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Variations in Sunshine Duration Related to Air Quality Index and Some Meteorological Parameters: A Case Study in Eastern Anatolia Region

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Abstract: The procurement and production of energy have become a significant issue for energy needs, especially in industrial processes and household usage. The increase in urban activities and the industry has increased the energy needs in urban areas. Many researchers focus on the issues of conservation, sustainability, and energy saving. Solar energy and sunshine duration present a solution for sustainable development. This paper introduces the analysis of ground-based observations for sunshine duration and other related meteorological variables, i.e., climate elements and air quality index. Daily data of meteorological variables were examined to determine the changes in sunshine duration, a proxy variable essentially used to estimate solar radiation and plan air quality management systems in urban regions with other environmental factors. The analysis was performed using statistical methodologies. Utilizing multivariate statistical technique, which involves Principal Component Analysis (PCA as a pattern recognition method), the analysis of sunshine duration was carried out for Erzurum city in Turkey using variables in the atmospheric environment. PCA analysis with orthogonal rotations, i.e., Varimax, Quartimax, and Equamax, presented similar results. In annual and seasonal periods, duration of sunshine is negatively associated with precipitation. Furthermore, in winter, sunshine duration varies significantly with atmospheric pressure positively; in spring, with cloud cover negatively; in summer, with cloud cover, relative humidity, and minimum air temperature negatively. Additionally, the duration of sunshine on the previous day is significantly related to the air quality index.

Keywords: sunshine duration, Air Quality Index, climate change, Principal Component Analysis, Erzurum

1. Introduction

Environmental factors such as urban air quality and climate have been handled in recent years in various applications, especially in planning urban life areas. Climate is an essential element for human life and all survivals on Earth. The Industrial Revolution, especially anthropogenic activities such as burning fossil fuels, caused climate change. Climate change threatens human life and the planet in many ways and various regions.

In recent years, the increase in the rate of development of technology, rapid population growth, and the associated increase in production have accelerated the depletion of non-renewable energy sources. Consumption of fossil resources has serious consequences for nature and inflicts damage. Therefore, it is an urgent obligation and necessity to give up the usage of traditional energy sources based on fossil fuels. The use of fossil fuels causes global warming and acid rain. Carbon dioxide, sulfur compounds, lead, and other toxic chemical compounds are emitted into the atmosphere. Against this, countries have increased their efforts to use alternative energy sources.

The studies and investments in renewable energy have increased worldwide due to climate change and its related environmental problems, scarcity of energy resources, increasing population, and increasing energy demand based on economic growth (Kandirmaz et al. 2014, Mirzabe et al. 2022). The main energy source is the sun, which humans and all living things need for their lives. Solar radiation is in the form of radiant energy transmitted from the sun to the land surface. In addition, solar radiation considerably affects the climate of a particular region (Kaiser & Qian 2002, Zheng et al. 2008). Solar energy, one of the renewable energy sources, is inexhaustible and unlimited. Defining the information on solar radiation and related sunshine duration values is needed for sustainable life and development in various regions. Sunshine duration has a significant role in climate formation and is linked to the survival and development of all living things, such as humans, animals, and plants (Ghanghermeh et al. 2022). Because of a crucial input weather element, sunshine duration is utilized in many applications such as power plants planning, vegetation, agriculture, tourism, architecture, building design, photovoltaic, and thermal systems. Sunshine duration is considered a good representative of solar radiation (Xia 2010). It is especially an important parameter for estimating the solar radiation where solar radiation measurement cannot be made or data is missing (Adhikari et al. 2013). Sunshine duration is associated with solar radiation using the Angstrom-Prescott formula (Almorox and Hontoria, 2004). Sunshine duration (or bright sunshine hours) is determined as the daily sum of the times of direct solar radiation exceeding the threshold value of 120 W/m^2 defined by the World Meteorological Organization (Hassan et al. 2021).

Sunshine duration is a significant atmospheric factor involving studies on different subjects and disciplines such as agriculture (Brown 2013), climate change (Matuszko & Węglarczyk 2015), and solar radiation (Almorox & Hontoria 2004, Hassan et al. 2021, Kaba et al. 2018). Sunshine duration varies depending on time and region (Karume et al. 2007). Sunshine duration can influence many physical and chemical processes in any region. Furthermore, the climate of regions can be characterized by utilizing the sunshine duration parameter, e.g., tourism and health issues (WMO 2008).

Furthermore, there are also studies on the effects of atmospheric parameters such as sunshine duration and other meteorological elements on environmental factors and human health in urban areas (Chang et al. 2022, Cui et al. 2021, Gu et al. 2019, Jiang et al. 2022, Li et al., 2022, Wang et al. 2021, Yan et al. 2022, Kandirmaz & Kaba 2014). Further, a short duration of sunshine may increase depression risk (Ji et al., 2023). In addition, sunshine duration is related to psychological elements, mortality by exposure to sunshine, and circadian rhythms (Fu & Wang 2023). Sunshine duration interacts with other climate elements, e.g., precipitation, relative humidity, etc., and atmospheric pollutants.

Sunshine duration in a given location adheres to some parameters involving geographical factors such as elevation, longitude, and latitude; astronomical factors, e.g., hour angle, declination angle; meteorological factors, e.g. cloud, precipitation; and physical parameters such as atmospheric components e.g., particulate matter, carbon dioxide, sulfur dioxide, dinitrogenous. Therefore, the change in sunshine duration has been examined due to the abovementioned factors. Many researchers have centered at the associations between sunshine duration and the other atmospheric variables such as spatiotemporal analysis (Tang et al. 2022), geographical distribution (Pashiardis et al. 2023), atmospheric circulation (Bartoszek & Matuszko 2021), global warming (Sanchez-Lorenzo et al. 2009), climatic trends (Marin et al. 2014), evapotranspiration (Allen et al. 1998), aerosol optical depth (Sanchez-Romero et al. 2016), ultraviolet radiation (Baker-Bloker 1980), relative humidity and precipitation (Goni et al. 2019), cloud cover (Bartoszek et al. 2020, Kandirmaz 2006, Matuszko 2012), temperature (van den Besselaar et al. 2015), wind (Yang et al. 2009). Moreover, atmospheric circulation conditions, such as thermohaline circulation in the North Atlantic, significantly affect sunshine duration variability (Marsz et al. 2022).

Climate change caused the increase in temperature via greenhouse gases originating from anthropogenic emissions in urban regions. Anthropogenic activities may cause changes in the duration of sunshine (Tang et al. 2022). Additionally, because of urbanization, anthropogenic activities lead to changes in land cover and land use in urban areas, which means an increase in reconstruction instead of vegetation area. The urban structures, e.g., buildings, asphalt, and concrete structures absorb solar energy during the day and emit it at night, thus preventing the cooling of the atmosphere and surface in urban areas. The reduction in sunshine duration in urban regions has bigger values than rural regions, expressing the effect of urbanization on sunshine duration (Zongxing et al. 2012). Sunshine duration is related to wind speed, relative humidity, precipitation, cloud cover, and solar radiation with high correlation (Zongxing et al. 2012). Clouds have the highest impact on regulating the radiation incoming to the surface of Earth (Sanchez-Lorenzo et al. 2009). Furthermore, cloud types can be a driving factor for variability in sunshine duration, such that an increase in low cloud opacity may be the main driver of a decrease in sunshine duration (Li et al. 2011). Similarly, high clouds are transparent compared to medium and low clouds (Josefsson & Landelius 2000) and do not lead to attenuation in sunshine hours.

