Journal of Architectural Sciences and Applications
JASA 2024, 9 (2), 815-830
Research article
e-ISSN: 2548-0170
https://dergipark.org.tr/en/pub/mbud

Understanding Air Pollution Risk Patterns in Ankara: Influence of Human and Meteorological Factors

Nuriye Ebru YILDIZ [1]*, Şükran ŞAHİN [2]

ORCID 1: 0000-0002-3508-4895
ORCID 2: 0000-0002-3730-2534
[1] *Niğde Ömer Halisdemir University, Faculty Architecture, Department of Landscape Architecture, 51000, Niğde, Türkiye*
[2] *Ankara University, Faculty of Agriculture, Department of Landscape Architecture, 06110, Ankara Türkiye*
***e-mail**: ebruyildiz@ohu.edu.tr*

Abstract

In order to determine the air pollution risk in Ankara city centre, a series of analyses including quantitative measurements of anthropogenic and meteorological parameters were carried out. After the quantitative results were normalised, relevant categorical values were assigned to each parameter. These parameters were overlaid with the overlapping technique by considering their weight scores. According to the research findings, almost all of Çankaya, the south of Yenimahalle and the east of Etimesgut were found to have "Very High (5)" and "High (4)" levels of air pollution, respectively. The results show that 19.78% of the total study area has "very high", 28.92% "high", 30.33% "medium", 16.68% "low" and 4.29% "very low" air pollution risk levels. In future studies, different parameters with different weights can be added to the method based on other environmental factors and requirements in the research area.

Keywords: *Air quality, human effects, urban planning, geographic information systems.*

Ankara'da Hava Kirliliği Risk Deseninin Anlaşılması:Antropojenik ve Meteorolojik Etkiler

Öz

Ankara kent merkezinde hava kirliliği riskinin belirlenmesi amacıyla antropojenik ve meteorolojik parametrelere ilişkin nicel ölçümleri içeren bir dizi analiz süreci yürütülmüştür. Nicel sonuçlar normalize edildikten sonra, her bir parametreye ilgili kategorik değerler atanmıştır. Bu parametreler, ağırlık puanları dikkate alınarak üst üste bindirme tekniği ile çakıştırılmıştır. Araştırma bulgularına göre, Çankaya'nın neredeyse tamamı ile Yenimahalle'nin güneyi ve Etimesgut'un doğusunun sırasıyla "Çok Yüksek (5)" ve "Yüksek (4)" düzeylerinde hava kirliliği tespit edilmiştir. Sonuçlar, toplam çalışma alanının %19,78'inde "çok yüksek", %28,92'sinde "yüksek", %30,33'ünde "orta", %16,68'inde "düşük" ve %4,29'unda "çok düşük" hava kirliliği risk düzeylerinin bulunduğunu göstermektedir. Gelecek çalışmalarda, araştırma alanındaki diğer çevresel faktörlere ve gereksinimlere bağlı olarak yönteme farklı ağırlıklarda farklı parametreler eklenebilir.

Anahtar Kelimeler: *Hava kalitesi, insan etkileri, kent planlama, coğrafi bilgi sistemleri.*

Citation: Yıldız, N. E. & Şahin, Ş. (2024). Understanding air pollution risk patterns in Ankara: Influence of human and meteorological factors. *Journal of Architectural Sciences and Applications*, 9 (2), 815-830.

DOI: https://doi.org/10.30785/mbud. 1457692

Received: *March 23, 2024 –* ***Accepted:*** *October 03, 2024*

1. Introduction

The effects of air pollution on human health are one of the major environmental issues caused by industrialization and urban development (WHO, 1992; Hosseiniebalam & Ghaffarpasand, 2015). The population growth over the past century has led to an increase in the number of housing, industrial structures, and vehicles. The increase in building density and traffic density are significant sources that contribute to higher levels of pollutants in the lower layers of the atmosphere. Additionally, due to increased energy demands and the continuous use of non-renewable energy sources, the release of hazardous pollutants into the atmosphere continues (Karimi et al., 2016). The most common pollutants in the atmosphere include carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO and NO_2), particulate matter (PM), smoke, soot, and dust. The sources and effects of air quality variables are shown in Table 1 (CEE, 2018).

Table 1. Air Pollutants and Their Sources (CEE, 2018)

Pollutant	Source
Sulfur Dioxide (SO2)	Fossil Fuel Combustion, Vehicle Emissions
Nitrogen Oxides (NOX)	Vehicle Emissions, High-Temperature Combustion Processes
Particulate Matter (PM)	Industry, Vehicle Emissions, Fossil Fuel Combustion, Agriculture, Secondary Chemical Reactions
Carbon Monoxide (CO)	Incomplete Combustion Products and Vehicle Emissions
Ozone (O3)	The Transformation of Traffic-Generated Nitrogen Oxides and Volatile Organic Compounds (VOC) by Sunlight

In addition to the target limit values for air pollutants in the Turkish Air Quality Control Regulation, limit values reported by the European Union, the World Health Organization (WHO), and the European Environmental Agency are also available (Menteşe, 2017). According to the Clean Air Right Platform (2021), in Turkey, 97.7% of the 175 stations (171 stations) had PM10 averages in 2020 that exceeded the limit values set by the World Health Organization (WHO). When the legal limit values set for Turkey are evaluated, it is observed that the annual PM10 average exceeds national limits in 45 out of 72 provinces where sufficient measurements were taken. Additionally, the WHO's technical guidance states that '24-hour PM10 measurement values should not exceed the limit of 50 $\mu g/m^3$ on more than 35 days in a year.' However, it has been found that the specified limit is exceeded in 66.9% (83 stations) of the 124 stations where measurements were taken (Clean Air Right Platform, 2021; Yıldız, 2022). Nevertheless, in the updated WHO (2021), guideline values that should not be exceeded for particulate matter (PM10), particulate matter (PM2.5), nitrogen dioxide (NO_2), ozone (O_3), and carbon monoxide (CO) levels in the air have been lowered (Clean Air Right Platform, 2022). However, in districts such as Istanbul and Ankara, where coal is especially used for heating purposes and where urbanization and traffic are intense, air pollution values are increasing day by day. In Ankara, only a minimum of 90% data acquisition is ensured in 6 out of 18 air pollution measurement stations. When the values of these stations are analyzed, it is seen that the annual average particulate matter concentration in Ankara exceeds the national limit value (Clean Air Right Platform, 2022).

