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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Impacts of Meteorological Parameters on Tropospheric Ozone Concentrations in Çanakkale

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Abstract
Meteorological factors have a significant impact on the formation and transport of tropospheric ozone. In addition to the meteorological factors, solar radiation and associated chemical reactions, topography, and pollution sources also affect the ozone concentration levels (O_3). In this study, the influences of the meteorological factors (temperature, wind speed, relative humidity, solar radiation) on O_3 were investigated for Çanakkale throughout the 2014-2018 period. It was found that O_3 concentration levels in summer season are linked with the high humidity and, especially high temperature. The statistical analysis indicated that O_3 concentrations at Çan district (SE Çanakkale) were positively correlated with temperature during summer and autumn seasons (r=0.53). Similarly, a statistically significant positive correlation was found at Lapseki station of Çanakkale during autumn (r=0.48), spring (r=0.41), and summer months (r=0.40), respectively. On the other hand, relative humidity (RH) displayed negative correlations with O_3 at Çan and Lapseki stations. In addition, negative correlation was observed between nitrogen oxides (NO_X) and O_3 values measured at Lapseki station. The main important factors affecting ozone concentration levels in Çanakkale were found as local meteorological conditions and long-range transportation of pollutants from anthropogenic sources (e.g. vehicle, industrial emissions, volatile organic compounds (VOCs) emitted from solvents and industry).
Keywords: Tropospheric ozone, air quality, meteorological factors, correlation coefficient, Çanakkale

I. INTRODUCTION

Ground-level ozone (O_3) is one of the six criteria air pollutants (particulate matter (PM), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and lead (Pb)). It is a chemical generated from gases (many of which come from anthropogenic causes) in the lower atmosphere by solar radiation-driven photochemistry [1]. Nowadays, ground-level ozone is constantly increasing especially in urban areas of developed countries. Similarly, increases are observed in rural areas as well [2-3].

Ground-level ozone differs from the ozone layer in the upper atmosphere [4]. Ozone is produced from oxygen in the stratosphere, the upper layer of the atmosphere, via processes triggered by solar radiation. Approximately 90% of ozone is created in the stratosphere, where it performs a critical function in absorbing UV radiation, which is dangerous to life on Earth if it exceeds critical limits. However, tropospheric ozone damages vegetation, ecosystems, agricultural products, materials, and human health because of its highly reactive chemical characteristics [5].

Tropospheric ozone is formed from the emissions of NO_x and volatile organic compounds (VOC_s). Methane (CH_4) and CO also contribute but at a lesser degree [5]. The rate of photochemical processes forming ozone in the atmosphere is influenced by solar radiation, temperature and geographical factors. Ozone gases are emitted from a diverse range of anthropogenic (e.g. road transport, international maritime shipping, aircraft, thermal power plant, industrial activities, solvent use, biomass burning) and natural sources (e.g. soils and lightning). In addition to this, ozone concentrations may rise as a result of climate change [6-8].

Ozone is influenced by meteorological factors as well as anthropogenic emissions. Meteorological factors such as strong solar radiation [9], cloudiness, high temperature [10-11], low relative humidity [10], atmospheric stability and location of the pollutant source affect the ozone concentrations. Otero et al., (2016) investigated the association between local and synoptic meteorological conditions and surface ozone concentrations over Europe

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in spring and summer seasons [12]. Li et al., (2017) showed that high temperature, low relative humidity, easterly wind and low wind speed (ws) conditions influence urban ozone episodes in China [10]. Chen et al., (2020) indicated that temperature was the most influential factor for ground ozone concentrations in China [9].

Many epidemiological studies have shown that exposure to ozone leads to a wide range of health problems such as increased asthma morbidity and mortality, reduced lung function, bronchial symptoms and lung diseases [13-15]. In European Union, annually 14.000 respiratory hospital admission is related with ozone concentrations [5]. Diaz et al., (2018) analyzed the relationship between high ozone concentrations and daily mortality and found a positive relationship between them, especially among susceptible children who play outdoors in polluted environments [16]. In addition to children, the elderly and cardiovascular patients are adversely affected by ozone concentrations.