Moreover, the emission of air pollutants is one of the main drivers in decreasing solar radiation (Qian et al. 2007). There is a linkage between solar radiation and anthropogenic aerosols (Kaiser & Qian 2002, Zheng et al. 2008, Yang et al. 2009, Qian et al. 2007). Further, clouds and aerosols interact differently (Ramanathan et al. 2011). Air pollutants and Air Pollution Index (or Air Quality Index) are linked to sunshine duration and lead to variations in its magnitude (Wang et al. 2012).

The present study aims to reveal the interactions and variations of sunshine duration with other atmospheric elements and the air quality index. There is a lack of studies on the analysis of sunshine duration with PCA. This is the first attempt to use the PCA concept for sunshine duration analysis in Erzurum. Pattern recognition methods have generally been used in climatological and related studies.

2. Materials and Methods

This study utilizes a five-year dataset of sunshine duration, other meteorological variables, and air quality index. Daily data of maximum temperature (TMX), minimum temperature (TMN), sunshine duration (DSR), precipitation (PCP), pressure (PRS), cloud cover (CLC), relative humidity (RLH), wind speed (WDS), evaporation (EVN) were provided from meteorological station belonging to National Meteorological Service in Erzurum during 2019-2023. Air pollutants data for the air quality index were obtained from the Ministry of Environment, Urbanism, and Climate Change (MOEUC 2024).

Erzurum is a settlement in the country's northeast region, far from the sea and surrounded by high mountains to the south, north, and east (41.16°E and 39.55°N). The altitude above sea level of the province is 1859 m. A continental climate prevails in Erzurum, which is one of the highest and coldest provinces. Winters are generally very cold and snowy; summers are very hot and dry. The annual minimum, maximum, and average temperatures for long-term meteorological data are -0.5°C, 12°C, 5.8°C. The annual average values of sunshine duration, wind speed, relative humidity, number of rainy days, and precipitation are 7 h, 2.7 m/s, 63.3%, 121.6, 629.3 mm, respectively. The prevailing winds are in the West-SouthWest direction in winter, whereas East-NorthEast in summer. Air pollution in Erzurum is caused by the long and cold winter season due to fuels that are burned for heating purposes. In addition, the city's topography is surrounded by mountains, and the meteorological structure makes dilution of these pollutants difficult. Further, the fact that some residential areas are in the prevailing wind direction means that pollutants are carried to the city center and cause increased air pollution.

Before performing the exploratory analysis, two statistical tests were conducted to determine whether the meteorological variables are homogeneous. Parametric and non-parametric statistical tests, such as One-Way ANOVA and the Kruskal-Wallis test, were applied on the dataset to analyze the homogeneity situation. Following the homogeneity analysis, the exploratory analysis was used to evaluate the interactions in variables. An exploratory analysis was carried out to detect possible excesses and explore joint patterns when assessing meteorological elements. This purpose was accomplished utilizing the PCA tool. One of the statistical analysis programs, Statistical Package for Social Science (SPSS), was used to examine the homogeneity status and pattern recognition analysis.

The method of PCA is applied to unite subgroups together to define the significant climate variables in the present study, which are the most effective. Less prominent variables from the entire dataset are removed during the course of the analysis. The principal components are computed by sequencing in a way that the first principal component describes the highest rate of changeability in the data. The second principal component describes the highest rate of changeability that was not described by the first principal component (Pires et al. 2008).

This method builds new unrelated orthogonal variables named as principal components that cover the best part of the original variance. The principal components are linear compositions of the input variables. To simplify the explication of the principal components, the varimax rotation was implemented to maximize their approach to the original input parameters (Richman 1986). The standardized scores of each principal component are computed by the formula shown in Equation 1:

$$s_{mj} = v_{1m}z_{1j} + v_{2m}z_{2j} + \cdots + v_{km}z_{kj} \tag{1}$$

where k is the explanatory variables' number, m is the number of principal component, j is the number of measurements (1,2,3,,….,n)., z and v show the standardized value, and the standardized weight, respectively, for associated measurements and variables.

Before assessing the statistical analysis, relative value of sunshine duration (RDSR) or otherwise relative sunshine duration (has value 0 to1) is computed by formula S/So, where S is the observed value of DSR while So (also called as daylength) is the maximum value of DSR. Equations 2 to 4 are utilized for estimating day length.

In Soneye (Soneye 2021), the solar declination angle can be calculated as follows,

$$\delta = 23.45 * sin\left(\frac{360}{365}(284 + n_d)\right) \tag{2}$$

In addition, the average sunrise hour angle (in degrees), ω_s is calculated by Equation (2),

$$\omega_s = cos^{-1}(-tan\delta tan\varphi) \tag{3}$$

In the paper written by Mustafa et al. (Mustafa et al. 2022), day length, S_0 is calculated by the formula given below,

$$S_0 = \left(\frac{2}{15}\right)\omega_s \tag{4}$$

where δ is the solar declination angle (in degrees), φ is the latitude of the location, n_d is the year's day beginning from January 1st.

Following the completeness of the computation of the relative value of sunshine duration, the air quality index was calculated. Sunshine duration is associated with other meteorological variables. Similarly, air pollutants are also related to these meteorological elements such as cloud cover, solar radiation, wind speed, and air temperature via the Pasquill–Gifford–Turner protocol. Due to its indirect effect, the Air Quality Index calculated by air pollutants was also included in this analysis study, considering that it may be related to sunshine duration. Air Quality Index (AQI), which is used to characterize the air quality in any location, is a parameter utilized by the authorities of air quality management in cities. National air quality index (AQI) is calculated for 5 main pollutants such as ozone (O_3), particulate matter (PM_{10}), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) shown in Table 1 which constructed depending on Turkish National Ambient Air Quality Standards.

AQI is calculated using a sub-index formula presented by the United States Environmental Protection Agency (USEPA) based on the criteria for air pollutants' concentrations (Eqn. 5).

$$I_p = \left[\frac{(I_{Hi}-I_{Lo})}{(BP_{Hi}-BP_{Lo})}\right]\left(C_p - BP_{Lo}\right) + I_{Lo} \tag{5}$$

where C_p is the actual concentration for p^{th} pollutant, I_p describes the air quality index for p^{th} pollutant, I_{Lo} and I_{Hi} is in order of the sub index value that corresponds to BP_{Lo} and to BP_{Hi}, BP_{Lo} and BP_{Hi} is the breakpoint which is lesser than or equal to C_p and the breakpoint which is larger than or equal to C_p.

Table 1. Breakpoints of air pollutants for the air quality index (AQI) (CDR 2020)

Breakpoints						
O_3 (µg/m^3) (8-hour)	PM_{10} (µg/m^3) (24 hour)	CO (µg/m^3) (8 hour)	SO_2 (µg/m^3) (1 hour)	NO_2 (µg/m^3) (1 hour)	AQI	Category Index
0-120	0-50	0-5500	0-100	0-100	0-50	Good
121-160	51-100	5501-10000	101-250	101-200	51-100	Moderate
161-180^B	101-260	10001-16000^L	251-500	201-500	101-150	Sensitive
181-240^U	261-400	16001-24000	501-850	501-1000	151-200	Unhealthy
241-700	401-520	24001-32000	851-1100	1001-2000	201-300	Very unhealthy
>701	>521	>32001	>1101	>2001	301-500	Hazardous

L: Limit value, B: Information threshold, U: Warning threshold

After calculating the air quality index for the five pollutants, the one with the biggest value is determined as the daily AQI.