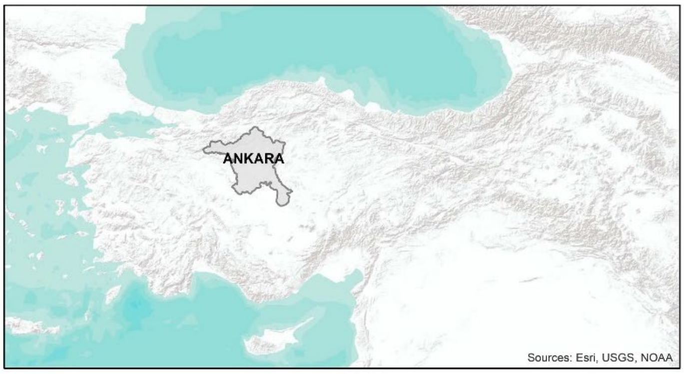
Air pollutants are released into the atmosphere from various sources, and the concentration of pollutants in the atmosphere depends not only on the amount emitted but also on the atmosphere's ability to retain or disperse these pollutants (Karimi et al., 2016). Understanding the behavior of meteorological parameters such as wind speed, wind direction, precipitation, and temperature is crucial for predicting air pollution. This is because the atmosphere is governed by these meteorological parameters and carries pollutants in the air away from their sources (Çelik & Kadı, 2010; Khedairia & Khadir, 2012; Jayamurugan et al., 2013). The combination of emission intensity from different pollutant sources and meteorological parameters determines a condition known as air pollution risk (Bay Area Air Quality Management District, 1998; Mofarrah & Husain Badr, 2011). Therefore, in assessing air pollution risk, both sources of air pollution and meteorological parameters need to be considered together. Pollution sources can vary depending on land use and population density in urban areas.

Especially in densely populated urban areas with high levels of settlement and industrialization, measuring or predicting air pollution using mathematical methods has become an important issue (Ahern et al., 2014). For example, using remote sensing methods and techniques, aerosols in the atmosphere can be measured by the MODIS device placed on the Aqua satellite and air quality modeling can be performed using Aerosol Optical Depth (AOD) data (CEE, 2018). In order to evaluate air quality, interpolation methods can be used for air pollution distribution through geographic information systems software by using daily pollutant measurements obtained from air pollution measurement stations (Toros et al., 2018). In addition, in the international literature, Gassmann & Mazzeo (2000), Pisoni et al. (2009), Achillas et al. (2011), Hosseiniebalam & Ghaffarpasand (2015), Karimi et al. (2016), Habibi et. al. (2017), Zhou et. al. (2020), the distribution of potential air pollution risk was determined using parameters such as traffic and population density, climate parameters, land cover or use. However, in these studies, mostly anthropogenic, meteorological or socioeconomic parameters were evaluated and the effect of microclimatic temperature or heat island effect on air pollution was not analyzed. Unlike the studies in which potential air pollution was determined using multi-criteria decision-making techniques, in this study, in order to determine the potential air pollution risk in the urban core of Ankara, in addition to population density, land use, wind, precipitation data, the urban heat island effect parameter was also included in the method. The parameters specified within the scope of the method were overlaid by taking into account the weight scores in Karimi et al. (2016). In this study, the urban core of Ankara was selected as the study area due to the fact that the annual average particle amount obtained from the air pollution measurement stations is above the national limit values and only 6 of the 18 air pollution measurement stations have a minimum data coverage of 90%.

2. Material & Method

2.1. Study Area

The main material of the study is the core of the city of Ankara, which is located between the northern latitudes of 39°14'46" to 40°13'35" and the eastern longitudes of 32°14'24" to 33°09'49" (Figure 1).



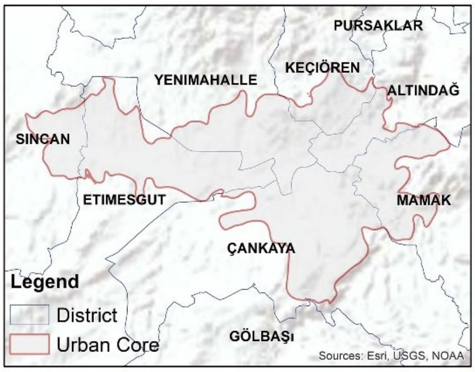


Figure 1. Study area

2.2. Data Sets

The data sets used in the research, their sources, and data details can be found in Table 2. ArcGIS 10.5 software was utilized for Geographic Information Systems and Remote Sensing analyses, and the projection system of the data sets used was set to "WGS_1984_UTM_Zone_36N.

Table 2. Data sets, sources, and data details

Data Sets	Source	Data Details
2012 Urban Atlas (Land Cover) (1/25.000)	Copernicus Land Monitoring Service (CLMS, 2022)	Vector (Polygon)
2018 Population Density Data	(General Directorate of GIS, 2021) Ministry of Environment and Urban Planning, General Directorate of Geographic Information Systems, Directorate General of Geographic Information	Raster (1000x1000m)
Long-term (1959-2018) All Variables Bulletin	(General Directorate of Meteorology, 2022) Republic of Turkey Ministry of Agriculture and Forestry, Directorate General of Meteorology	Vector (Point) Digitization by Station Coordinates
Urban Heat Island	Yıldız (2022) This is one of the ecological indicator analyses conducted in the doctoral thesis by Yıldız (2022) in the Department of Landscape Architecture at Ankara University Faculty of Science, Institute of Science.	Raster (100x100m)
Urban Core	Yıldız (2022) The core of the city boundary was used in the doctoral thesis conducted by Yıldız (2022) in the Department of Landscape Architecture at Ankara University Faculty of Science, Institute of Science.	Vector (Polygon)

2.3. Method

In this study, Geographic Information Systems (GIS) methods and techniques were employed to determine the risk of air pollution. In line with the objectives of the study, anthropogenic factors potentially contributing to air pollution in the core of Ankara city, as well as meteorological parameters, were evaluated. Population density and land cover parameters were utilized to assess the risk of air pollution resulting from human impacts, while meteorological parameters such as wind, precipitation, and urban heat island were included as layers in the methodology. The population density parameter in the study is the 1000 m x 1000 m 2018 population density data obtained from the Ministry of Environment and Urban Planning, General Directorate of Geographic Information Systems, Directorate General of Geographic Information (General Directorate of GIS, 2021). The land use parameter in the study consists of 1/25.000 scale urban atlas data obtained from Copernicus Land Monitoring Service (CLMS, 2022). Long-term (1959-2018) All Variables Bulletin data obtained from the Republic of Turkey Ministry of Agriculture and Forestry, Directorate General of Meteorology were used to obtain wind and precipitation distribution maps. A spatial wind distribution map was obtained by interpolation method using precipitation values converted to point data in ArcGIS. In order to determine the precipitation distribution, the precipitation values in the Long-term (1959-2018) All Variables Bulletin were adjusted for elevation using the Schreiber method in Çiçek & Ataol (2009). The urban heat island effect parameter used in this study was obtained from the work conducted by Yıldız (2022) for Ankara.

In landscape planning studies where different and multiple indicators are used, these parameters cannot be evaluated directly, and all parameters need to be converted into common categorical values (Vihervaara et al., 2017). For this reason, the quantitative results of each sub-layer were normalized and converted into categorical data ranging from "very low (1)" to "very high (5)". In the final stage, each sub-layer was overlaid using the overlay method based on weight values to obtain an integrated result. In this study, parameters and rankings obtained through the multi-criteria decision-making technique, in line with the expert opinions from Karimi et al. (2016), have been adapted to Ankara city (Table 3). Unlike the temperature parameter in Karimi et al. (2016), the urban heat island effect parameter was included for the Ankara city core. Thus, parameters such as building volume, slope, and elevation in the city core were considered (Yıldız, 2022), resulting in a more accurate prediction of air pollution risk for the city core. By overlaying layers and criteria based on weight levels, air pollution densities and spatial distributions were determined (Figure 2).

