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ORIGINAL RESEARCH ARTICLE

The effects of mobile thermal power plants on air quality in Turkey

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ABSTRACT

In this study, daily averages of air quality parameters were measured in two stations (S1 and S2) of the organized industrial district in Samsun. The meteorological variables were measured at only one station (S1), such as temperature, relative humidity, wind speed, solar radiation, and ambient pressure in 2007, and the daily promised limit for nitrogen dioxide has been especially exceeded at 206 times for 1st station. However, exceeds of the limit value in 2006 for 1st station was reduced by approximately 3.5 times. The daily nitrogen dioxide concentration did not exceed the daily limit of WHO[1] as for 2nd station. The results obtained showed that under the influence of dominant wind direction, the second station measurement results are higher than that of the first station. To determine all of the possible environmental effects, the measurements should be analyzed from a multi-point perspective.

Keywords: Mobile; Power Plant; Ambient Air Quality; Samsun

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1. Introduction

Fossil-fuelled power plants have been supplying electricity for industrial use since the late 1880s[2]. In thermal power plant, the heat used for boiling the water is obtained by burning a fossil fuel, where the heat is delivered by the exhaust of a gas turbine[3]. Conventional fossil-fuel power plants are the major source of industrial air pollution and major gaseous pollutants emitted are carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxides (NO_x), and certain hydrocarbons and volatile organic compounds (VOC_s)[4]. The main fuel types used in industries are fuel oil, lignite, liquefied petroleum gas, natural gas, and others (wood, biomass, petroleum coke, biogas) in the developing countries[5,6].

No. 6 fuel oil (also called Bunker C oil or residual fuel oil) widely used in Thermal Power Plant in developing countries is the residuum from crude oil after naphtha-gasoline, whereas No. 1 fuel oil and No. 2 fuel oil have been removed. No. 6 fuel oil can be blended directly to heavy fuel oil or made into asphalt. Residual fuel oil is more complex in composition and impurities than distillate fuels. Polycyclic aromatic hydrocarbons (including the alkylated derivatives) and metal-containing constituents are components of No. 6 fuel oil[7]. **Table 1** lists the details of the illustrative analysis of typical residual oil (No.6). The sulphur in heavy fuel oil (No.6) contributes significantly to the particulate emissions by virtue of its oxidation and combination with water to generate sulphates, which bind together with the soot to increase the emissions[8].

Table 1. Typical properties of residual oil

Parameters	Fuel oil (No.6)
ASTM maximum kinematic viscosity, cs	50 (212º F)
ASTM water and sediment, max. vol.%	2.0
Specific gravity, 60/60º F (15.5º C)	0.986
Carbon residue, %	12.0
Ash, wt%	0.10
Netheating value, Btu/lb (kcal/kg)	17.677 (9.821)
Sulfur, wt%	2.7
Oxygen, wt%	0.62
Nitrogen, wt%	0.32
Hydrogen, wt%	10.5

The annual installed capacities of Turkey are composed of 66.8% thermal, 32.8% hydroelectric and 0.4% geothermal and wind energy, respectively. Turkey's primary energy sources include hard coal, lignite, fuel oil, natural gas, hydro, geothermal, wood, animal and plant wastes, solar, as well as secondary energy sources like coke briquettes[9]. The distribution of installed capacity by primary energy resources are 5.3% for hard coal and asphaltite, 18.3% for lignite, 3.7% for fuel oil, 0.1% for diesel oil, and 26.4% for natural gas in Turkey[10]. Thermal power plants (with a total installed power capacity of 12808.9 MW) in Turkey are generally used to meet the electricity demand as seen in **Table 2**.

Table 2. Thermal power plants in Turkey[10]