World Health Organization (WHO) sets a target value of 100 µg/m^3 as a maximum daily 8 hours mean for O_3 to protect human health. As of January 1, 2022, the target value for O_3 in Turkey is 120 µg/m^3 as a maximum daily 8-hour mean. However, even if the legal limit values are achieved, health problems can still arise.

Studies in Turkey mainly focused on the factors causing the changes in PM_{10} concentration levels, such as long-range transport [17-19], local meteorological factors [20], and their impact on health problems [21-22]. For Ozone, Im et al., (2006) analyzed hourly ozone, NO_X and VOC concentrations during summer and found that decrease in inversion heights in the early hours of the day leads to increase in ozone concentrations [23]. Can (2017) found that the highest ozone value is observed in summer season [24]. Unal et al., (2021) analyzed relationship between air pollution and asthma, bronchitis and pneumonia and found that pneumonia, asthma and bronchitis cases were associated with increases in ozone concentrations [25].

The existence of power plants, industrial facilities, and growing sea traffic resulted in considerable increases in pollutant concentrations in Çanakkale. In this study, ozone values measured in Çan and Lapseki districts between 2014-2018 are determined and their temporal and spatial distributions are shown. In addition, relationship between meteorological parameters (temperature, wind speed, relative humidity, and solar radiation) and ozone concentrations are examined. For Lapseki station, relationship between NO_X and ozone was also studied. Also, pollutant sources are identified and variation of pollutant concentrations depending on meteorological factors are estimated. Seasonal and regional ozone exposure levels are determined.

II. DATA AND METHODOLOGY

2.1. Study Area and Air Quality Data

The study area and sampling sites in Çanakkale, Turkey are shown in Figure 1. Çanakkale is a province located in the Northwest of Turkey, within the Marmara Region. This province lies on both Asian and European sides of the Dardanelles. Due to its geographical features, the climate of this province is transitional between the Mediterranean climate and the Black Sea climate and has the characteristics of the Mediterranean climate. The average minimum temperature is measured at the lowest in February (-4.2ºC) and the highest average temperature is measured in August (+35.8 ºC). The prevailing wind direction is northerly winds. The most precipitation is observed in December, January and February.

In this study, ozone concentration data measured in Çan and Lapseki stations from January 2014 to December 2018 were provided by the National Air Quality and Monitoring Network database [26]. Furthermore, wind speed (m/s), wind direction, temperature, solar radiation, total precipitation, relative humidity values of the meteorological stations are obtained from the Turkish State Meteorological Service. Meteorological data used in this study represent characteristic meteorological properties of the pollutant source area. These monitoring stations are fully automated and provide hourly recordings. Data validation is conducted regularly by the Air Quality Monitoring Center of the Ministry of Environment and Urban Planning (MoEUP). As reported in Sahin (2020), incomplete recordings from the dataset were deleted and used data validation and measurement methodologies [27]. Figure 1 shows the locations of air quality monitoring stations and meteorological stations.

2.2. Statistical Analysis

Correlation matrix was used to analyze the strength of the association between O_3 concentrations, NO_X levels and meteorological factors (temperature, wind speed, solar radiation and RH). All statistical calculations and graphics were done using R version 3.1.2 [28].

The regions and seasons with the highest concentrations of pollutants were found by utilizing the inverse distance weighted (IDW) interpolation technique. This method is widely used in the research of air quality [29-30].

