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Winter Season SO_2 Measurements in Bursa and Comparison with Rural and Urban Area Values

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Abstract

Sulfur dioxide (SO_2) is known to be one of the combustion end products of sulfur containing fossil fuels. In particular, cities with heavy industrial activities have high levels of SO_2 concentrations. In this study, SO_2 measurements were carried out in the city center of Bursa and on the campus of Uludağ University, which is a semi-rural area. Unlike the campus, the city center is highly populated and its vicinity is heavily industrialized.

Daily SO_2 values were obtained by computing the averages of the half hourly integrated measurements. Sulfur dioxide samples were collected in January, February and March in order to represent the winter season. Data were gathered during 1996, 1997, 1998 and 1999. Data from the first three years represent the city of Bursa while the data from 1999 represent the Uludağ University campus. The average of the data from 1996, 1997 and 1998 gave an SO_2 concentration of 189.5 ± 48.3 μg/m^3. On the other hand, the average the data from 1999 gave a concentration of 18.1 ± 7.9 μg/m^3. These values were compared to each other, to the standards, and to the other measured values from Turkey and the rest of the world.

Key Words: Air pollution, Sulfur dioxide, Bursa, Urban area, Rural area.

Bursa'da Kış Sezonu Kükürt dioksit Ölçümleri ve Kentsel ve Kırsal Alan Değerleriyle Karşılaştırılması

Özet

Kükürt dioksit (SO_2), kükürt içeren fosil yakıtların yanma ürünlerinden birisi olarak bilinir. Özellikle ağır endüstriyel aktivitelerin olduğu şehirler yüksek SO_2 konsantrasyon seviyelerine sahiptirler. Bu çalışmada, SO_2 ölçümleri Bursa şehir merkezinde ve yarı kırsal bir alan olan Uludağ Üniversitesi Kampüsü'nde gerçekleştirilmiştir. Kampüsün aksine, Bursa şehir merkezi çok nüfuslu ve etrafı yoğun olarak endüstrileşmiştir.

Günlük SO_2 ölçümleri yarım saatlik birleştirilmiş ölçümlerin ortalamasından elde edilmiştir. SO_2 ölçümleri, verilerin kış sezonunu temsil etmesi için Ocak, Şubat ve Mart aylarında toplanmıştır. Örnekler 1996, 1997, 1998 ve 1999 yıllarında toplanmıştır. İlk üç yılın verileri Bursa şehir merkezini temsil ederken, 1999 yılının verileri Uludağ Üniversitesi Kampüsü'nü temsil etmektedir. 1996, 1997 ve 1998 yıllarının ilk üç ay ortalaması 189.5 ± 48.3 μg/m^3 SO_2 konsantrasyonu değerini vermiştir. Öte yandan, 1999 yılının kış sezonu 18.1 ± 7.9 μg/m^3'lük ortalamaya sahiptir. Bu değerler kendi aralarında, standartlarla ve Türkiye ve Dünya'dan ölçülmüş diğer değerlerle mukayese edilmiştir.

Anahtar Sözcükler: Hava kirliliği, Kükürt dioksit, Kentsel alan, Kırsal alan.

Introduction

Sulfur compounds enter the atmosphere through either natural phenomena or anthropogenic activities. Nonanthropogenic sulfur may enter the atmosphere mainly as H_2S from volcanoes and from the biological decay of organic matter, and from the reduction of sulfate, which may come from volcanoes and sea salt (Elsom, 1992; Manahan, 1991). Hydrogen sulfide (H_2S) in the atmosphere is rapidly converted to sulfur-dioxide (SO_2).

Anthropogenic SO_2 comes from the combustion of sulfur-containing fossil fuels, sulfuric acid plants and the processing of sulfur-containing metal ores. Table 1 summarizes some important sources of SO_2 in the USA, Canada and Turkey. The distributions of the emissions from similar source categories are quite different and this difference is a result of variances in industrial activities, size and distributions of population, forest areas, energy source and other factors (Moroz, 1996).

Table 1. Nationwide Emissions of Sulfur Oxide Pollutants (106 tonnes/year).

Source	Sulfur oxides (USA)[a] (1991)	Sulfur dioxide (Canada)[b] (1985)	Sulfur oxides (Turkey)[c] (1996)
Transportation	0.99	0.09	N.D.
Fuel combustion	16.55	1.02	1.15
Industrial processes	3.16	2.57	0.65
Solid waste disposal	0.02	0.02	N.D.
Miscellaneous	0.01	N.D.	N.D.