Name of power plant	Location	Fuel type	Total capacity (MW)	Type of unit
Çatalağzı	Zonguldak	Hard coal	3,000	Steam
Afşin-Elbistan A	K. Maraş	Lignite	13,550	Steam
Afşin-Elbistan B	K. Maraş	Lignite	14,400	Steam
Çan	Çanakkkale	Lignite	3,200	Steam
Kangal	Sivas	Lignite	4,570	Steam
Orhaneli	Bursa	Lignite	2,100	Steam
Seyitömer	Kütahya	Lignite	6,000	Steam
Tunçbilek A	Kütahya	Lignite	650	Steam
Tunçbilek B	Kütahya	Lignite	3,000	Steam
Ambarlı	İstanbul	Fuel oil No.5/No.6	6,300	Steam
Hopa	Artvin	Fuel oil No.4	500	Steam
Çukurca	Hakkari	Diesel oil	10	Internal combustion
Ambarlı KÇ	İstanbul	Natural gas	13,509	Combined cycle
Bursa KÇ	Bursa	Natural gas	14,320	Combined cycle
Aliağa GT+KÇ	İzmir	Natural gas	1,800	Combined cycle
Hamitabat KÇ	Kırkale	Natural gas	1,1200	Combined cycle
Soma A	Manisa	Lignite	440	Combined cycle
Soma B	Manisa	Lignite	9,900	Steam
Kemerköy 1,2,3	Muğla	Lignite	6,300	Steam
Yatağan	Muğla	Lignite	6,300	Steam
Yeniköy	Muğla	Lignite	4,200	Steam
Samsun 1	Samsun	Natural gas	2,400	Combined cycle

2. Experimental protocols

2.1 Site description

The organized industrial district (OID) in the present study located (41º14′51″ N-41º13′21″ N; 36º25′57″ E-36º28′57″ E) at Tekkekoy in Samsun as seen in **Figure 1**. OID is situated at a distance of 12 km in the east from city center of Samsun. There are small and medium scale units of industries and big scale units of several industries in this area.

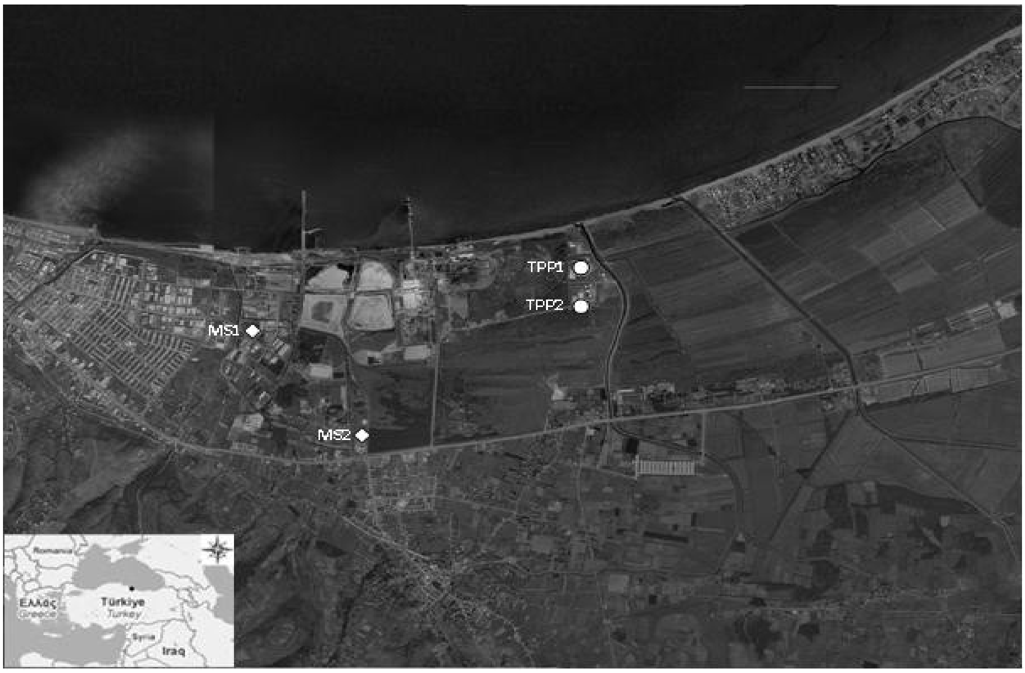
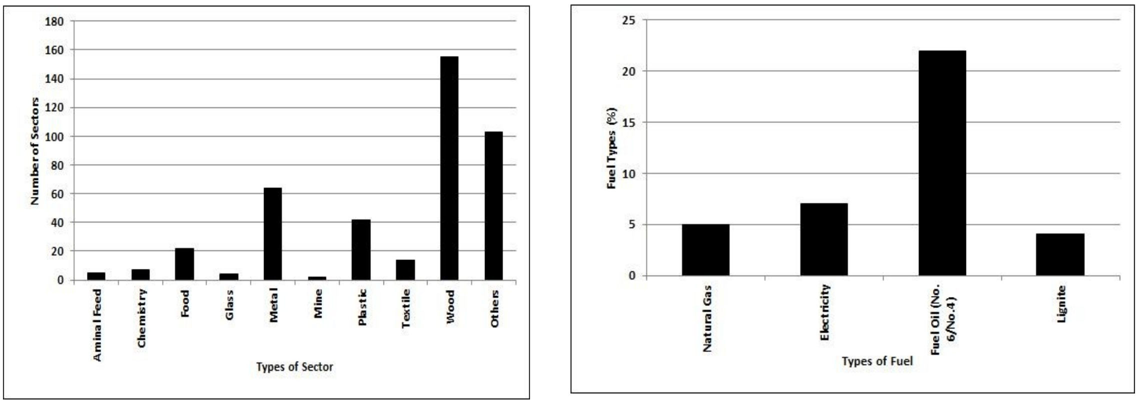