3. Results and Discussion

The changes in sunshine duration and interactions with meteorological variables were investigated using a pattern recognition method, PCA, on annual and seasonal times during 2019-2023. Three rotation methods, such as Varimax, Quartimax, and Equamax which provide high component loadings, have been used in factor analysis. For the annual term, findings of PCA with varimax rotation were represented in Figure 1 and Tables 2-3. The eigenvalues describing most of the aggregate variation of components used in the PCA method are presented as a scree plot in Figure 1. As mentioned in the scree plot, ten principal components have been generated, but four of them have been chosen because their eigenvalues were greater than 1.

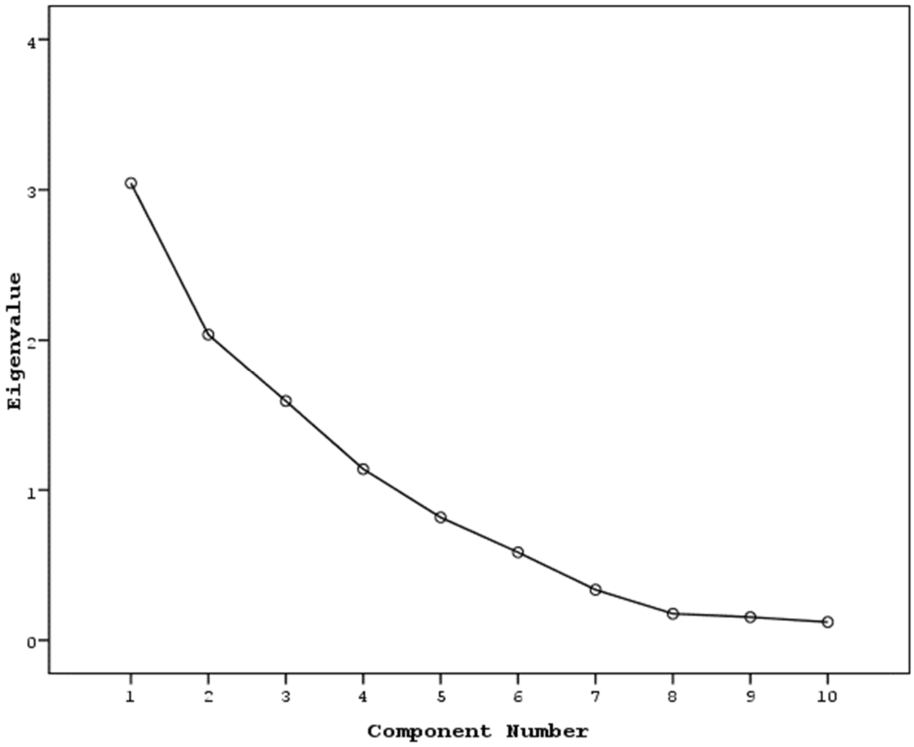

Fig. 1. Scree plot

An eigenvalue greater than 1 is generally considered statistically significant for principal components (Yidana et al. 2008). Table 2 shows four principal components with eigenvalues above 1 that were extracted via PCA over an annual period. After the varimax rotation, the first principal component (TMN, TMX, EVN) explained the 20.893% variance in the data while the second (CLC, AQI, RLH), third (PCP, RDSR), and fourth (WDS, PRS) explained 20.827%, 18.626%, and 17.786%, respectively.

Table 2. Total variance explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.045	30.449	30.449	3.045	30.449	30.449	2.089	20.893	20.893
2	2.037	20.37	50.819	2.037	20.370	50.819	2.083	20.827	41.720
3	1.592	15.923	66.741	1.592	15.923	66.741	1.863	18.626	60.346
4	1.139	11.39	78.132	1.139	11.390	78.132	1.779	17.786	78.132
5	0.817	8.171	86.303						
6	0.584	5.844	92.147						
7	0.336	3.357	95.504						
8	0.176	1.757	97.261						
9	0.153	1.532	98.793						
10	0.121	1.207	100						

According to Table 3, all input variables were grouped into four principal components. All statistically significant variables in each component were indicated in bold. It can be seen that the relative value of sunshine duration increases due to a significant decrease in precipitation. In addition, a high decrease in wind speed is related to a moderate increase in pressure; there is an increasing trend in cloud cover, air quality index, and relative humidity; a high increase in minimum temperature is related to a moderate increase in maximum temperature and evaporation.

Table 3. Rotated component matrix

Variable	Component			
	1	2	3	4
TMN	**0.927**	-0.056	-0.153	-0.022
TMX	**0.771**	-0.376	0.386	-0.004
EVN	**0.657**	-0.047	0.379	-0.232
CLC	-0.115	**0.766**	-0.245	-0.071
AQI	-0.349	**0.758**	0.347	-0.126
RLH	0.002	**0.697**	-0.016	0.45
PCP	-0.122	-0.078	**-0.824**	0.354
RDSR	0.096	-0.095	**0.769**	0.322
WDS	0.203	0.118	0.149	**-0.872**
PRS	0.064	0.509	0.269	**0.716**

Furthermore, to evaluate the relations on a seasonal basis, the factor loadings after varimax rotation for winter, spring, summer, and fall were also obtained using the PCA technique through the daily data of 2019-2023. These relations based on PCA were demonstrated in Table 4 (a-d). For visual presentation, a three-dimensional plot for components was also indicated in Figure 2 for winter.

