Astr. ve Uzay Bil. Göz. Uyg. Arş.Mrk.	Kayseri	35.55	38.71	1094
UZAYMER	Uzay Bil. ve Güneş¸ En. Arş. Uyg. Mrk.	Adana	35.35	37.06	112

Table 4. Yearly average of AL for all observatories in Turkey. Column definitions are the same as in Table 2. The SQM is in mpsas units, and SQM values were converted from AL for 2019.

Obs.	Ave-All	Ave-19	L.R.	R^2	SQM
AÜKR	11.09	14.40	0.79	0.42	17.8
ÇAAM	0.26	0.30	0.01	0.48	21.0
DAG	0.27	0.27	0.02	0.50	21.1
EGE	1.79	2.21	0.14	0.80	19.3
İNÜ	4.24	5.00	0.58	0.57	18.7
İÜO	138.03	130.04	-3.09	0.40	16.0
TUG	0.10	0.14	0.01	0.60	21.6
TURAG	0.10	0.13	0.01	0.90	21.7
UZAYBİMER	47.99	58.89	2.84	0.94	16.6
UZAYMER	10.47	9.53	-0.05	0.01	18.1