Figure 1. Location of the monitoring site and air pollutant of sources in the map of Orion-ME (from Google Earth).
Note: MS1:1st Measurement Station; MS2: 2nd Measurement Station; TP1: Thermal Power Plant 1; TP2: Thermal Power Plant 2.



(a) **(b)**

Figure 2. The percent of industries according to type sectors **(a)** and using fuel **(b)** OID in Samsun.

The types of fuel used for the plants in the industrial regions are as follows: natural gas (33%), electricity (59%), fuel oil of No.4 and No.6 (5%) and lignite (3%) as seen in **Figure 2b**. Natural gas and electricity are the primary fuel type in the organized industrial region.

The mobile power plants are situated about 14 Km North East of Samsun. The power plant selected for the study was 262 MW fuel oil (No.6) fired-power plant with totally two units (131 and 131 MW). The fuel oil type used in mobile power plants located in Samsun is fuel oil No. 6 in residue fuel oil obtained from İzmir Refinery of Tupras Turkey Petroleum Co. The total sulfur content of residue fuel oil was % 2.8 by weighing[11,12].

Petroleum fuels, named fuel oil NO. 6, which are residual fuels, are used in the mobile power plants. The total fuel oil-feed consumption in the mobile power plants are approximately 1168.49 ton/day (610.60 and 557.89 ton/day)[12]. The average properties of the fuel-oil in the mobile power plant in Samsun are given in **Table 3**[12,13]. The mobile power plants were operated from 1 August 2007 to 16 February 2008. In this study, the air quality data were collected from observational station St-1 from April 2006 to April 2008 and from observational station St-2 from August 2007 to April 2008.

Table 3. Properties of fuel oil in the mobile power plant in Samsun[12]

Parameters	**MPP-1 (Samsun-1)**	**MPP-1 (Samsun-2)**
	Fuel oil (No.6)	Fuel oil (No.6)
Sulfur (%)	2.74	2.74
Ash (%)	-	0.042
Lower heating value (Kcal/kg)	9850	9,850
Fuel Consumption (ton/day)	610,60	55,789

2.2 Meteorological data

All meteorological data for 1st station was measured by using meteorological sensors produced by Lastem Company. Fifteen minutes surface meteorological data recorded at the 1st station at fifteen minute intervals include wind speed and direction, air temperature, relative humidity, barometric pressure, and solar radiation. Meteorological data were collection started on 1 April 2006 and ended on 15 November 2007 as seen in **Figure 3a**. Meteorological sensors were placed on the top of air quality measurement vehicle and 4.5 m on the surface of the ground for 1st measurement station. All data were recorded at fifteen minutes intervals.