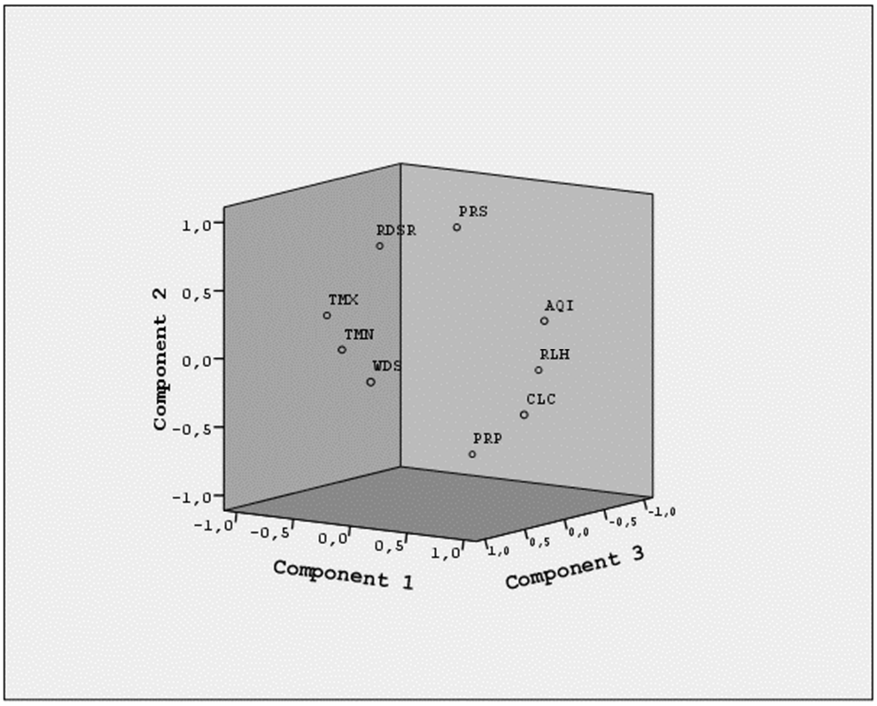

Fig. 2. 3D plot of components in rotated space

Since winter evaporation data are unavailable, they were not included in the analysis. In winter three principal components were obtained which explained 29.041% (CLC, AQI, TMX, RLH), 25.166% (PRS, PRP, RDSR), 23.409% (WDS, TMN) of total variance 77.615%. According to a second principal component, RDSR varies with increasing pressure and decreasing precipitation. For spring, five principal components with cumulative variance 81.023% have occurred with partial variances 20.460% (CLC, RDSR, PRP), 17.448% (TMN, TMX), 15.098% (WDS), 15.097% (PRS, RLH), 12.920% (AQI, EVN) respectively. For the first principal component, a high decrease in RDSR is related to an increase in cloud cover highly and precipitation moderately. In summer, four principal components with variances 30.465% (CLC, TMN, PRP, RLH, RDSR), 23.265% (EVN, TMX), 15.632% (PRS, WDS), 11.582% (AQI) were selected as statistically significant with total variance 80.944% in data. The first principal component shows the interaction that a moderate decrease in RDSR is linked to a high increase in cloud cover, minimum temperature, precipitation, and a moderate increase in relative humidity. In fall, four principal components were obtained with partial variances 22.891% (RDSR, PRP), 21.260% (TMX, PRS, RLH, WDS), 14.231% (AQI, TMN), 13.791% (EVN, CLC) of total variance 72.173% in data. For this season, precipitation is responsible for a change in RDSR. A high increase in precipitation leads to a high decrease in RSDR.

Table 4. Rotated component matrix for seasonal terms with Varimax rotation

(a) Winter				(b) Spring					
Variable	Component			Variable	Component				
	1	2	3		1	2	3	4	5
CLC	**0.881**	-0.344	0.180	CLC	**0.772**	0.129	0.108	0.175	0.053
AQI	**0.827**	0.293	-0.153	RDSR	**-0.755**	0.332	-0.029	-0.056	0.174
TMX	**-0.662**	0.270	0.457	PRP	**0.673**	0.245	-0.484	-0.248	0.262
RLH	**0.584**	-0.135	-0.427	TMN	0.253	**0.897**	0.241	-0.017	-0.057
PRS	0.081	**0.908**	-0.117	TMX	-0.270	**0.849**	-0.222	0.062	-0.099
PRP	0.105	**-0.777**	-0.277	WDS	0.067	0.043	**0.890**	-0.072	0.054
RDSR	-0.528	**0.724**	-0.016	PRS	-0.119	0.095	-0.288	**0.848**	0.149
WDS	0.064	-0.077	**0.943**	RLH	0.323	-0.059	0.239	**0.811**	-0.019
TMN	-0.272	0.110	**0.825**	AQI	-0.173	-0.134	0.191	0.157	**0.836**
EVN	No observation data			EVN	-0.371	-0.002	0.432	0.058	**-0.673**
Eigenvalue	2.614	2.265	2.107	Eigenvalue	2.046	1.745	1.510	1.509	1.292
% of Variance	29.041	25.166	23.409	% of Variance	20.460	17.448	15.098	15.097	12.920
Cumulative %	29.041	54.206	77.615	Cumulative %	20.460	37.907	53.005	68.103	81.023

(c) Summer					(d) Fall				
Variable	Component				Variable	Component			
	1	2	3	4		1	2	3	4
CLC	**0.843**	-0.301	0.016	-0.208	RDSR	**-0.874**	0.047	-0.076	0.033
TMN	**0.823**	0.304	0.371	0.036	PRP	**0.810**	-0.065	-0.220	0.195
PRP	**0.770**	-0.539	-0.012	-0.014	TMX	-0.064	**-0.778**	-0.120	0.232
RLH	**0.720**	-0.312	0.144	0.017	PRS	-0.533	**0.712**	-0.017	0.118
RDSR	**-0.670**	0.070	0.511	-0.328	RLH	0.410	**0.681**	-0.049	0.300
EVN	-0.133	**0.890**	-0.190	-0.030	WDS	0.202	**-0.654**	0.269	0.115
TMX	-0.193	**0.856**	0.158	0.036	AQI	0.079	0.060	**0.911**	-0.166
PRS	0.108	0.019	**0.894**	0.164	TMN	0.365	0.286	**-0.664**	-0.255
WDS	-0.172	0.474	**-0.530**	0.219	EVN	-0.043	-0.137	-0.065	**0.842**
AQI	-0.026	0.025	0.055	**0.964**	CLC	0.480	0.105	0.073	**0.607**
Eigenvalue	3.046	2.327	1.563	1.158	Eigenvalue	2.289	2.126	1.423	1.379
% of Variance	30.465	23.265	15.632	11.582	% of Variance	22.891	21.260	14.231	13.791
Cumulative %	30.465	53.730	69.362	80.944	Cumulative %	22.891	44.151	58.382	72.173

Moreover, the relative value of sunshine duration for the previous day was included as an input variable to the analysis. The attempt to enclose the RDSRp revealed different relations for RDSR. In annual terms, a high increase in RDSR is related to a moderate decrease in air quality index, a high decrease in precipitation, and a high increase in wind speed. RDSRp is related to cloud cover for the previous day. In winter, a moderate decrease in RDSRp is related to a high increase in AQI. In contrast, as expected, RDSR has a high increasing trend with increasing pressure and a moderate decrease in precipitation and cloudiness. In spring, RDSR varied moderately due to high precipitation and increased cloud cover, whereas a moderate decrease in evaporation. Besides, RDSRp decreased moderately with a significant increase in minimum and maximum temperatures. In summer, a moderate decrease in RDSR occurred with the high increase in cloud cover, minimum temperature, precipitation, and moderate increase in relative humidity. It was seen that a significant increase in RDSRp was accompanied by a significant decrease in AQI. In the fall, RSDR variability has shown a high decrease because of a high increase in precipitation. RDSRp has changed moderately due to cloud cover and evaporation.

Furthermore, after the varimax rotation, the other orthogonal rotation methods, Equamax and Quartimax, were also used in the analysis. Orthogonal rotations with Kaiser Normalization maximize aggregate loadings of component variances. Equamax rotation is a kind of Varimax rotation, ensuring the factors' simplification. Quartimax rotation also provides the simplification of variables.

Table 5 shows the annual rotated component loadings after Quartimax and Equamax rotations. Both methods demonstrate that relative sunshine duration is highly related to precipitation, but inversely in the annual term. Air quality index, cloudiness, and relative humidity are positively associated with each other. Similar relations have occurred between the three variables, i.e., evaporation and maximum and minimum air temperatures at moderate and high levels. However, a decrease in wind speed is related to an increase in atmospheric pressure to a high degree.