[a]: Source: *National Air Quality and Emission Trend report, 1991,* U.S. EPA Report 450-R-92-001, October 1992.
[b]: Source: *Canadian Emissions Inventory of Common Air Contaminants, 1985,* Environment Canada Report EPS 5/AP/2, March 1990.
[c]: Source: Müezzinoğlu, A., Elbir, T., Bayram, A., "Inventory of Emissions from Major Air Pollutant Categories in Turkey," *Environ. Eng. and Policy,* Vol. 1, No. 2, pp: 109-116, 1998.
N.D.: no data.

In the atmosphere, SO_2 is converted to SO_3 and then it reacts with water to produce sulfuric acid, which is toxic to vegetation at 0.2 ppm (560 $\mu g/m^3$) and is very corrosive to some metals such as nickel, steel, iron and copper (Corbitt, 1990; Stiling, 1992). Concentrations at 1-5 ppm (2800-14000 $\mu g/m^3$) cause a detectable response in people and vegetation (Stiling, 1992). The major health impacts of sulfur dioxide include effects on breathing, respiratory illness, weakness of lung defenses, increase in the effects of existing respiratory and cardiovascular disease, and death (Henry and Heinke, 1996; Benitez, 1993; Peavy et al., 1985).

An effect generally known is the formation of acid rain (H_2SO_4) by the reaction of sulfur oxides and atmospheric moisture (Park, 1987). Acid rain may have a pH as low as 2 and is responsible for acidifying streams, dams, and lakes. Therefore, not only are fish killed, but also the surface water is left too acidic for reinhabitation. For example, the acidification of fresh waters in Scandinavia may be caused by emissions from the industrial part of western Europe, including the United Kingdom (Goudie, 1986). Moreover, countries in North America and western Europe have political problems in controlling SO_2 pollution and the migration of acidic rain clouds across borders (Peavy et al., 1985).

The atmosphere has a very dynamic structure that may have large changes spontaneously in temperature, humidity, composition, and sunlight intensity. Therefore, different chemical processes may dominate. In the atmosphere SO_2 is eventually converted to sulfuric acid and sulfate salts. Some of the possible SO_2 reaction routes might be outlined as follows (Seinfeld, 1986; Finlayson-Pitts and Pitts, 1986; Manahan, 1991):

a) Photocehemical and chemical reactions in gaseous phase,

b) reactions in water droplets,

c) Reactions on solid particulate matter.

The primary natural removal processes for SO_2 are reactions with OH radicals and dry deposition after conversion into sulfate particles (Hewitt and Stugers, 1993). While aerosols are formed, solar radiation is scattered and cloud formation is affected because aerosols act as condensation nuclei (Wuebbles, 1993). Society has made some important progress in sulfur dioxide control, for example, the early monitoring studies started in the USA in the 1960s. Moreover, in Turkey, sulfur dioxide and other air pollutants were regulated by the air quality protection regulation (AQPR) in 1986. Table 2 summarizes the air quality standards for SO_2 from different constituents. Due to these regulations, not only does the environment stay clean, but also health expenditures decrease. A study done in 1982 indicated that pollution reductions on air contaminants between 1970 and 1978 saved about $16 billion annually in costs associated with early deaths and illness in the USA (Stiling, 1992).

Table 2. Ambient Air Quality Standard for SO_2 (μg/m^3) (TAQPR, 1986; Henry and Heinke, 1996; Abron and Corbitt, 1990; WHO, 1987)

Turkish (1986)		U.S. EPA (1992)	Ontario, Canada (1992)	WHO Guidelines (1987)
STL	LTL	Primary	Desirable max	Guideline
400 900*	150	80 - AAM 365 - 24 h	54 - AAM 260 - 24 h 650 - 1 h	50 - AAM 125 -24 h

STL: Short term limit, LTL: Long term limit.

*: Maximum hourly average,

AAM: Annual arithmetic mean,

Primary standards define air quality levels that protect the public health. Secondary standards protect the public welfare.

Due to its natural and anthropogenic sources, sulfur dioxide can be found all over the world. Concentrations measured at different places fluctuate depending on the distance from the source, geological structure (ventilation) and meteorological conditions (dispersion and transport). In general, when city size increases, the SO_2 concentration level also increases. Moreover, fossil fuels used in industrial applications increase the SO_2 concentration of the atmosphere.

Sulfur dioxide can be detected both in industrial and pristine areas; however, the concentrations are quite different (Sharma, 1997; Özer et al., 1996; Elsom, 1992; Seifeld, 1986). In this study, two different places were considered for the assessment of SO_2 pollution. The main objectives of this study were to determine the sulfur dioxide concentration differences in a semi-rural and an urban area and to compare these measurements with the values from different places in the world.

Experimental

Atmospheric measurements were carried out in the months of January, February and March. Sulfur dioxide (SO_2) data were obtained for four years, between 1996 and 1999. Measurements from the first three years represented the city center of Bursa while the measurements from the last year (1999), represented the Uludağ University campus.