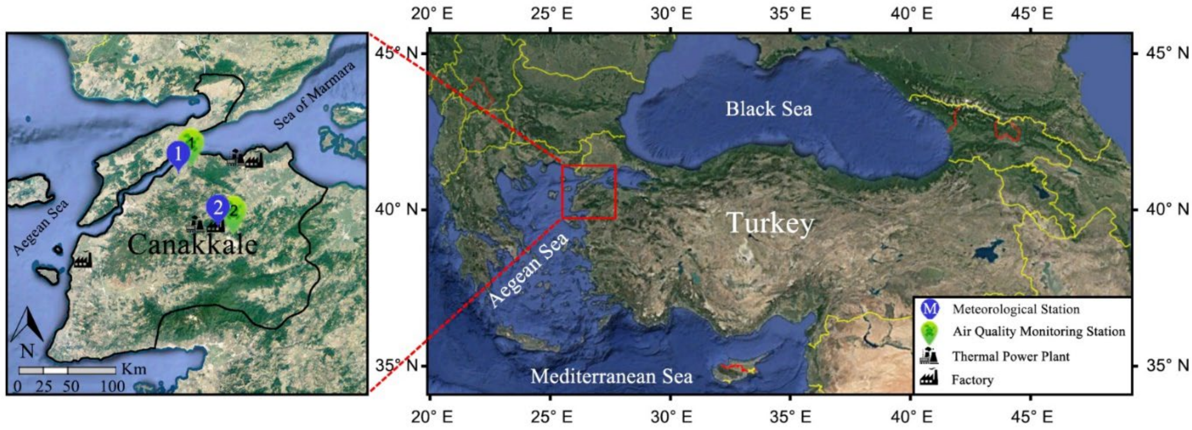

Figure 1. Locations of air quality monitoring stations (green) and meteorological stations (blue) in Çanakkale (NAQMS, 2022)

III. RESULTS AND DISCUSSION

3.1. Daily and Seasonal Variations of Air Pollutants

Daily variation of O_3 concentrations from two air quality stations were obtained by using the long-term data for Çanakkale. Figure 2 presents daily average ozone concentrations of 2014-2018 for Çan and Lapseki stations. Ozone is present on almost all days of the year. Particularly, during summer, ozone levels are seen to exceed 100 µg/m^3. Ozone values are commonly higher in spring and summer than they are in autumn and winter. Peak summertime levels are higher in Çan and Lapseki. Examining Lapseki Station data with respect to WHO O_3 limit value (100 µg/m^3) showed that 35% of summer data exceeded the limit value. Çanakkale province attracts a lot of tourists, especially in the summer months.

As Lapseki District is located at the junction between İstanbul and İzmir, there is an increase in traffic in the summer months. This situation causes an increase in ferry services and the number of vehicles which eventually lead to an increase in ozone concentration. As a result, the highest ozone concentrations occur during periods of sunny weather.

O_3 is known as a reactive air pollutant. Traffic and industrial activities together with meteorological factors, topography and chemical reactions increase its concentration levels [31-32]. Seasonal variation of O_3 concentrations is more apparent in summer months than in winter due to it is particularly dependent on effective solar radiation, high humidity and high temperature [33]. In Çanakkale, average measurement values are highest in summer with 61 µg/m^3, and lowest in winter with 29 µg/m^3 (Fig. 3). Similar results have been reported in previous research by Yuska et al., 2003; Gong et al., 2018 [34-35].

Ozone concentrations in the study area found to be typically at their highest during summer and at their lowest during winter (Fig. 3c and 3a). When the measured ozone levels were examined spatially, high ozone concentrations in the province were generally found in Lapseki and Çan districts. In the summer season, the highest value for O_3 concentrations was found as 93 µg/m^3 in Lapseki, and this was measured as 77 µg/m^3 in Çan. Çan has lower elevation than its surrondings. This geographical situation leads to suspension of air pollutants and inversion. Low wind speed, especially during summer season, causes increase in air pollutant concentrations.