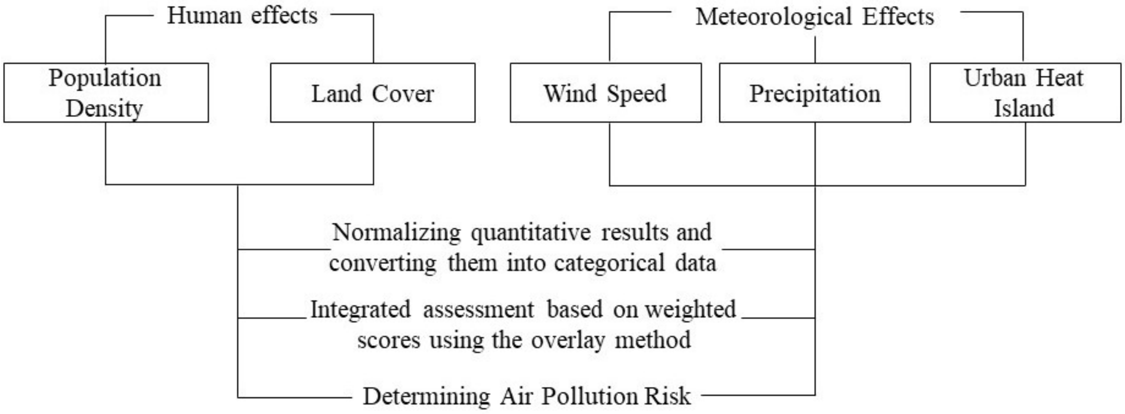


Figure 2. Methodology

Table 3. Weight Degrees of Layers and Sub-Criteria (Adapted from Karimi et al. 2016)

Layers	Weight Score	Sub-Layers	Weight Score
Human Effects	0.3	Population Density	0.75
		Land Cover	0.25
Meteorological Effects	0.7	Wind Speed	0.6
		Precipitation	0.2
		Urban Heat Island	0.2

3. Research Findings

In this section, the human impacts and meteorological effects on air pollution risk have been assessed.

3.1. Human Effects

Population Density: The increase in population density is one of the most significant factors contributing to the increase in CO_2 emissions and other air pollutant parameters in urban areas (Pata & Yurtkuran, 2018). Increasing population density signifies increased fossil fuel consumption, industrialization, and vehicle traffic. Therefore, in studies related to air pollution and carbon storage, when examining the relationships between growth and energy consumption, population density should also be considered as an important variable (Rahman, 2017). The amount of pollutant emissions in the air is higher in regions with high population density, increased vehicle usage, or intensive industrialization. Population density is defined as the number of people per square kilometer (Karimi et al., 2016). This density indicates how much energy is consumed in an area. Therefore, this indicator is crucial for assessing air quality and is particularly important for determining human density, which has a strong impact on emission intensity. In this study, the parameter of population density represents the air pollution risk generated by the number of people per unit area in square kilometers. The obtained population density data were classified into 5 categories: very high (5), high (4), medium (3), low (2), and very low (1). The population density map can be seen in Figure 3. In the core of Ankara city, areas with high and very high population density include the south of Keçiören, the east of Yenimahalle, the southwest of Mamak, and the south and east of Çankaya.

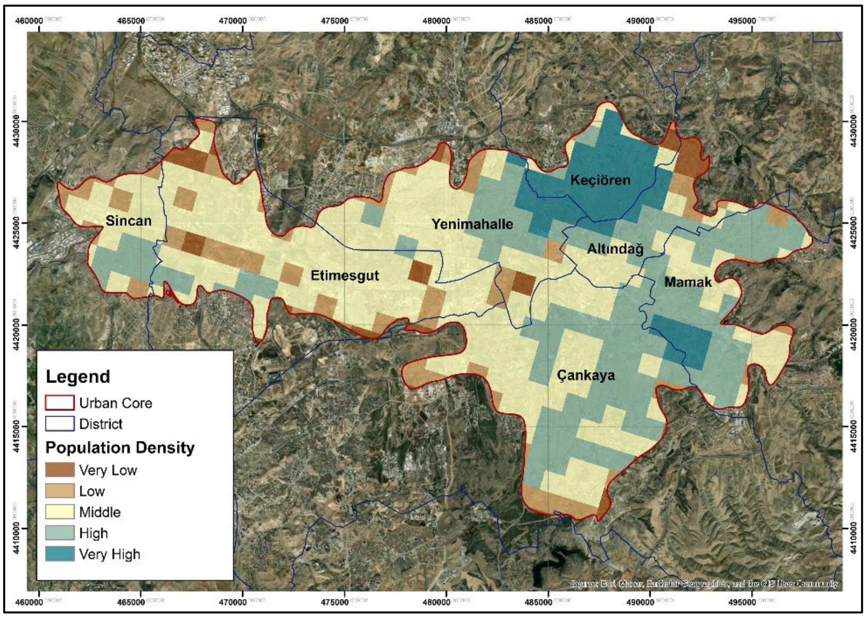


Figure 3. Population Density Map

Land Cover: Increased population density in urban areas, especially in cities, leads to significant changes in land cover (LC) and brings various disadvantages to the city center and its surroundings (Oke, 1973; Voogt & Oke, 2003; Weng et al., 2004). One of the most significant of these adverse effects is the emergence of air pollution. In areas where residential and industrial density is high in cities, traffic density is also high. Along with urbanization, green areas within the city decrease, and the amount of emissions in these areas increases (Karimi et al., 2016). Therefore, it is possible to say that land cover classes have different effects on air pollution. In this context, the land cover of Ankara city was evaluated, and scores ranging from 1 to 5, indicating the levels of air pollution for each land cover class, were assigned. The land cover (Level 1) map can be seen in Figure 4. The land cover classes of the core of Ankara city, along with their areas and air pollution levels, are presented in Table 4. The largest land cover class in the city core is industrial, commercial, public, military, private units (6290 ha), and discontinuous urban settlement (6147 ha).