2.3 Pollutant data for station-1 (S1)

The sensor of air quality parameters were placed on the top of air quality measurement vehicle and 4.5 m on the surface of the ground (**Figure 3a**). Measurements were made continuously during every 15 minutes and ninety-six data values were collected daily. The instruments were calibrated at least eight times in a year by using calibration gases. Calibration of the ozone analyzer was done regularly with the help of a built-in ozone generator. A sulfur dioxide is measured using an analyzer AF 22 M of Environment S.A. (France) based on absorption of UV Fluorescence Method. The minimum detection limit of the analyzer is about 1 ppb and its response is about 10 s. The linearity is reported as ±1 % of F.S (Environment S.A. France). Nitrogen Oxides (NO, NO_X, NO_2) are measured using an analyzer AC 32M of Environment S.A. based on Chemiluminescence Method. The minimum detection limits of the analyzer are reported to be about 0.2 ppb (response time 30 s.). A Carbon monoxide is measured using an analyzer CO 12M of Environment S.A. (France) based on absorption of infrared light. The minimum detection limits of the analyzer are reported to be about 50 ppb (response time 30 s). A particulate matter was measured by using an analyzer PM 101M of Environment S.A. (France) based on the absorption of beta radiation by matter. The minimum detection limits of the analyzer are reported to be about 0.5 $\mu g.m^{-3}$.

2.4 Pollutant data for station-2 (S2)

The sensor of air quality parameters were placed approximate 2.5 m on the surface of the ground (**Figure 3b**). A sulfur dioxide is measured using an analyzer 100 EH of Teledyne API (USA) based on absorption of UV Fluorescence Method. The minimum detection limit of the analyzer is about 1 ppb and its response is about 30 s. The linearity is reported as ± 1% of F.S. Nitrogen Oxides (NO, NO_X, NO_2) are measured using an analyzer 200E of Teledyne API based on Chemiluminescence Method. The minimum detection limits of the analyzer are reported to be about 0.4 ppb. A carbon monoxide is measured using an analyzer 300E of Teledyne API based on absorption of infrared light. The minimum detection limits of the analyzer are reported to be about 40 ppb. A particulate matter is measured by using an analyzer PM 101 M of Teledyne API based on the absorption of beta radiation by matter. The minimum detection limits of the analyzer are reported to be about 0.5 µg.m^{-3}.

(a) **(b)**

Figure 3. The 1st and 2ed ambient air quality measurement stations, S1 **(a)** and S2 **(b).**

3. Results and discussion

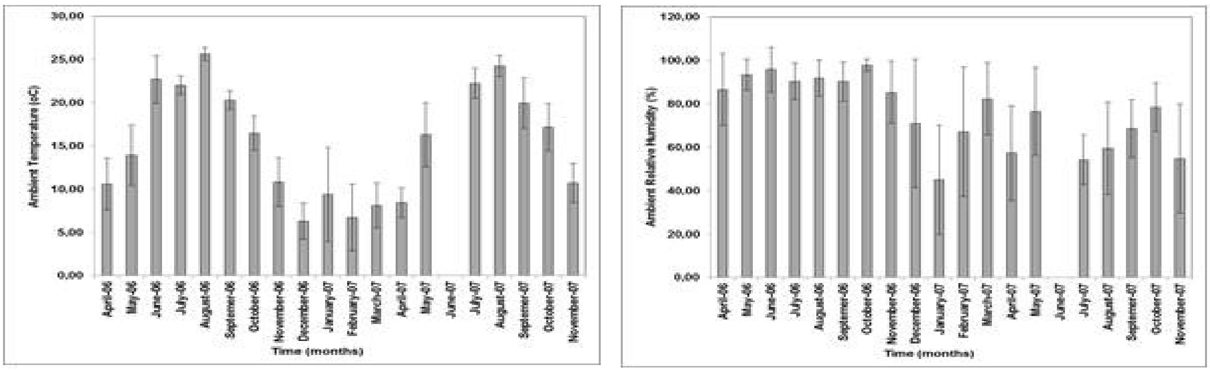
The average yearly temperature, relative humidity, and solar radiation are 15.3 ± 6.6 °C, 77.3 ± 17.8 %, and 154.19 ± 253.7 W.m^{-2} respectively. The average annual of wind speed is 1.11 ± 0.78 m.s^{-1}. At a height of 4.5 m, wind speed recorded was always less than 8.9 m.s^{-1}. The wind speeds well around 1-2 m.s^{-1} during the day and almost 0.1-1.2 m.s^{-1} during the night. North (N) and Northwest (NW) were found out to be dominating wind direction as seen in **Figure 4**.

The removal rate of the pollutants by the wind is supposed to be proportional to the sum of the projection of the effective wind direction, and on the pollutant concentration[14].