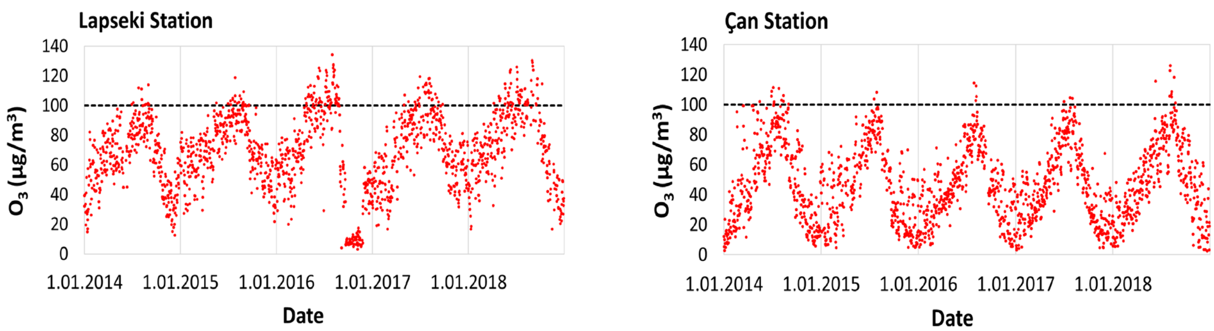

Figure 2. Daily variations of and O_3 concentrations for 2014-2018 (The limit values of O_3 is shown by the black dashed straight line).

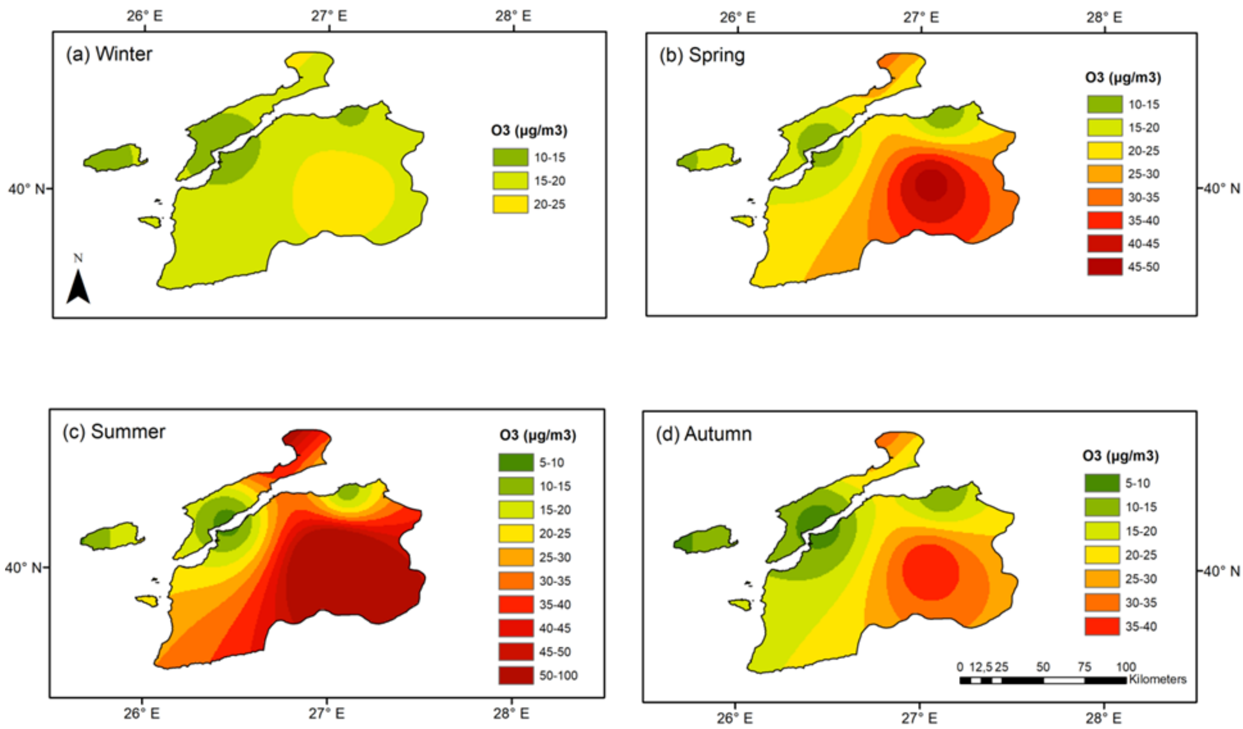

Figure 3. Interpolation results of O_3 concentrations (μg/m^3) in 2014-2018.