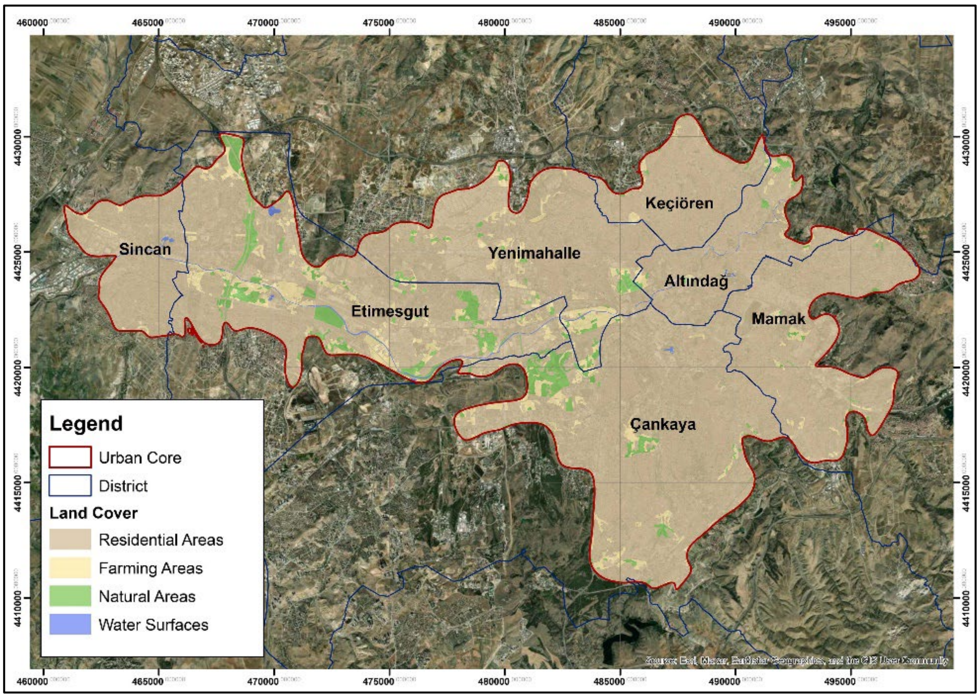


Figure 4. Land cover map

Table 4. Land cover classes and air pollution levels

Land Cover Class	Code	Land Cover/Land Use	Area (ha)	Percentage (%)	Air Pollution Level
Residental Areas	11100	Continuous urban fabric (S.L. > 80%)	3.775	11.40	5
	11210	Discontinuous dense urban fabric (S.L. 50% - 80%)	6.147	18.57	5
	11220	Discontinuous medium density urban fabric (S.L. 30% - 50%)	2.129	6.43	5
	11230	Discontinuous low density urban fabric (S.L. 10% - 30%)	1.064	3.21	5
	11240	Discontinuous very low density urban fabric (S.L. < 10%)	318	0.96	5
	11300	Isolated structures	5	0.02	5
	12100	Industrial, commercial, public, military, and private units	6.290	19.00	5
	12210	Fast transit roads and associated land	84	0.25	5
	12220	Other roads and associated land	4.235	12.79	5
	12230	Railways and associated land	179	0.54	5
	12400	Airports	397	1.20	5
	13100	Mineral extraction and dumpsites	408	1.23	5
	13300	Construction sites	358	1.08	5
	13400	Land without current use	1.538	4.65	5
	14100	Green urban areas	1.952	5.90	4
	14200	Sports and leisure facilities	471	1.42	4
Farming Areas	21000	Arable land (annual crops)	1.572	4.75	3
	22000	Permanent crops	5	0.02	3
	23000	Pastures	591	1.79	2
	31000	Forests	44	0.13	1
	32000	Herbaceous vegetation associations	1.350	4.08	1
	33000	Open spaces with little or no vegetation	49	0.15	1
Water Surface	50000	Water	141	0.43	1

3.2. Meteorolgical Effects

Wind Speed: The fundamental parameter affecting the movement of pollutants in the atmosphere is wind speed and direction. Essentially, the higher the wind speed, the more extensive the distribution of pollutants in the atmosphere (Karimi et al., 2016). Wind speed values obtained from the General Directorate of Meteorology (MGM) of the Ministry of Agriculture and Forestry were input into meteorological stations located in Ankara, and spatial distribution of point data was achieved through interpolation techniques. The obtained wind speed distribution values were classified from very low to very high on a scale from 1 to 5 based on wind speed. Figure 5 shows the spatial distribution map of wind speed. In an area where wind speed is very high, polluted air will be transported through the atmosphere with the wind. Therefore, it is possible to say that air pollution is very low in a location with high wind speed.

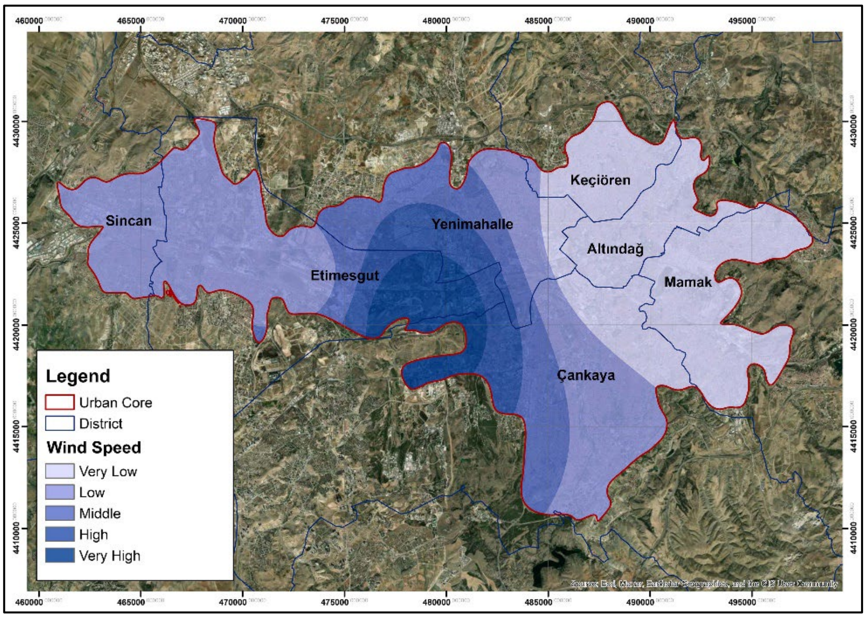


Figure 5. Wind speed map

Precipitation: Another meteorological criterion that needs to be evaluated for the determination of air pollution is precipitation. Precipitation has a cleansing effect on the atmosphere by washing out particles and having the ability to dissolve gaseous pollutants, making it a factor that contributes to cleaning polluted air. Areas with frequent and heavy precipitation generally have better air quality (Karimi et al., 2016). In relation to air pollution, the daily average precipitation required to cleanse the atmosphere of pollutants should be greater than 5 mm (Safavi & Alijani, 2006; Karimi et al., 2016). In this study, precipitation values obtained from the General Directorate of Meteorology (Table 5) were adapted to elevation using the Schreiber method. The obtained data shows that the annual precipitation amount for the Ankara city core ranges from 411.8 to 701.2 mm, and these values are in harmony with the topography. Figure 6 shows the precipitation map of the Ankara city core, and Table 6 lists the air pollution levels for precipitation classes.