The sulfur dioxide (SO_2) sampling and measurement device was located in Altıparmak, a busy and crowded district of downtown Bursa. The instrument was located on the third floor of the Osmangazi Kaymakamlığı building. The building was located in a mixed residential, institutional and commercial area. The Altıparmak district consists of mostly high-rise buildings and traffic is always heavy.

Uludağ University, the next measurement site during the fourth year, is located on the outskirts of Bursa. It is near the Bursa-İzmir highway about 20 km from the center of Bursa. It is covered mainly with trees, grass and buildings that are not close to each other, and atmospheric ventilation is better. The campus is not affected by the air of Bursa unless wind comes from that direction.

The sampling device was placed in one of the laboratories of the Environmental Engineering Department on the campus, in a two-story building. The other buildings were low-rise buildings and there was some distance between the buildings. There were trees and grassy places around the building where the sampling device was placed. Therefore, no effects from traffic, residential and industrial sources were expected.

An environnement AF21MSO_2 device was employed for SO_2 measurements. The detection principle is based on measuring fluorescence in ultraviolet light. The sample is directed to a reaction chamber where it is irradiated by ultraviolet radiation at 214 nm. Molecules reconstruct a specific fluorescence in the ultraviolet. This fluorescence is visualized by a special tube and this signal is converted into digital values for processing by a microprocessor calculating the averages of the measured data.

Measurements were made continuously during the sampling period unless a problem occurred. Integrated measurements were recorded every 30 minutes and forty-eight data values were collected daily. Afterwards an average value was computed for each day.

Bursa

Bursa is an important province in terms of agriculture, industry and commerce sectors. It has a surface area of about 11000 km^2 and has borders with İstanbul, İzmit, Bilecik, Kütahya, Balıkesir, and the Marmara Sea (Figure 1).

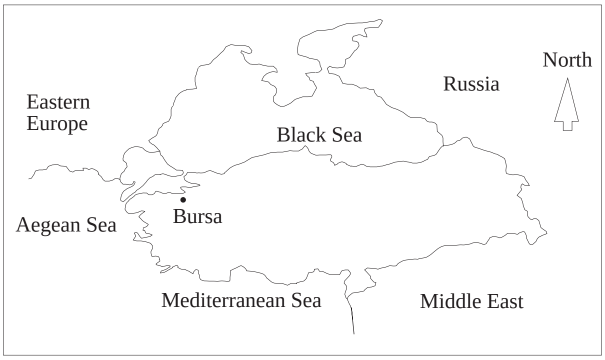

Figure 1. Location of the City of Bursa.

The climate of Bursa is a mixture of Mediterranean and Black Sea climates. While winter months are not very cold, the summer months are not dry. The average yearly temperature for the city is about 14°C. The average yearly precipitation is about 730 mm and it occurs mainly in winter and spring months.

Based on the meteorological data obtained from the Bursa Airport field, the prevalent wind direction was determined to be NE and it was 13.2% of the total number of winds (Bursa BŞB, 2000). In general, northerly winds were more prevalent than southerly winds. This is important because industrial complexes are located in the northern part of Bursa, and northerly winds may carry the pollutants from the industrial areas to the city. One reason for the prevalence of northerly winds is the location of Bursa, because it is on the southern foot of Mount Uludağ. Average monthly wind speeds, which were classified based on 16 different wind directions, varied between 0.2 and 5.3 m/s (Bursa BŞB, 2000).

Meteorological data

Meteorological measurements in Bursa are made at the Airport field by Devlet Meteoroloji İşleri Müdürlüğü. However, this place is far from (about 15 km) the point where we collected our samples. There are many high-rise buildings and hills between the airport and the place where the measurements were obtained. This results in big fluctuations in wind velocities as well as wind directions obtained from both places. Therefore, it is not suitable to use meteorological values obtained from the Bursa Airport in relation to the data gathered from the city center of Bursa. Yet an overview of meteorological characteristics of Bursa is mentioned above.

Results and Discussion

With a population of over one million, Bursa is one of the most crowded cities in Turkey. The city is located in the northwest of Anatolia and it is surrounded by mountains, which have strong effects on atmospheric dispersion. Bursa has heavy industry consisting of automotive, textile, and food industries. Due to insufficient ventilation and high population and industrial densities, Bursa has a potential for serious air pollution problems.

Table 3 summarizes some SO_2 values given for urban areas. The values reported for Bursa were determined from the yearly (12-month) averages of 1996 and 1997. The values for Bursa are higher than for most of the other cities listed in Table 3. The sampling place is probably one of the reasons because it is located in a highly polluted district with limited opportunities for dispersion of pollutants due to high buildings. Therefore, in general an average concentration for Bursa would be lower than the value presented in Table 3.