The results of seasonal terms for the Quartimax rotation are presented in Table 6. For winter, a decrease in maximum air temperature is associated with increased cloud cover, air quality index and relative humidity in moderate and high levels (occurred as the first component). An increase in sunshine duration is consistent with increased atmospheric pressure and decreased precipitation. Additionally, wind speed and minimum air temperature are highly positively correlated with each other. A decrease in sunshine duration in spring is related to increased cloud cover and precipitation. Also, an increased air quality index is highly related to decreased evaporation. In summer, a decrease in sunshine duration is related to cloud cover, precipitation, minimum temperature, and relative humidity (in the first principal component). Evaporation and maximum air temperature are positively related. Atmospheric pressure is negatively associated with wind speed. In the fall, the duration of sunshine is related to precipitation to a high degree (in the 1st principal component). Furthermore, the increment in atmospheric pressure and relative humidity is associated with the decrement in wind speed and maximum air temperature (in 2nd principal component). The air quality index is inversely related to minimum air temperature (in the 3rd principal component), whereas cloud cover and evaporation have a positive relation (in the 4th principal component).

Table 5. Rotated component matrix for annual term with Quartimax and Equamax rotations

(a) Quartimax					(b) Equamax				
Variable	Component				Variable	Component			
	1	2	3	4		1	2	3	4
CLC	**0.75**	-0.124	-0.266	-0.128	TMN	**0.927**	-0.058	-0.149	-0.023
AQI	**0.746**	-0.355	0.324	-0.213	TMX	**0.767**	-0.385	0.385	-0.009
RLH	**0.737**	0.005	-0.007	0.382	EVN	**0.658**	-0.041	0.390	-0.215
TMN	-0.054	**0.926**	-0.159	-0.018	CLC	-0.109	**0.774**	-0.234	-0.029
TMX	-0.361	**0.776**	0.389	0.001	AQI	-0.345	**0.762**	0.359	-0.065
EVN	-0.057	**0.658**	0.362	-0.255	RLH	0.001	**0.665**	-0.024	0.496
PCP	-0.06	-0.123	**-0.801**	0.408	PCP	-0.122	-0.090	**-0.838**	0.317
RDSR	-0.048	0.105	**0.787**	0.283	RDSR	0.089	-0.128	**0.756**	0.343
WDS	0.039	0.193	0.096	**-0.888**	WDS	0.211	0.174	0.183	**-0.854**
PRS	0.581	0.068	0.295	**0.647**	PRS	0.059	0.455	0.249	**0.758**
Eigenvalue	2.14	2.10	1.84	1.73	Eigenvalue	2.08	2.04	1.88	1.82
% of Variance	21.43	21.02	18.40	17.28	% of Variance	20.82	20.36	18.76	18.20
Cumulative %	21.43	42.45	60.86	78.13	Cumulative %	20.82	41.18	59.94	78.13

Table 6. Rotated component matrix for seasonal terms with Quartimax rotation

(a) Winter				(b) Spring					
Variable	Component			Variable	Component				
	1	2	3		1	2	3	4	5
CLC	**0.878**	-0.301	0.256	CLC	**0.774**	0,125	0.113	0.171	0.038
AQI	**0.822**	0.330	-0.087	RDSR	**-0.749**	0,335	-0.037	-0.053	0.190
TMX	**-0.709**	0.242	0.398	PRP	**0.682**	0,242	-0.483	-0.251	0.238
RLH	**0.623**	-0.111	-0.376	TMN	0.254	**0,895**	0.245	-0.019	-0.059
PRS	0.048	**0.910**	-0.120	TMX	-0.267	**0,851**	-0.221	0.063	-0.096
PRP	0.163	**-0.773**	-0.259	WDS	0.063	0,041	**0.890**	-0.073	0.066
RDSR	-0.557	**0.698**	-0.068	PRS	-0.109	0,096	-0.290	**0.848**	0.150
WDS	-0.011	-0.067	**0.946**	RLH	0.324	-0,061	0.242	**0.810**	-0.019
TMN	-0.345	0.103	**0.798**	AQI	-0.155	-0,133	0.177	0.155	**0.843**
EVN	No observation data			EVN	-0.388	-0.001	0.440	0.061	**-0.658**
Eigenvalue	2.797	2.199	1.990	Eigenvalue	2.056	1.745	1.515	1.508	1.278
% of Variance	31.080	24.428	22.107	% of Variance	20.563	17.450	15.155	15.079	12.776
Cumulative %	31.080	55.508	77.615	Cumulative %	20.563	38.013	53.168	68.247	81.023

(c) Summer					(d) Fall				
Variable	Component				Variable	Component			
	1	2	3	4		1	2	3	4
CLC	**0.868**	-0.226	0.001	-0.203	RDSR	**-0.869**	0.063	-0.091	0.073
PRP	**0.815**	-0.467	-0.028	-0.007	PRP	**0.820**	-0.073	-0.208	0.157
TMN	**0.799**	0.377	0.356	0.036	TMX	-0.064	**-0.774**	-0.143	0.233
RLH	**0.748**	-0.246	0.129	0.022	PRS	-0.515	**0.721**	-0.008	0.143
RDSR	**-0.663**	0.004	0.526	-0.326	RLH	0.436	**0.675**	-0.025	0.282
EVN	-0.216	**0.874**	-0.184	-0.042	WDS	0.191	**-0.665**	0.254	0.106
TMX	-0.266	**0.836**	0.164	0.026	AQI	0.056	0.035	**0.914**	-0.166
PRS	0.122	0.030	**0.890**	0.171	TMN	0.369	0.297	**-0.648**	-0.274
WDS	-0.225	0.460	**-0.527**	0.208	EVN	-0.006	-0.136	-0.073	**0.842**
AQI	-0.029	0.034	0.048	**0.964**	CLC	0.507	0.094	0.082	**0.585**
Eigenvalue	3.239	2.148	1.554	1.153	Eigenvalue	2.322	2.142	1.405	1.349
% of Variance	32.391	21.480	15.544	11.529	% of Variance	23.216	21.420	14.046	13.491
Cumulative %	32.391	53.871	69.415	80.944	Cumulative %	23.216	44.636	58.682	72.173

Table 7 shows seasonal relations for meteorological variables obtained after the Equamax rotation method. In winter, cloudiness, air quality index, and relative humidity are related positively, but negatively, with maximum air temperature. Increase in relative sunshine duration is consistent with an increase in atmospheric pressure and a decrease in precipitation. Furthermore, wind speed and minimum air temperature are positively associated with each other. For spring, a decrease in relative sunshine duration is related to increased cloudiness and precipitation, as expected. An increase in the air quality index is related to decreased evaporation. Additionally, both air temperatures are highly correlated; similarly, atmospheric pressure and relative humidity are positively related at a high level. In summer, a decrease in sunshine duration is associated with increased cloudiness, relative humidity, precipitation, and minimum air temperature. Maximum air temperature and evaporation are related to in high degree. Additionally, an increase in atmospheric pressure is related to a decrease in wind speed. In the fall, an increase in precipitation is responsible for the decrease in the duration of sunshine. Cloudiness is associated with evaporation positively. Furthermore, the air quality index is negatively related to minimum air temperature. Also, increased atmospheric pressure and relative humidity are related to decreased maximum air temperature and wind speed.