In this study, emission sources were examined during cold (November to April) and warm (May to October) periods of the district. In general, cold season in the city begins in November and ends in April, similar to Arslan et al., 2022 [22]. The relationship between ozone and other pollutants varies depending on the season and location. Particularly, higher ozone levels are observed in the warm season than cold season in Çanakkale. Changing patterns of traffic emissions have the greatest impact on urban ozone levels. As a result of intensive ship crossing in Lapseki district, higher O_3 concentrations were observed in warm season (Fig. 4). On the other side, it could still reach high levels during colder months due to long-range transport by wind. Higher O_3 concentrations recorded in Çan and Lapseki during southerly and southwesterly winds, respectively in cold season. Similarly, increases are observed by southerly winds in warm season as well in Çan district (Fig. 4).

In addition to the vehicle emissions, sea traffic, domestic heating, and long-range transport, industrial facilities are crucial for high amount of pollutant values in Çanakkale. Particularly, coal-fired power plants pose threat to city. Çan Lignite Plant, Çan Thermal Power Station, Çanakkale Ceramic Factory, Akçansa, ICDAS are examples of important industrial factories in the mining and energy sectors. Furthermore, low grade heating fuels and a great amount of motor vehicles lead to low air quality.

The formation and transport of tropospheric ozone are influenced by meteorological parameters. Especially, high temperature and light wind are effective in the formation and accumulation of ozone concentration. In this study, in order to determine the effect of meteorological factors and NO_x on ozone concentration, the relationship between temperature, relative humidity, wind speed, solar radiation, NO_x and ozone concentration was investigated. The values obtained as a result of the correlation between ozone concentration and meteorological factors are shown in Figure 5 and Figure 6. Wind speed is the most important mechanism that determines the movement of pollutants in the atmosphere. The horizontal and vertical components of wind speed play a role in the distribution of pollutants. A positive correlation was found between wind speed and ozone in winter months. A positive correlation (r=0.53) was found between temperature and ozone concentration in summer and autumn seasons. In the spring season, it was calculated as 0.38. Similarly, at Lapseki station, a positive correlation was calculated in autumn (r=0.48), spring (r=0.41), and summer (r=0.40). Also, positive correlation was found between solar radiation and ozone in autumn (r=0.32) and spring (r=0.47) seasons. However, it was determined that there was a negative correlation between NO_X concentration and ozone. Decrease in NOx concentration would lead to increase in O_3 levels. In spring and winter season, they were calculated as -0.52 and -0.46, respectively. In addition, negative correlation was observed between ozone concentration and relative humidity. There is a negative correlation between relative humidity and temperature. As the temperature increases, the relative humidity decreases. For this reason, ozone concentration is observed at high temperatures and low relative humidity values.