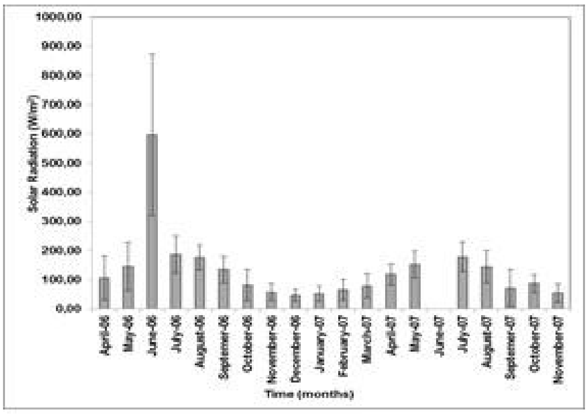
The wind speed has reached the highest values between July and August according to the daily average total 518 values in 2006 and 2007 (**Figure 4**). An average monthly of the wind speed increased for July and August of about 2-2.5 m.s^{-1}.

The wind speed was also decreased for an increase in NO_2, higher decrease of carbon monoxide (CO), particulate matter (PM), and sulfur dioxide (SO_2) during July and August 2006. A Nitrogen dioxide (NO_2) increased during July and August 2006, while carbon monoxide (CO), particulate matter (PM), and sulfur dioxide (SO_2) were also decreased, with higher wind speed during July and August 2006[14].

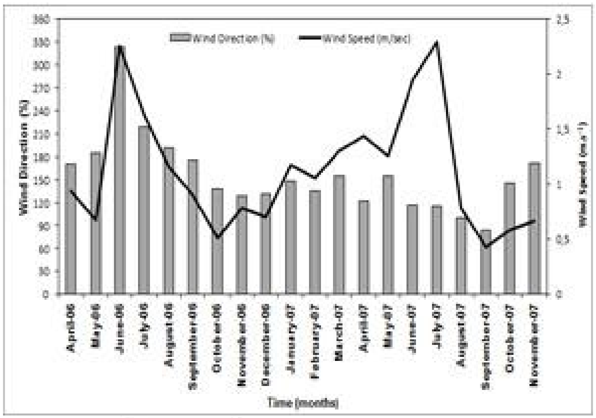
In this period, the prevailing wind direction is northwest and northeast of the measurement points covering the region thought to be caused by the increase of large-scale industrial facilities. In 2007, the wind speed is higher in July and August signifies east tending the prevailing wind direction is south. During this period, the increase in the amount of CO and SO_2 was observed.



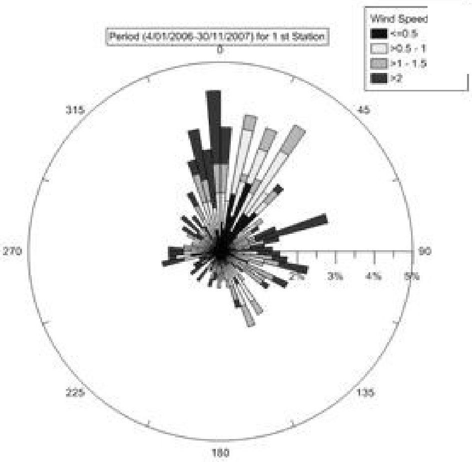
(a) **(b)**



(c)



(d)



(e)

Figure 4. The ambient air temperature **(a)**, ambient relative humidity **(b)**, solar radiation **(c)**, dominant wind direction **(d)**, and wind speed **(e)** for in the 1st station**.**

3.1 Carbon monoxide

The carbon monoxide measurements were only carried out July to December mounts as seen in **Figure 5**. When between these mounts measured, carbon monoxide values are examined, and carbon monoxide values in second situation was higher than that in first situation, but it was seen that European Union limit values did not exceeded in both the situations as seen in **Table 4**. Carbon monoxide at the 1st station was measured lower when thermal power plant was operated. During the same period, Carbon monoxide at the 2nd station was measured lower than 1st station. The reason is that the predominant wind direction was southwest from August to December.

3.2 Particulate matter

The measurements of particulate matter at the 1st station were higher than 2nd station between July and December and the limit values have exceeded (**Figure 5**). This situation shows that the increases in particulate matter in the area are higher than sulfur dioxide, and while the mobile station has operated, the measured values have exceeded the limits (**Table 4**).