Table 7. Rotated component matrix for seasonal terms with Equamax rotation

(a) Winter				(b) Spring					
Variable	Component			Variable	Component				
	1	2	3		1	2	3	4	5
CLC	**0.881**	-0.354	0.159	CLC	**0.767**	0.140	0.178	0.100	0.085
AQI	**0.827**	0.284	-0.170	RDSR	**-0.767**	0.319	-0.056	-0.016	0.140
TMX	**-0.649**	0.276	0.472	PRP	**0.650**	0.252	-0.243	-0.484	0.311
RLH	**0.572**	-0.141	-0.440	TMN	0.245	**0.902**	-0.016	0.233	-0.049
PRS	0.088	**0.907**	-0.116	TMX	-0.281	**0.845**	0.061	-0.225	-0.102
PRP	0.090	**-0.777**	-0.281	PRS	-0.133	0.090	**0.849**	-0.282	0.145
RDSR	-0.520	**0.730**	-0.003	RLH	0.325	-0.055	**0.812**	0.234	-0.018
WDS	0.084	-0.080	**0.941**	WDS	0.076	0.047	-0.071	**0.891**	0.030
TMN	-0.253	0.110	**0.831**	AQI	-0.208	-0.140	0.164	0.220	**0.818**
EVN	No observation data			EVN	-0.333	-0.003	0.051	0.414	**-0.704**
Eigenvalue	2.565	2.281	2.140	Eigenvalue	2.023	1.745	1.513	1.497	1.324
% of Variance	28.501	25.341	23.774	% of Variance	20.232	17.449	15.128	14.973	13.241
Cumulative %	28.501	53.842	77.615	Cumulative %	20.232	37.681	52.809	67.782	81.023

(c) Summer					(d) Fall				
Variable	Component				Variable	Component			
	1	2	3	4		1	2	3	4
CLC	**0.830**	-0.328	0.044	-0.216	RDSR	**-0.877**	0.028	-0.060	-0.007
TMN	**0.824**	0.279	0.389	0.037	PRP	**0.796**	-0.057	-0.233	0.233
PRP	**0.749**	-0.567	0.020	-0.027	TMX	-0.062	**-0.783**	-0.095	0.228
RLH	**0.703**	-0.336	0.170	0.007	PRS	-0.552	**0.701**	-0.027	0.094
RDSR	**-0.681**	0.111	0.487	-0.330	RLH	0.382	**0.686**	-0.076	0.320
EVN	-0.093	**0.891**	-0.210	-0.009	WDS	0.213	**-0.642**	0.284	0.122
TMX	-0.164	**0.865**	0.137	0.052	AQI	0.103	0.088	**0.906**	-0.166
PRS	0.084	0.029	**0.897**	0.156	TMN	0.358	0.273	**-0.680**	-0.235
WDS	-0.139	0.465	**-0.541**	0.233	EVN	-0.081	-0.142	-0.057	**0.839**
AQI	-0.025	0.007	0.063	**0.964**	CLC	0.451	0.115	0.064	**0.628**
Eigenvalue	2.950	2.392	1.585	1.168	Eigenvalue	2.252	2.108	1.445	1.413
% of Variance	29.496	23.922	15.850	11.675	% of Variance	22.518	21.077	14.447	14.131
Cumulative %	29.496	53.418	69.269	80.944	Cumulative %	22.518	43.596	58.042	72.173

Sunshine duration is influenced by atmospheric and geographical parameters such as cloud cover and types, humidity, atmospheric aerosols, and additionally a terrain's aspect and slope, respectively (Reddy 1974, Robaa 2008, Xiaochen et al. 2015). Sunshine duration is associated with precipitation, wind speed, relative humidity, and air temperature (Abdelwahed & Snyder 2015, Kaba et al. 2017, Umoh et al. 2013, Yin 1999, Yang et al. 2009).

This study examines the influences of individual parameters, such as air quality index and meteorological variables on relative sunshine duration, also known as the percentage of sunshine duration. Additionally, the relations among all utilized variables have been evaluated. Because all meteorological parameters interact with each other in the atmospheric environment (Zateroglu 2021). For instance, the amount of atmospheric aerosols in the atmosphere affects the amount of clouds. Furthermore, air pollutant concentrations in urban regions influence meteorological factors, e.g., relative humidity, precipitation, and air temperature (Emberlin & Norris-Hill 1996). Moreover, Clasius-Clapeyron represents the variation in humidity with temperature. So, according to this equation, relative humidity is influenced by air temperature. Further, the Pasquill–Gifford–Turner protocol expresses the relation between the concentrations of air pollutants and vertical air temperature, wind speed, cloud cover, and solar radiation (solar radiation is closely related to sunshine duration). According to this scheme, in stable conditions of the atmosphere, the amount of air pollution is highly associated with those meteorological variables mentioned above (Zateroglu 2022).

Principal Component Analysis, including components in rotated space, scree plot, and component loading plot with orthogonal rotations, has ensured the relations in the highest degree between the variables in each component. Three orthogonal rotation methods, i.e., Varimax, Quartimax, and Equamax, presented similar results.

According to the results in the present study, duration of sunshine is adversely linked to relative humidity and precipitation (Goni et al. 2019). Sunshine duration is significantly related to cloud cover (Bartoszek et al. 2020, Kaba et al. 2024, Matuszko 2012). Further, it is positively related to wind speed and temperature, whereas negatively to humidity and precipitation (Tang et al. 2022). Sunshine duration and air temperature have similar variations unlike cloud cover and relative humidity (Marin et al. 2014). Moreover, the variation in sunshine duration is associated with air quality index related to air pollution, as anthropogenic activities caused climate change (Tang et al. 2022).

4. Conclusion

The interest in alternative energy sources is growing because fossil resources will be depleted rapidly with increasing need, and cause severe damage to nature. The most important renewable energy source is solar energy. Sunshine duration, associated with air quality index and other atmospheric parameters, is a significant element in predicting the amount of solar radiation. This study aimed to investigate the variability of sunshine duration with other climate variables and air quality index and to reveal their relations. The pattern recognition method accepts inputs of pressure, evaporation, wind speed, precipitation, relative humidity, cloud cover, relative value of sunshine duration in the current and previous days, air quality index, and minimum and maximum temperatures. Annual analysis demonstrates that sunshine duration is highly affected by precipitation inversely. According to seasonal variations, sunshine duration changes substantially with pressure positively and with precipitation negatively in winter; cloud cover and precipitation negatively in spring; cloud cover, precipitation, relative humidity, and minimum air temperature negatively in summer; precipitation negatively in fall.

According to the findings presented in this study, it can be concluded that the PCA-based method performed well in determining the links between sunshine duration and the meteorological variables mentioned above. This result can be applied to sunshine duration forecasting that may be addressed in future works in the studied area or a relevant site of a forecasting operation in each given urban area. Additionally, the relations between the meteorological variables, i.e., climate elements and air quality index, can be used in making precautionary regulations and planning to improve the climate scenarios and the environmental protection policies in urban regions. Furthermore, it is recommended that these relations be investigated using alternative methods such as multi-criteria decision methods.