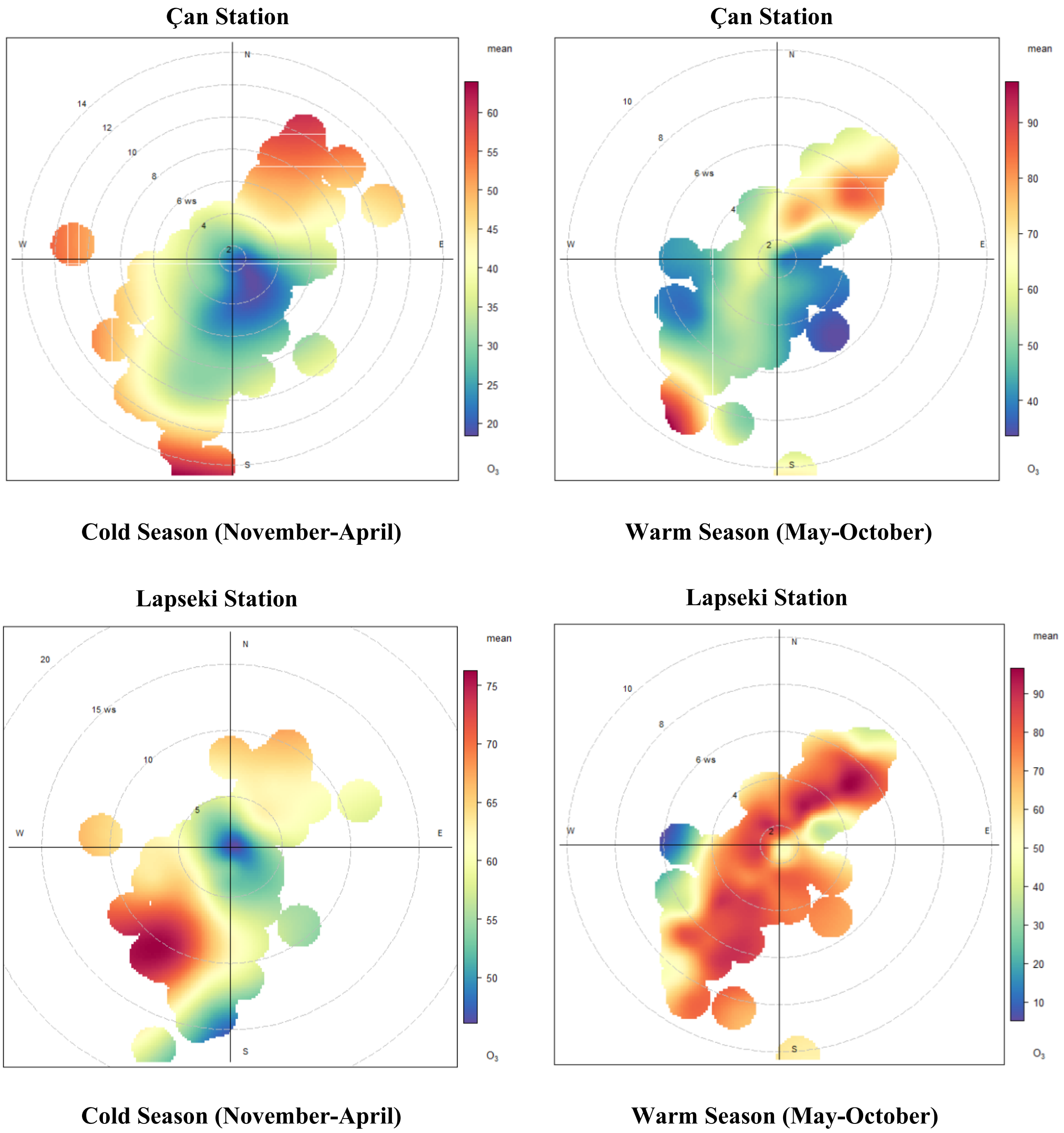

Figure 4. Polar plot of O_3 concentrations during the period of January 2014 to December 2018.

Çan Station

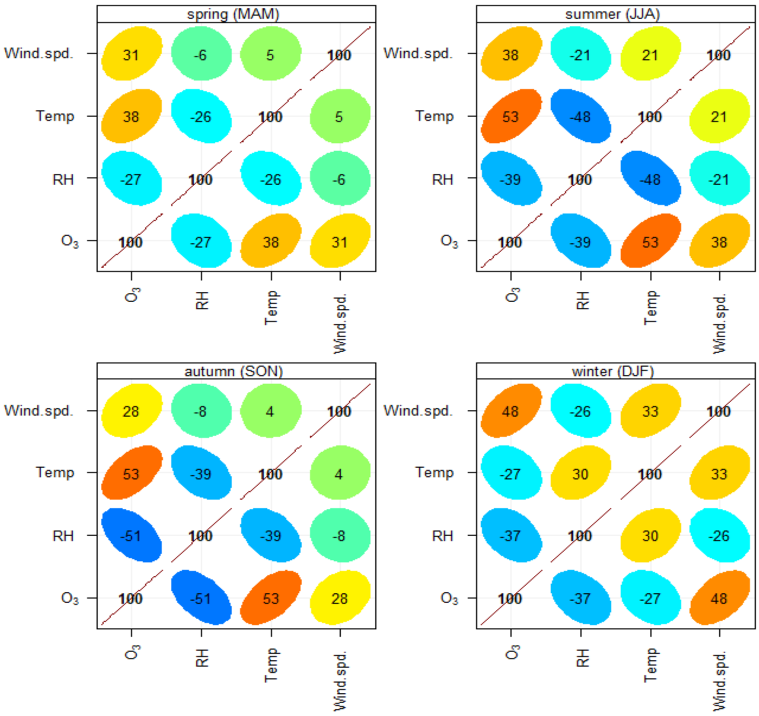

Figure 5. Correlation plots of O_3, relative humidity, temperature and wind speed using hourly data from 2014 to 2018 in Çan Station