Table 5. Annual average precipitation values for Ankara City (General Directorate of Meteorology, 2022)

No	Meteorological Station	Annual Average Precipitation Amount (mm)
1	Akıncı-Mürted	356.6
2	Ankara	409.3
3	Ayaş	427.1
4	Bala	433.2
5	Beypazarı	410.1
6	Esenboğa	411.0
7	Etimesgut	385.8
8	Güvercinlik	359.4
9	Kalecik	411.9
10	Kızılcahamam	575.4
11	Polatlı	363.1

Table 6. Air pollution levels & precipitation classes

Precipitation Amount (mm)	Hava Kirliliği Düzeyi	
411.78 – 459.45	Very Low	5
459.45 – 498.04	Low	4
498.04 – 554.57	Middle	3
554.57 – 595.65	High	2
695.65 – 701.20	Very High	1

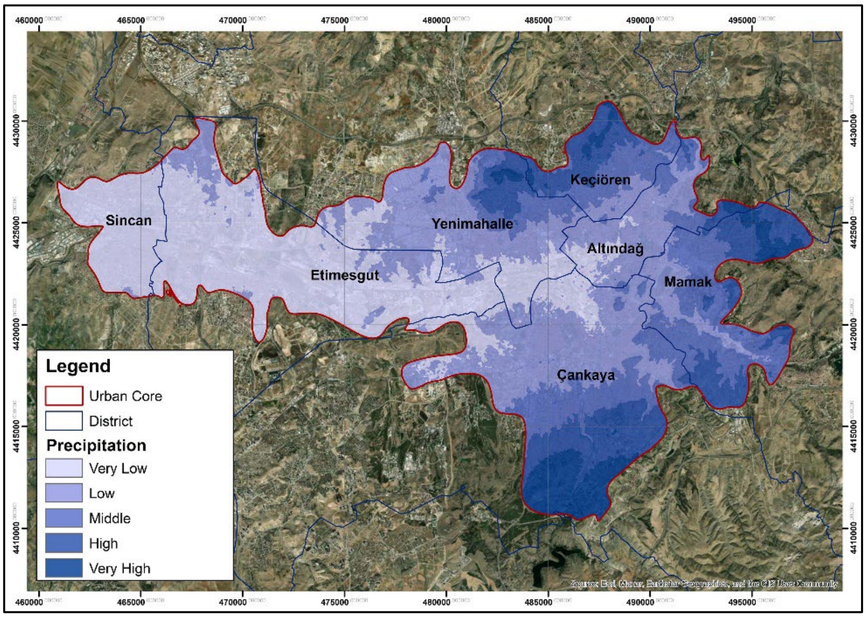


Figure 6. Precipitation map obtained with the Schreiber Method

Urban Heat Island Map: Air masses with high temperatures tend to increase pollutants (Viswanathanand & Krishnamurti, 1989). Urban heat islands also tend to increase pollutants in the atmosphere due to the hot air masses they emit. At the same time, urban heat islands, which occur in areas with intense urbanization, lead to higher energy consumption in these areas. This forces cities to produce more greenhouse gases to meet the demand of power plants. Therefore, increased emissions reduce air quality and increase pollution (EPA, 2022). For this reason, the heat island effect was included in the study. Figure 7 shows the urban heat island effect map obtained from Yıldız (2022) for Ankara. The map reveals that areas with high building volume, such as the northeast of Çankaya, the southeast of Yenimahalle, and the south of Keçiören, also have a high urban heat island effect. However, in areas with high elevation or a large amount of green space, such as the southeast of Çankaya, the urban heat island effect is low.

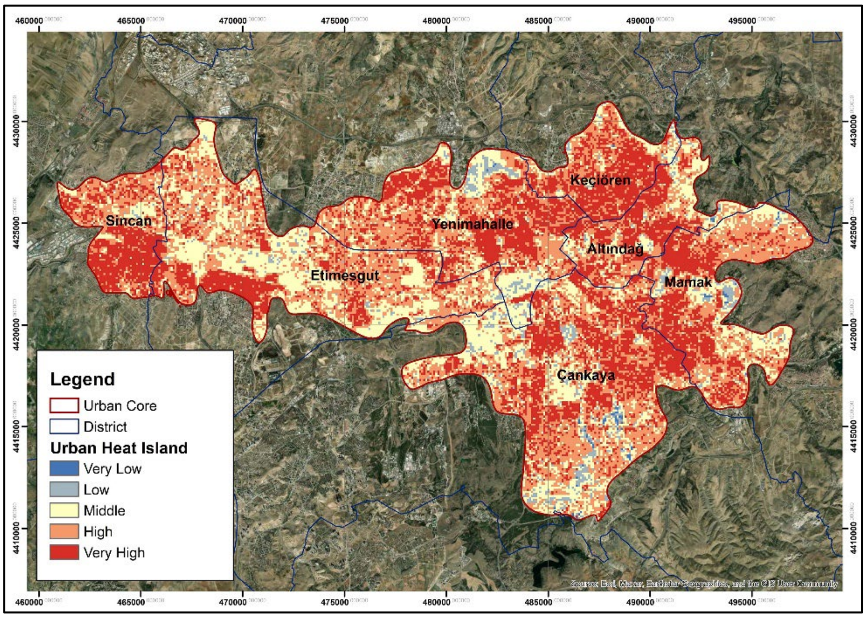


Figure 7. Urban heat ısland map (Yıldız, 2022)

4. Conclusion & Discussion

In this study, the integrated evaluation of anthropogenic effects (land cover and population density) and meteorological parameters (wind, precipitation, urban heat island) was aimed to determine the risk of air pollution in the core of Ankara city. In the methodology of the study, sub-factors related to two main factors, anthropogenic and meteorological, which could cause air pollution, were added to the analysis as layers. The quantitative results obtained for each sub-factor were normalized, and the result values for the parameters were transformed into categorical data, ranging from 1 (very low) to 5 (very high). In the final stage, the weight scores for the sub-parameters were transformed into a single integrated result map using the overlay method. With this method applied in the core of Ankara city, the air pollution risk of the study area has been identified (Figure 8).

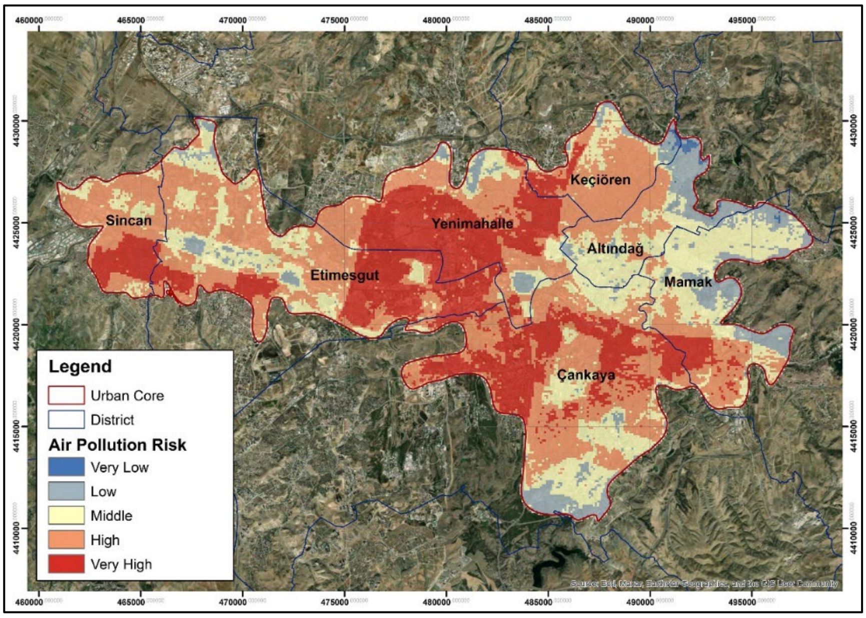


Figure 8. Air pollution risk map

In the resulting map, the risk of air pollution in the east of Etimesgut, southwest of Yenimahalle, southeast of Sincan, south of Mamak and almost all of Çankaya and Keçiören Districts is determined as "high (4)" and "very high (5)". District-specific air pollution levels are in Figure 9. The air quality risk levels and their spatial extents in the district centers are presented in Table 7, while the air quality risk levels and their spatial extents in the total study area are provided in Table 8. The results indicate that "very high" air pollution risk levels are present in 19.78% of the total study area, "high" levels in 28.92%, "moderate" levels in 30.33%, "low" levels in 16.68%, and "very low" levels in 4.29%.