References

Abdel-Wahed, M. H. & Snyder R. L. (2015). Calculating sunshine hours and reference evapotranspiration in arid regions when solar radiation data are limited. *Irrigation and Drainage*, *64*, 419-425.

Adhikari, K. R., Bhattarai, B. K. & Gurung, S. (2013). Estimation of Global Solar Radiation for Four Selected Sites in Nepal Using Sunshine Hours, Temperature and Relative Humidity. *Journal of Power and Energy Engineering*, *1*, 1-9.

Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. (1998). Crop evapotranspiration – Guidelines for computing crop water requirements – *FAO Irrigation and drainage paper 56. FAO – Food and Agriculture Organization of the United Nations*, Rome.

Almorox, J. & Hontoria, C. (2004). Global solar radiation estimation using sunshine duration in Spain. *Energy Conversion and Management*, *45*, 9-10, 1529-1535.

Baker-Blocker, A. (1980). Ultraviolet radiation and melanoma mortality in the United States. *Environ Res*, *23*, 24-28.

Bartoszek, K., Matuszko, D. & Soroka, J. (2020). Relationships between Cloudiness, Aerosol Optical Thickness, and Sunshine Duration in Poland. *Atmos. Res.*, *245*, 105097.

Bartoszek, K. & Matuszko, D. (2021). The influence of atmospheric circulation over Central Europe on the long-term variability of sunshine duration and air temperature in Poland. *Atmos. Res.*, *251*, 105427.

Brown, I. (2013). Infuence of seasonal weather and climate variability on crop yields in Scotland. *Int J Biometeorol*, *57*, 605-614.

CDR (2020). Provincial Environment Situation Report (in Turkish, "Erzurum İli 2019 Yılı Çevre Durum Raporu"). *Ministry of Environment, Urbanism and Climate change*. https://csb.gov.tr (accessed on 20.12.2024)

Chang, Z., Chen, Y., Zhao, Y., Fu, J., Liu, Y., Tang, S., Han, Y. & Fan, Z. (2022). Association of sunshine duration with acute myo-cardial infarction hospital admissions in Beijing, China: a time-series analysis within summer. *Sci Total Environ*, *828*, 154528.

Cui, Y., Gong, Q., Huang, C., Guo, F., Li, W., Wang, Y. & Cheng, X. (2021). The relationship between sunlight exposure duration and depressive symptoms: a cross-sectional study on elderly Chinese women. *PLoS One*, *16*, 7, e0254856.

Emberlin, J. C. & Norris-Hill, J. (1996).The influence of wind speed on the ambient of concentrations of polleb from Graminae, Platanus and Betula in the air of London, England. In: M. Muilenberg and H. Burge (eds). *Aerobiology*, 27-38. CRC Press, Lewis Publishers, Boca Raton.

Fu, Y. & Wang, W. (2023). Association between provincial sunshine duration and mortality rates in China: Panel data study. *Heliyon*, *9*, e15862.

Ghanghermeh, A., Roshan, G. & Halabian, A. (2022). Projecting spatiotemporal variations of sunshine duration with regards to climate change in Iran as a step towards clean energy. *Sustain. Energy Technol. Assess.*, *53*, 102630.

Goni, S., Adannou, H. A., Diop, D., Drame, M. S., Tikri, B., Barka, M. & Beye, A. C. (2019). Long-Term Variation of Sunshine Duration and Their Inter-Action with Meteorological Parameters over Chad, Central Africa. *Natural Resources*, *10*, 47-58.

Gu, S., Huang, R., Yang, J., Sun, S., Xu, Y., Zhang, R., Wang, Y., Lu, B., He, T., Wang, A., Bian, G. & Wang, Q. (2019). Exposure-lag-response association between sunlight and schizophrenia in Ningbo, China. *Environ Pollut*, *247*, 285-292.

Hassan, M. A., Abubakr, M. & Khalil, A. (2021). A profile-free non-parametric approach towards generation of synthetic hourly global solar irradiation data from daily totals. *Renew Energy*, *167*, 613-628.

Jiang, G., Ji, Y., Chen, C., Wang, X., Ye, T., Ling, Y. & Wang, H. (2022). Effects of extreme precipitation on hospital visit risk and disease burden of depression in Suzhou, China. *BMC Public Health*, *22*, 1710.

Ji, H., Chen, C., Xu, G., Song, J., Su, H. & Wang, H. (2023). Effects of sunshine duration on daily outpatient visits for depression in Suzhou, Anhui Province, China. *Environmental Science and Pollution Research*, *30*, 2075-2085.

Josefsson, W. & Landelius, T. (2000). Effect of clouds on UV irradiance: as estimated from cloud amount, cloud type, precipitation, global radiation and sunshine duration. *J Geophys Res*, *105*, D4, 4927-4935.

Kaiser, D. P. & Qian, Y. (2002). Decreasing trends in sunshine duration over China for 1954-1998: indication of increased haze pollution? *Geophys Res Lett*, *29*, 21, 2042.

Kaba, K., Erdi, E., Avci, M. & Kandirmaz, H. M. (2024). Estimation of monthly sunshine duration using satellite derived cloud data. *Theoretical and Applied Climatology*, *155*, 5727-5743.

Kaba, K., Sarigul, M., Avci, M. & Kandirmaz, H. M. (2018). Estimation of daily global solar radiation using deep learning model. *Energy*, *162*, 126-135.

Kaba, K., Kandirmaz, H. M. & Avci, M. (2017). Estimation of daily sunshine duration using support vector machines. *International Journal of Green Energy*, *14*(4), 430-441.

Kandirmaz, H. M., Kaba, K. & Avci, M. (2014). Estimation of Monthly Sunshine Duration in Turkey Using Artificial Neural Networks. *International Journal of Photoenergy*, *2014*(1), 680596.

Kandirmaz, H. M. & Kaba, K. (2014). Estimation of Daily Sunshine Duration from Terra and Aqua MODIS Data. *Advances in Meteorology*, *2014*(1), 613267.

Kandirmaz, H. M. (2006) A model for the estimation of the daily global sunshine duration from meteorological geostationary satellite data. *Int J Remote Sens*, *27*(22), 5061-5071.

Karume, K., Banda, E. J. K. B., Mubiru, J. & Majaliwa, M. (2007). Correlation between sunshine hours and climatic parameters at four locations in Uganda. *Tanzania Journal of Science*, *03*, 93-100.

Li, C., Yu, J.-L., Xu, J.-J., He, Y.-C., Qin, K.-Z., Chen, L., Huang, H-F. & Wu, Y.-T. (2022). Interactive effects of ambient air pollution and sunshine duration on the risk of intrahepatic cholestasis of pregnancy. *Environmental Research*, *215*, 114345.

Li, W., Hou, M. & Xin, J. (2011). Low-cloud and sunshine duration in the low-latitude belt of South China for the period 1961-2005. *Theor Appl Climatol*, *104*, 473-478.

Marin, L., Birsan, M. V., Bojariu, R., Dumitrescu, A., Micu, D. M. & Manea, A. (2014). An overview of annual climatic changes in Romania: Trends in air temperature, precipitation, sunshine hours, cloud cover, relative humidity and wind speed during the 1961–2013 period. *Carpathian J. Earth Environ. Sci.*, *9*, 253-258.