Daily average values of PM between the months of April to July in 2007 showed a decrease from the previous year, and this is thought to result from the prevailing wind direction. In addition, in the two measuring stations, PM value of the second measurement station was higher from August to November 2007. That is because the second measu-rement station lies in the vicinity of industrial coal screening, crushing plants or the Samsun high-way vehicles from the Army.

3.3 Nitrogen oxides

In terms of nitrogen oxides, the limit values were not exceeded during all the year, but results of measurement in the 2nd station are higher than first situation when July to December is compared

(**Figure 5**). Although the annual limit is not exceed in the first station, the hourly limit values of European Union were exceed especially for nitrogen dioxide 733 times in 2006 and 206 times in 2007 as seen in **Table 4**.

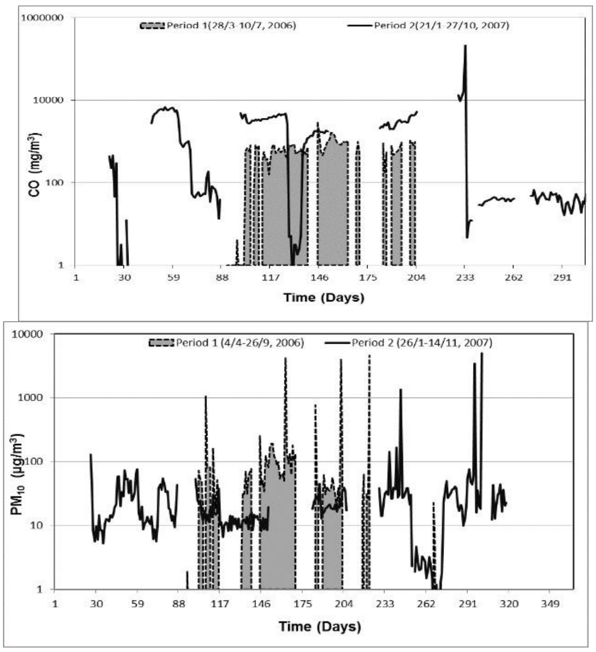
Nitrogen dioxide — NO_2 time series analysis shows that NO_2 concentrations measured during spring are higher than those observed during autumn for station-1 in 2006. While the mobile power plant was operating, an increase of approximately 136 % in NO_2 concentrations was observed in relation to previous year in the autumn of 2007 and an increase approximately 370 % in total NO_x concentration was observed according to previous year in the autumn of 2007.

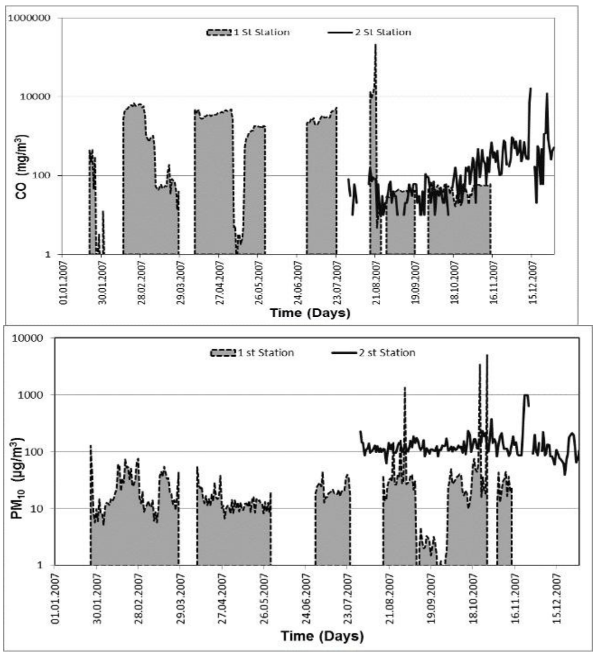
Thermal power plants are operating in NO_2 values between August and December in 2007 according to the same period in 2006 increased by first station. However, considering the wind direction, the prevailing wind direction is south, while it turns to be east tending for the period of August to December. Thus, in 2007, an increase of NO_2 is fully rooted in thermal power plants because the southeast wind pollutant is provided transport to the Black Sea. According to research done throughout the year in 2007, there was a reduction of NO_2.