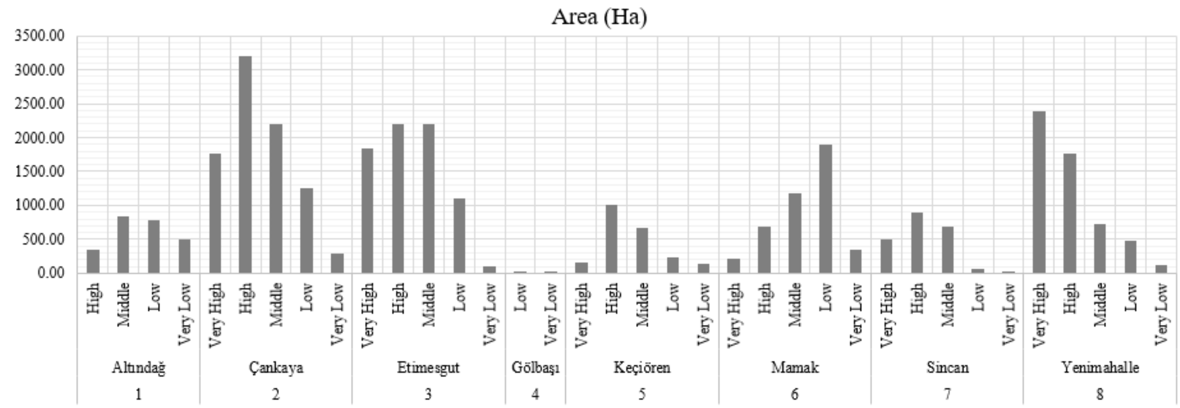


Figure 9. District-specific air pollution levels

Table 7. District-specific air pollution levels and areas (ha)

Number	District	Air Pollution	Area (Ha)
1	Altındağ	High	340.80
		Middle	834.90
		Low	777.43
		Very Low	495.88
2	Çankaya	Very High	1771.79
		High	3190.94
		Middle	2197.07
		Low	1262.31
		Very Low	285.52
3	Etimesgut	Very High	1843.11
		High	2197.91
		Middle	2205.05
		Low	1104.09
		Very Low	95.68
4	Gölbaşı	Low	0.26
		Very Low	2.37
5	Keçiören	Very High	163.95
		High	1000.99
		Middle	659.68
		Low	225.65
		Very Low	130.71
6	Mamak	Very High	218.22
		High	681.72
		Middle	1179.32
		Low	1896.64
		Very Low	341.91
7	Sincan	Very High	503.33
		High	896.76
		Middle	682.76
		Low	64.53
		Very Low	29.00
8	Yenimahalle	Very High	2394.23
		High	1770.54
		Middle	717.72
		Low	483.87
		Very Low	115.56

Table 8. Air quality risk levels and their spatial extents in the total area (ha)

	Very High	High	Middle	Low	Very Low	Total Area
Area (ha)	6894.63	10079.7	10573.8	5814.8	1496.63	34859.46
Area (%)	19.78	28.92	30.33	16.68	4.29	100

The study has identified areas at risk of air pollution. The existing pollution burden can be interpreted below the limit values and alert thresholds for air pollutants under the Turkish Air Quality Assessment and Management Regulation. However, a risk assessment like the one applied in this study provides a proactive action area shedding light on areas where pollutants may intensify in the future. Moreover, this method enables a quick assessment for urban areas where long-term air pollution measurements are scarce or conducted at very few points. Particulate matter (PM10) measurement studies started in 2016, yielding information only for 8 measurement points, including Bahçelievler, Cebeci, Demetevler, Dikmen, Kayaş, Keçiören, Sincan, and Sıhhiye (National Air Quality Bulletin, 2024). In Table 9, the particulate matter (PM10) measurements in the core of Ankara city are presented. Having only 8 measurement points is highly inadequate for the accurate detection of air pollution at the city scale. Therefore, there is no air pollution map available for Ankara city as a whole based on actual measurements. This study is important in guiding urban design and practices, predicting the potential consequences of human interventions on air quality, and mitigating adverse effects.

Table 9. PM10 (μg/m^3) measurements in the core of Ankara City (National Air Quality Bulletin, 2024)

District/Year	2016	2017	2018	2019	2020	2021	2022	WHO's annual PM10 limit values (20 μg/m^3)
Bahçelievler	-	53	47	37.36	53.39	37.66	43.07	The annual average threshold has been exceeded in all years since 2016.
Batıkent	-	-	-	-	-	34.01	-	
Cebeci	65	61	47	81	91.87	-	-	
Demetevler	62	62	65	51	55.63	42.75	38.11	
Dikmen	67	61	60	33	41	-	-	
Etimesgut	-	-	-	-	-	32.74	27.17	
Etlik	-	-	-	-	-	30.22	43.13	
Kayaş	80	100	60	45.32	40	53.98	32.62	
Keçiören	56	68	61	43	41	36.02	24.7	
Ostim	-	-	-	-	-	47.69	47.4	
Sincan	51	61	67	44	56.62	51.08	40.54	
Siteler	-	-	-	-	-	99.64	79.28	
Sıhhiye	72	85	61	50.09	48.17	52.69	50.68	
Törekent	-	-	-	-	-	26.25	34.22	

While determining the parameters used in the study, studies by Gassmann & Mazzeo (2000), Pisoni et al. (2009), Achillas et al. (2011), Hosseiniebalam & Ghaffarpasand (2015), Karimi et al. (2016), Habibi et. al. (2017), Zhou et. al. (2020) were utilised. In these studies, parameters that directly or indirectly affect air quality and air pollution potential such as population density, land use, wind, precipitation, temperature are included. In this study for the city of Ankara, the methods and parameters used by Karimi et al. (2016) were primarily used to estimate the air pollution risk at a higher scale. However, the method does not incorporate some key underlying indicators (e.g., topography, building density, etc.) that could enhance the accuracy of determining pollution risk spatially. In this context, in this study conducted for the Ankara city core, unlike Karimi et al. (2016), the urban heat island parameter was included in the method. Thus, building density and topographic effects in the city were taken into account, and air pollution risk was estimated more accurately based on microclimatic factors in the city core. This is because areas with a high urban heat island effect in the research area have higher air pollution due to the hot air generated by microclimatic factors in the city. Urban heat islands also increase energy demand for cooling, especially in built-up areas during the summer, and this in turn increases hot air masses. Companies supplying electricity typically use fossil fuel power plants to meet most of this demand, leading to an increase in pollutant levels and greenhouse gas emissions (EPA, 2022). However, these power plants are not located in the city core but rather on the outskirts or outside the city, and they contribute to climate change in the atmosphere of their installation area. This situation has an indirect effect on urban areas. In addition, there is a negative relationship between wind speed and topographic height and air pollutants. As air rises from the ground, it expands and cools. Thus, moisture in the air condenses to form clouds. Under these conditions, there are no problems with air pollution in the troposphere, and pollutant parameters do not settle. Similarly, in areas with increased wind speed, air pollutant parameters cannot adhere and are transported to different regions (Kara, 2012). This situation can be significant in the context of open and green spaces in urban areas, but the opposite can occur in the city core with high building density. Structures not only block wind speed but also, by causing inversion in the urban atmosphere, prevent rising hot air, which in turn causes polluted and hot air to settle in the city core (Karimi et al., 2016).