Marsz, A. A., Matuszko, D. & Styszynskab, A. (2022). The thermal state of the North Atlantic and macro-circulation conditions in the Atlantic-European sector, and changes in sunshine duration in Central Europe. *Int J Climatol.*, *42*, 748-761.

Matuszko, D. & Węglarczyk, S. (2015). Relationship between sunshine duration and air temperature and contemporary global warming. *Int J Climatol*, *35*, 3640-3653.

Matuszko, D. (2012). Infulence of cloudiness on sunshine duration. *Int J Climatol.*, *32*, 1527-1536.

Mirzabe, A. H., Hajiahmad, A., Keyhani, A. & Mirzaei, N. (2022). Approximation of daily solar radiation: A comprehensive review on employing of regression models. *Renewable Energy Focus*, *41*, 143-159.

MOEUC (2024). *Ministry of Environment, Urbanism and Climate Change*, https://sim.csb.gov.tr (accessed on 10.12.2024)

Mustafa, J., Alqaed, S., Almehmadi, F. A. & Jamil, B. (2022). Development and comparison of parametric models to predict global solar radiation: a case study for the southern region of Saudi Arabia. *Journal of Thermal Analysis and Calorimetry*, *147*, 9559-9589.

Pashiardis, S., Pelengaris, A. & Kalogirou, S. A. (2023). Geographical Distribution of Global Radiation and Sunshine Duration over the Island of Cyprus. *Appl. Sci.*, *13*, 5422.

Pires, J. C. M., Sousa, S. I. V., Pereira, M. C., Alvim-Ferraz, M. C. M. & Martins, F. G. (2008). Management of air quality monitoring using principal component and cluster. Analysis e part I: SO_2 and PM_{10}. *Atmospheric Environment*, *42*, 1249e1260.

Qian, Y., Wang, W., Leung, L. R. & Kaiser, D. P. (2007). Variability of solar radiation under cloud-free skies in China: the role of aerosols. *Geophys Res Lett*, *34*, L12804.

Ramanathan, V., Crutzen, P.J., Kiehl, J. T. & Rosenfeld, D. (2001). Aerosol, Climate and the Hydrological Cycle. *Science*, *294*, 5549, 2119-2124.

Reddy, S. J. (1974). An empirical method for estimating sunshine from total cloud amount. *Solar Energy*, *15*(4), 281-285.

Richman, M. B. (1986). Rotation of principal components. *J. Climatol.*, *6*(3), 293-335.

Robaa, S. M. (2008). Evaluation of sunshine duration from cloud data in Egypt. *Energy*, *33*(5), 785-795.

Sanchez-Lorenzo, A., Calbo, J., Brunetti, M. & Deser, C. (2009). Dimming / Brightenning over the Iberian Peninsula: Trends in Sunshine Duration and Cloud Cover and Their Relations with Atmospheric Circulation. *Journal of Geophysical Research*, *114*.

Sanchez-Romero, A., Sanchez-Lorenzo, A., González, J. A. & Calbó, J. (2016). Reconstruction of Long-Term Aerosol Optical Depth Series with Sunshine Duration Records. *Geophys. Res. Lett.*, *43*, 1296-1305.

Soneye, O. O. (2021). Evaluation of clearness index and cloudiness index using measured global solar radiation data: a case study for a tropical climatic region of Nigeria. *Atmosfera*, *34*, 1, 25-39.

Tang, C., Zhu, Y., Wei, Y., Zhao, F., Wu, X. & Tian, X. (2022). Spatiotemporal Characteristics and Influencing Factors of Sunshine Duration in China from 1970 to 2019. *Atmosphere*, *13*, 2015.

Umoh, M. D., Udo, S. O. & Udoakah, Y. N. (2013). Global solar radiation studies due to sunshine hours and other meteorological parameters. *American Journal of Engineering and Applied Sciences*, *6*(3), 320-326.

van den Besselaar, E. J. M., Sanchez-Lorenzo, A., Wild, M., Klein Tank, A. M. G. & de Laat, A. T. J. (2015). Relationship between sunshine duration and temperature trends across Europe since the second half of the twentieth century. *J. Geophys. Res. Atmos.*, *120*, 10,823-10,836.

Wang, B., Wang, S., Li, L., Xu, S., Li, C., Li, S., Wang, J., He, H., Niu, J., Zhang, K. & Luo, B. (2021). The association between drought and outpatient visits for respiratory diseases in four northwest cities of China. *Climatic Change*, *167*, 2.

Wang, Y., Yang, Y., Zhao, N., Liu, C. & Wang, Q. (2012). The magnitude of the effect of air pollution on sunshine hours in China. *Journal of Geophysical Research*, *117*, D00V14.

WMO (2008). Guide to Meteorological Instruments and methods of observation. 7th ed., WMO Rep. 8, *World Meteorological Organization*, Geneva, Switzerland. pp.681.

Xia, X. (2010). Spatiotemporal changes in sunshine duration and cloud amount as well as their relationship in China during 1954-2005. *J. Geophys. Res. Atmos.*, *115*.

Xiaochen, Z., Xinfa, Q., Yan, Z., Jiaqi, G. & Yongjian, H.E. (2015). A Remote Sensing Model to Estimate Sunshine Duration in the Ningxia Hui Autonomous Region, China. *Journal of Meteorological Research*, *29*(1), 144-154.

Yan, M., Liu, N., Fan, Y., Ma, L. & Guan, T. (2022). Associations of pregnancy complications with ambient air pollution in China. *Ecotoxicology and Environmental Safety*, *241*, 113727.

Yang, Y., Zhao, N., Hu, Y. & Zhou, X. (2009). Effect of Wind Speed on Sunshine Hours in Three Cities in Northern China. *Climate Research*, *39*, 149-157.

Yang, Y. H., Zhao, N., Hao, X. F. & Li, C. Q. (2009). Decreasing trend of sunshine hours and related driving forces in North China. *Theor Appl Climatol.*, *97*, 91-98.

Yidana, S. M., Ophori, D. & Banoeng-Yakubo, B. (2008). A multivariate statistical analysis of surface water chemistry data-the Ankobra Basin, Ghana. *J Environ Manage*, *86*, 1, 80-87.

Yin, X. (1999). Bright sunshine duration in relation to precipitation, air temperature and geographic location. *Theoretical and Applied Climatology*, *64*(1), 61-68.

Zateroglu, M. T. (2022). Modelling the Air Quality Index for Bolu, Turkey. *Carpathian Journal of Earth and Environmental Sciences*, *17*(1), 119-130.

Zateroglu, M. T. (2021). Assessment of the effects of air pollution parameters on sunshine duration in six cities in Turkey. *Fresenius Environmental Bulletin*, *30*(02A), 2251-2269.

Zheng, X., Kang, W., Zhao ,T., Luo, Y., Duan, C. & Chen, J. (2008). Long-term trends in sunshine duration over Yunnan–Guizhou Plateau in Southwest China for 1961-2005. *Geophys Res Lett*, *35*, L15707.

Zongxing, L., Qi, F., Wei, Z., Yuanqing, H., Xufeng, W., Catto, N., G. G., W., Du, J., Aifang, C. & Meng H. (2012). Decreasing trend of sunshine hours and related driving forces in Southwestern China. *Theoretical and Applied Climatology*, *109*, 1-2.