3.4 Sulfur dioxide

The measurements at the 1st station were continued from April 2006 to November 2007 as seen in **Figure 6a**. The measurements at the 2nd station had continued until July 2007 to December 2007. After the mobile power plant operated again in July 2007, the sulfur dioxide at the 1st station was increasing in proportion to the previous year. But the sulfur dioxide at the 1st and 2nd station did not overcome upon 70 μg/m^3 between July and December and the measurements at the 1st station for 2006 and 2007 between July and December was higher than 2nd station. The reason for this was that the wind direction at the 1st station was northeasterly (NE) despite the wind direction was southern west (SW) at 2nd station. The sulfur dioxide measurement at the 2nd station was not received any day over European Union limit values (**Table 4**). The limit values were exceeded only one day at the 1st station in 2007.

Measurements of SO_2 thermal power station is operating in 1st August to December, 2007, with period increased slightly from the previous year. Comparison could not be made due to technical problems and measurements of SO_2 level. Compared with the daily SO_2 levels between 09/25/2007 and 10/16/2007, 1st station 2nd station data and the prevailing wind direction are higher than that measured in the southeast.





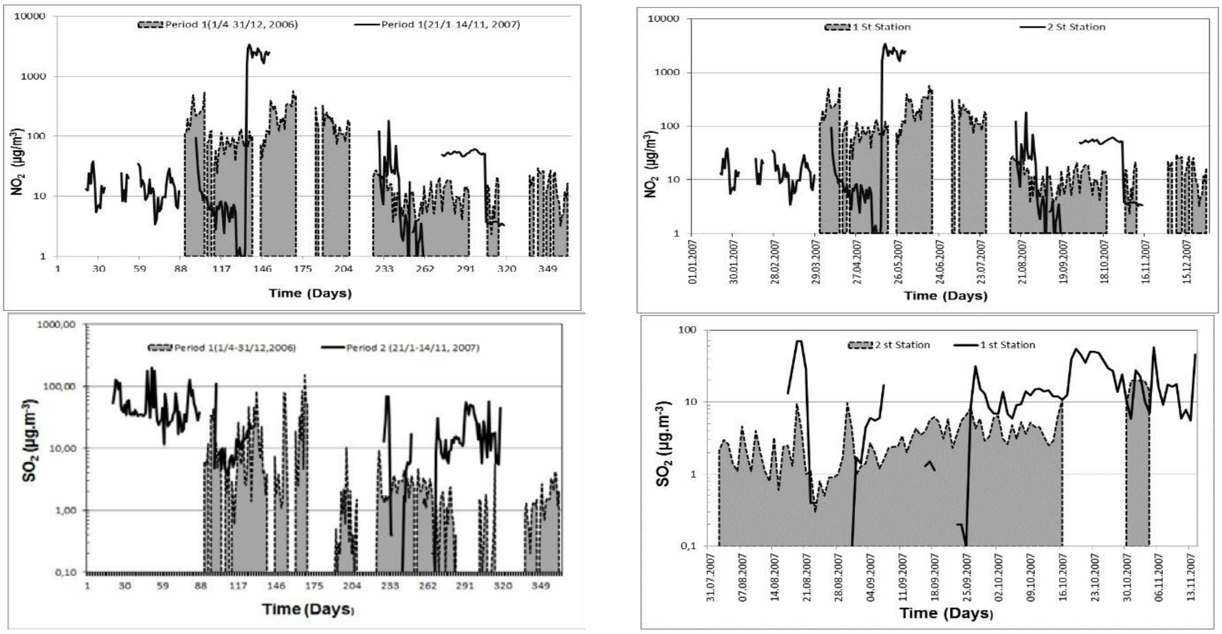
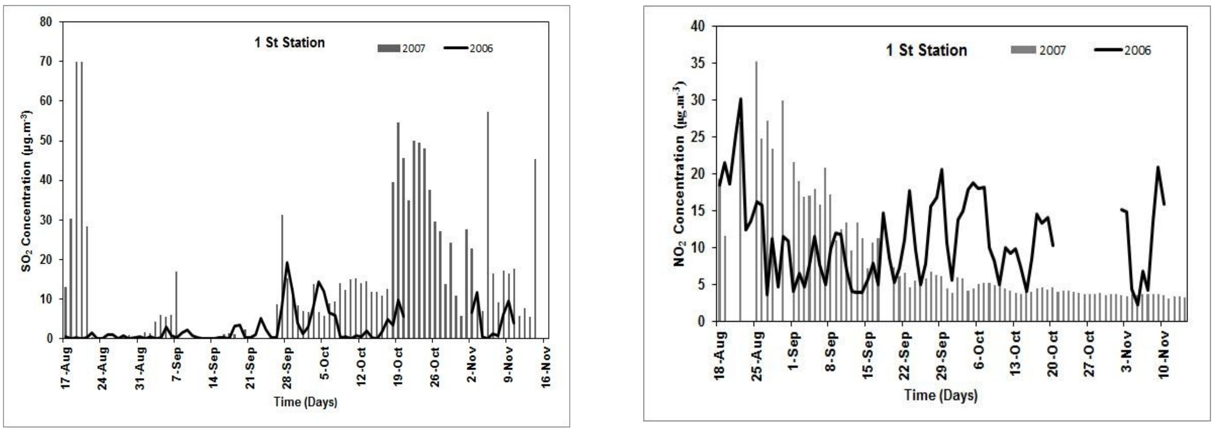