Lapseki Station

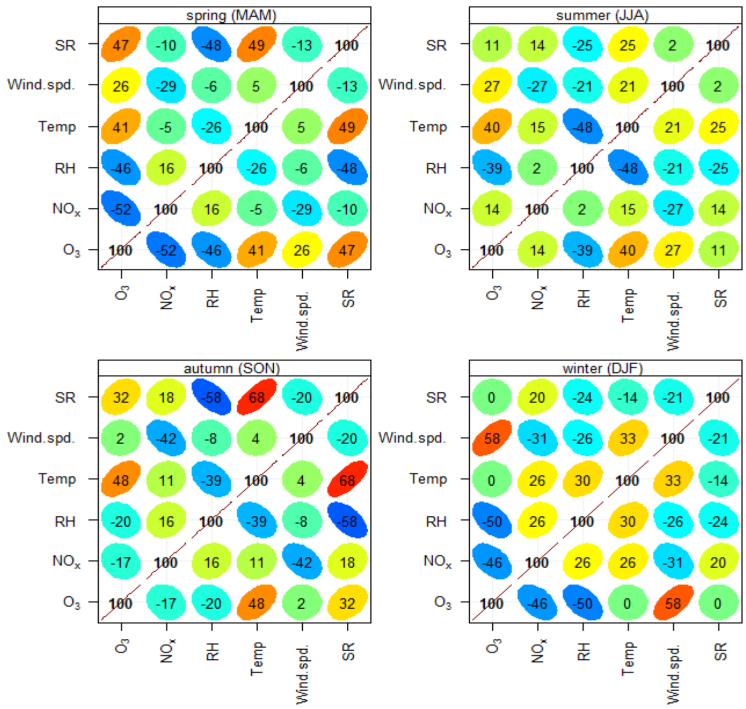

Figure 6. Correlation plots of O_3, solar radiation, relative humidity, temperature, wind speed and NO_X using hourly data from 2014 to 2018 in Lapseki Station

IV. CONCLUSION

In this study, temporal and spatial variations of ozone concentration measured between 2014-2018 in Çan and Lapseki districts were investigated. In addition, the relationship between ozone concentrations and meteorological parameters such as average daily temperature, wind speed and relative humidity was analyzed using regression analysis. Ozone levels reach higher levels in summer months compared to winter periods, as ozone levels are especially dependent on solar radiation and high temperature. The results indicated that O_3 has a positive correlation with temperature and solar radiation and a negative correlation with RH. As a result of anthropogenic emissions (e.g. cars, industrial boilers, refineries, chemical plants, thermal power plants and other sources that photochemically reactant) in Çanakkale, tropospheric ozone has strong seasonal variations, with higher concentrations in the summer. Ozone is created locally in polluted areas and increases concentration levels on a local scale by being carried by long-range transportation. Urban ozone concentrations are greatly influenced by traffic emissions. Decrease in traffic density causes a decrease in nitrogen oxides and thus the ozone concentration decreases. Ozone emissions are caused by population growth, technology advancements, economic development, changing land use, climate and other environmental changes. In order to reduce ozone emissions, energy production from fossil fuels should be reduced, transportation methods that do not use motor vehicles should be emphasized, and the emissions of industrial facilities should be strictly controlled. The measurement of ozone in the air should be done regularly at all measurement stations, and the results should be announced instantly. The public should be informed about ozone pollution and health problems caused by extreme temperatures, and warnings should be made in cases of excessive pollution. As a result of these actions other air pollutants and greenhouse gases will also be reduced. Less ozone in the troposphere means less damage to vegetation.

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