One important point obtained from the research findings is that wind speed is the most significant meteorological factor affecting the distribution of air pollution, especially in polluted areas like the city center of Ankara. Therefore, despite the high wind speeds observed in the city center of Ankara, it is seen that the air pollution risk is very high. The reason for this is that when various criteria such as high building density, relatively low topographic height, and lack of green areas in the city center are evaluated in an integrated manner, wind speed reduces its negative effect on air pollution. In short, in areas with a high amount of green spaces, high topographic height, and high wind speed, the amount of pollutants in the atmosphere decreases, and thus, air pollution decreases. In determining air pollution risk, land cover and population density also play a significant role, in addition to meteorological effects. The amount of pollutants in the air increases depending on industrial areas, industrial zones, and traffic density. In this context, in cities with high air pollution density, considering the dominant wind direction and speed, industrial and industrial areas should be planned in other regions of the city with high wind speed but low air pollution risk in terms of other parameters.

The research conducted within the scope of this study aimed to determine the air pollution risk, taking into account the current state of complex interactions between nature and society, as well as the boundaries of Ankara's city center. However, air movements are not limited to city center boundaries or administrative boundaries. Therefore, conducting air pollution-related studies by considering the values of climate stations in the surrounding districts and cities would contribute to obtaining much more accurate results. This research is considered an important step for future studies aimed at determining air pollution risk. The applied method allows researchers and urban planners to add new layers and assign criteria with appropriate weights to characterize urban air pollution. In future studies, different parameters with different weightings can be added based on the specific problems and requirements of the research area. In existing urban open and green spaces, the use of species with large canopy structures and deciduous species will increase the retention rate of pollutant gases. In this context, plant selection, spatial pattern design, surface roughness, and plant composition and configuration are critical issues in air flow risk. In new settlement areas, integrated consideration of topography, land uses, and the meteorological characteristics of the region in urban planning will contribute to producing healthy and sustainable settlement areas by reducing pollutant emissions to the atmosphere due to urbanization with meteorological effects.

In this study, GIS and Multi-Criteria Decision Making techniques were used to model a potential air pollution risk distribution that can form the basis for landscape planning and urban planning studies. What is important here is to provide a holistic assessment in order to reveal the integrated effect of the factors affecting air pollution, not on the basis of a single parameter. This study presents a methodological approach based on indicators. Strategies developed to reduce air pollution in urban planning can be examined in detail in different studies.

Acknowledgment

In this study, the boundaries of the research were determined based on the urban core boundary presented in the doctoral thesis (Yıldız, 2022). However, the air pollution modeling method used in this study differs from the one used by Yıldız (2022).

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. There is no conflict of interest.

References

Achillas, C., Vlachokostas, C., Moussiopoulos, N. & Banias, G. (2011). Prioritise strategies to confront environmental deterioration in urban areas: multicriteria assessment of public opinion and experts' views. *Cities*, 28, 414–423. DOI: https://doi.org/10.1016/j.cities.2011.04.003, Access Address (21.04.2024): https://www.sciencedirect.com/science/article/abs/pii/S0264275111000436.

Ahern, J., Cilliers, S. & Niemela, J. (2014). The concept of ecosystem services in adaptive urban planning and design: a framework for supporting innovation. *Landscape and Urban Planning*, 125: 254–259. DOI: http://dx.doi.org/10.1016/j.landurbplan.2014.01.020, Access Address (21.04.2024): https://www.sciencedirect.com/science/article/abs/pii/S0169204614000346?via%3Dihub.

Bay Area Air Quality Management District. (1998). Climate, Physiography, and air Pollution Potential, Bay Area and its sub-Regions. Access Address (21.04.2024): https://www.baaqmd.gov/.

Chamber of Environmental Engineers (CEE). (2018). Air Pollution Report. Access Address (18.05.2024): https://www.cmo.org.tr/raporlar.

Clean Air Right Platform (CARP). (2021). Dark Report 2021, Reveals the Health Impacts of Air Pollution in Turkey. Access Address (18.07.2024): https://www.temizhavahakki.org/kararapor2021/.

Clean Air Right Platform (CARP). (2022). Dark Report 2022, Reveals the Health Impacts of Air Pollution in Turkey. Access Address (18.07.2024): https://www.temizhavahakki.org/kararapor2022/.

Copernicus Land Monitoring Services (CLMS). (2022). 2012 Urban Atlas (Land Cover). Access Address (26.07.2022): https://land.copernicus.eu/en/dataset-catalog.

Çelik, B.G. & Kadı, İ. (2010). The relation between meteorological factors and pollutants concentrations in Karabük city. G.U. Journal of Science, 20(4): 87–95. Access Address (20.07.2023): https://dergipark.org.tr/tr/download/article-file/83081.

Çiçek, İ. & Ataol, M. (2009). Türkiye'nin Su Potansiyelinin Belirlenmesinde Yeni Bir Yaklaşım. *Coğrafi Bilimler Dergisi*, 7(1), 51–64. https://doi.org/10.1501/cogbil_0000000094.

Environmental Protection Agency (EPA). (2022). Heat Island Impacts. Access Address (25.07.2023): https://www.epa.gov/heatislands/heat-island-impacts.

Gassmann, M. & Mazzeo, N. (2000). Air Pollution Potential: Regional Study in Argentina. *Environmental Management*. 25(4): 375–382. DOI: https://doi.org/10.1007/s002679910029, Access Address (21.04.2024): https://link.springer.com/article/10.1007/s002679910029#citeas.

General Directorate of GIS. (2021). 2018 Population Density Data. Ankara.

General Directorate of Meteorology. (2022). Long years (1959-2018) all variables bulletin. Ankara.

Habibi, R., Alesheikh, A. A., Mohammadinia, A. & Sharif, M. (2017). An Assessment of Spatial Pattern Characterization of Air Pollution: A Case Study of CO and PM2.5 in Tehran, Iran. *ISPRS International Journal of Geo-Information*, 6(9), 270. Access Address (21.04.2024): https://www.mdpi.com/2220-9964/6/9/270.