Figure 5. Time series of pollutants observed at1st station for 2006 to 2007 and 2nd station for 2007.



(a) (b)

Figure 6. Time series of pollutants observed at 1st station **(a)** and 2nd station **(b)** for 2006 to 2007.

In **Figure 6**, According to the previous year, the amount of thermal power plants operated has increased with a higher SO_2 emission level. However, the value of low SO_2 in the months of August to September of 2007 was caused by the south-southwest prevailing wind direction. However, the thermal power plants are operating in the summer and autumn of 2007 during the previous year, according to an exponential reduction in NO_2 concentrations.

Table 4. The amount of pollutants exceeded limit values for 1st station

Air pollutants	Stations	Period	Limit (as µg/m^3)	Limit exceeded (2006)	Limit exceeded (2007)	References
PM_{10}	1	Daily	50	44 times	12 times	1999/30/EC (EU Directive)[15]
	2	Daily	50	-	50 times*	1999/30/EC (EU Directive)
SO_2	1	Daily	125	Once	5 times	1999/30/EC (EU Directive)
	2	Daily	125	-	-	1999/30/EC (EU Directive)
NO_2	1	Hourly	200	733 times	206 times	1999/30/EC (EU Directive)
	2	Daily	150	-	-	1999/30/EC (EU Directive)
CO	1	Hourly	10000	-	-	2000/69/EC (EU Directive)[16]
	2	Hourly	10000	-	-	2000/69/EC (EU Directive)

Note: * Only five months (August, September, October, November, and December)

4. Conclusions

In this study, the effects of mobile thermal power plants were investigated. When measurements of 1st and 2nd stations were compared at the same time period, finding that the 2nd station measurement results was higher than that of 1st station.

In 2007, the daily limit for nitrogen dioxide has been especially exceeded at 206 times for 1st station. However, the total time exceeds of the limit value in 2006 for 1st station was reduced by approximately 3.5 times.

The region's main sources of nitrogen dioxide pollution from mobile plants have not been concluded in 2007. In the region, between the years 2006 and 2007, increasing use of natural gas has led to reduction of pollutant concentrations. The daily nitrogen dioxide concentration did not exceed the daily limit of WHO as for 2nd station. In general, the maximum pollution results from nitrogen dioxide in both the two stations. But, in this case, the entire region in terms of nitrogen dioxide pollution could be the result that does not reveal. However, the entire region in terms of nitrogen dioxide pollution can not be revealed in this case. The results can be obtained that the dominant wind direction is considered dominant wind direction in the entire region.

For the first station, a decrease in the concentration of particulate matter has been observed compared with the previous year in 2007. However, for the second station, an increase in the concentration of particulate matter has been observed. The sources of the particulate matter pollution in the second station are estimated as mobile power plants, Samsun-Ordu of highway and other plants in OID.

The carbon monoxide and sulfur dioxide measurements for each in the two stations are under the limit values.

The second station measurement results were higher than that of the first station. This is because the prevailing wind direction is north and northeast. In terms of carbon monoxide and sulfur dioxide, pollution in the two stations has not been determined. The use of natural gas to reduce the pollutant concentration is affected by OID. The hourly nitrogen dioxide concentration did exceed the daily limit of EU Directive in the first station. This is not only caused by mobile power plants but also industrial plants in this region. For a full assessment of the impact of mobile power plants, there shall made multi-point measurements in these two stations.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

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