Hosseiniebalam, F. & Ghaffarpasand, O. (2015). The effect of emission sources and meteorological factors on Sulphur dioxide concentration of great Isfahan, Iran. *Atmospheric Environment*, 100:

94–101. DOI: https://doi.org/10.1016/j.atmosenv.2014.10.012, Access Address (21.04.2024): https://www.sciencedirect.com/science/article/abs/pii/S1352231014008012.

Jayamurugan, R., Kumaravel, B., Palanivelraja, S. & Chockalingam, M. P. (2013). Influence of temperature, relative humidity and seasonal variability on ambient air quality in a coastal urban area. International Journal of Atmospheric Sciences, Article ID 264046, 7 pages. DOI: https://doi.org/10.1155/2013/264046, Access Address (21.04.2024): https://www.hindawi.com/journals/ijas/2013/264046/.

Kara, G. (2012). Effect of Meteorological to Urban Air Pollutants: The Case of Konya. *S.U. Eng.-Architect. Fac. Journal*, 27 (3): 73 – 86. Online ISSN: 1304-8708. Access Address (21.04.2024): https://dergipark.org.tr/en/pub/sujest/issue/23227/248005.

Karimi, H., Soffianian, A., Mirghaffari, N. & Soltani, S. (2016). Determining air pollution potential using geographic ınformation systems and multi-criteria evaluation: A case study in ısfahan province in Iran. *Environmental Processes*, 3: 229–246. DOI: https://doi.org/10.1007/s40710-016-0136-4, Access Address (21.04.2024): https://link.springer.com/article/10.1007/s40710-016-0136-4#citeas.

Khedairia, S. & Khadir, M.T. (2012). Impact of clustered meteorological parameters on air pollutants concentrations in the region of Annaba, Algeria. *Atmospheric Research*, 113: 89–101. DOI: https://doi.org/10.1016/j.atmosres.2012.05.002, Access Address (21.04.2024): https://www.sciencedirect.com/science/article/abs/pii/S0169809512001305.

Menteşe, S. (2017). Soil, Water and air pollution in terms of environmental sustainability: Theoretical review. *Journal of International Social Research*, 10 (53): 381–389. DOI: https://doi.org/10.17719/jisr.20175334127, Access Address (21.04.2024): https://www.sosyalarastirmalar.com/abstract/soil-water-and-air-pollution-in-terms-of-environmental-sustainabilitytheoretical-review-75452.html.

Mofarrah, A .T. & Husain Badr, H. (2011). Design of urban air quality monitoring network: Fuzzy based multi-criteria decision-making approach. Dr. Nicolas Mazzeo (Ed.). *Air Quality Monitoring, Assessment and Management*, Section 2 (p.25-40). ISBN: 978–953-307-317-0. InTech. DOI: 10.5772/1029.

National Air Quality Bulletin (2024). Republic of Turkey Ministry of Environment, Urbanization and Climate Change, National Air Quality Monitoring Platform. Access Address (03.03.2024): https://ced.csb.gov.tr/hava-kalitesi-haber-bultenleri-i-82299.

Oke, T.R. (1973). City size and the urban heat island. *Atmospheric Environment*, 7(8): 769-779. DOI: 10.1016/0004-6981(73)90140-6, Access Address (03.03.2024): https://www.sciencedirect.com/science/article/abs/pii/0004698173901406?via%3Dihub.

Pata, U. K. & Yurtkuran, S. (2018). The Effect of Renewable Energy Consumption, Population Density and Financial Development on CO_2 Emissions: The Case of Turkey. *UİİİD-IJEAS (Prof. Dr. Harun Terzi Özel Sayısı)*: 303-318. ISSN: 1307-9832. DOI: https://doi.org/10.18092/ulikidince.441173, Access Address (21.04.2024): https://scite.ai/reports/the-effect-of-renewable-energy-dvGjXDR.

Pisoni, E., Carnevale, C. & Volta, M. (2009). Multi-criteria analysis for PM10 planning. *Environment*, 43: 4833–4842. DOI: https://doi.org/10.1016/j.atmosenv.2008.07.049, Access Address (21.04.2024): https://www.sciencedirect.com/science/article/abs/pii/S1352231008006924.

Rahman, M. M. (2017). Do population density, economic growth, energy use and exports adversely affect environmental quality in Asian Populous Countries?. *Renewable and Sustainable Energy Reviews*, 77, 506-514. DOI: https://doi.org/10.1016/j.rser.2017.04.041, Access Address (21.04.2024): https://www.sciencedirect.com/science/article/abs/pii/S1364032117305427.

Safavi, S. Y. & Alijani, B. D. (2006). Investigate meteorological and geographical parameters in air pollution, Tehran, Iran. *Geogr Res*, 58:99–112 (in Farsi).

Toros, H., Bağış, S. & Gemici, Z. (2018). Ankara'da hava kirliliği mekânsal dağılımının modellenmesi. *Ulusal Çevre Bilimleri Araştırma Dergisi*, 1(1), 20–53.

World Health Organization (WHO). (1992). Urban air pollution in megacities of the world. Blackwell, Oxford. Access Address (21.04.2024): http://alpha.chem.umb.edu/chemistry/ch471/documents/mageetal.pdf.

World Health Organization (WHO). (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. Access Address (21.04.2024): https://iris.who.int/handle/10665/345329. License: CC BY-NC-SA 3.0 IGO.

Vihervaara, P., Monenen, L., Santos, F., Adamescu, M., Cazacu, C., Luque, S., Genelletti, D. & Maes, J. (2017). Biophysical quantification. Burkhard, B. & Maes, J. (eds). *Mapping Ecosystem Services*. Pensoft Publishers, 75-83, Sofia.

Viswanathanand, P. & Krishnamurti, C. (1989). *Ecotoxicology and climate, effects of temperature and humidity on ecotoxicology of chemicals.* Ed. by P. Bourdeau, J. A. Haines, W. Klein and C. R. Krishna, John Wiley & Sons, pp: 139–152.

Voogt, J. A., & Oke, T. R. (2003). Thermal remote sensing of urban climate. *Remote Sensing of Environment*, 86, 370 – 384. Access Address (12.16.2024): https://www.sciencedirect.com/science/article/abs/pii/S0034425703000798?via%3Dihub.

Weng, Q., Lu, D. & Schubring, J. (2004). Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environment*, 89(4): 467-483. DOI: https://doi.org/10.1016/j.rse.2003.11.005, Access Address (21.04.2024): https://www.sciencedirect.com/science/article/abs/pii/S0034425703003390.

Zhou, J., Wang, J., Huang, H. & Liu, Y. (2020). Assessment of air quality using GIS and remote sensing: A case study of Guangzhou, China. *International Journal of Environmental Research and Public Health*, 17(5), 1234-1248.

Yıldız, N.E. (2022). *The use of ecological performance indicators and process model in urban planning: Ankara case (PhD Thesis)*. Ankara University, Institute of Science and Technology, Department of Landscape Architecture, 234, Ankara. Access Address (21.04.2024): https://tez.yok.gov.tr/UlusalTezMerkezi/giris.jsp.