Table 3. Ambient Air Concentrations for Some Urban Areas

Place	Concentration (μg/m^3)	Reference	Duration
Polluted air	56-560^a	Seinfeld, 1986	N.A.
City (Population: 1000000)	69	Goudie, 1986	N.A.
Industrialized region, Canada	14	Henry and Heinke, 1996	AAM
Industrialized region, Canada	1226 (max)	Henry and Heinke, 1996	1h
İstanbul, Turkey	86	Bayar, 1997	AAM-1996
Ankara, Turkey	40	Bayar, 1997	AAM-1996
İskenderun, Turkey	44	Örnektekin, 1997	AAM-1996
İzmir, Turkey	74	Elbir et al., 2000	AAM-1996
Bursa, Turkey	110	Taşdemir et al., 1998	AAM-1996
Bursa, Turkey	126 (except September)	Taşdemir et al., 1999	AAM-1997
Copenhagen, Denmark	39	Elsom, 1992	AAM-1984
Zagreb, Yugoslavia	80	WHO, Geneva	AAM-1984
Calcutta, India	54	Elsom, 1992	AAM-1984
Shenyang, China	219	Elsom, 1992	AAM-1984
Sydney, Australia	40	Bennett et al., 1985	1976-1980
Tokyo, Japan	53	Bennett et al., 1985	1976-1980
Pittsburgh, USA	73	U.S. EPA, 1990	AAM-1988

^{a}: Concentrations are reported in ppb and they are converted to μg/m^3 using 5°C and 1 atm.
AAM: Annual arithmetic mean.
N.A.: Not available.

The sulfur dioxide measurements studied in this article are for three months: January, February and March. These three months were chosen because the residential heating is observed at high levels in these months and they are consecutively ordered. The sulfur dioxide (SO_2) values for three months during 1996, 1997 and 1998 ranged from 120 to 260 μg/m^3 with an average of 189.5 ± 48.3 μg/m^3. Three-year averages for January, February and March were 220 ± 57.9, 195.7 ± 31.9, and 146.9 ± 44.4 μg/m^3, respectively. While January had the highest, March had the lowest SO_2 average concentration value. This is directly related to the ambient temperature and the amount of fuel used. Since January is colder than the other two months, the level of sulfur-containing fuel consumption is expected to be higher and as a result average SO_2 concentration is the highest. Table 4 illustrates the winter average values for other cities in Turkey.

Diurnal variations of average hourly SO_2 concentrations for Uludağ University campus did not follow the same pattern as the Bursa city center. The concentration level was almost steady after midnight until about 8:00 a.m. There was a sharp concentration increase between 8:00 a.m. and 10:00 a.m. Then, there was a continuous decrease in the concentration due to an increase in the air temperature during the afternoon hours. One possible reason for the concentration decrease in the evening hours is the shutdown of the university's heating system. There are some residence buildings for faculty members on the campus, but these appeared not to influence the quality of the campus atmosphere. Otherwise, there would be an increase in the concentration levels during the evening hours as seen in the city data.

The sampling place, located in the center of Bursa, had SO_2 background due to transportation, commercial and industrial activities taking place inside and around the city. This background level could be determined when there was no residential heating. Therefore, summer season measurements were used in the determination of this background level. The summer season SO_2 concentration average was as low as 34% of the winter season SO_2 concentration for the Bursa city center. This percentage suggests that most of the SO_2 pollution in winter was due to residential heating.

Table 4. Ambient Air Concentrations of Winter Season for Some Places in Turkey

City	Concentration (μg/m^3)	Reference	Duration
İstanbul	140	Bayar, 1997	Jan, Feb, March-1996
Ankara	70	Bayar, 1997	Jan, Feb, March-1996
Bursa	190	This study	Jan, Feb, March-1996-97-98
İzmir	150	Tuncel, 1995	Winter, 1990-95
Antalya	52	Tuncel, 1995	Winter, 1990-95
Adana	45	Tuncel, 1995	Winter, 1990-95
Sivas	297	Tuncel, 1995	Winter, 1990-95
Ordu	40	Tuncel, 1995	Winter, 1990-95
Tunceli	28	Tuncel, 1995	Winter, 1990-95
Erzurum	323	Tuncel, 1995	Winter, 1990-95

Diurnal fluctuations of average hourly SO_2 concentrations for winter season are demonstrated in Figure 2. The sulfur dioxide (SO_2) concentration difference between the city center of Bursa and Uludağ University campus is significant. After midnight, the concentration level tends to decrease and the minimum concentration level is reached at about 6:00 a.m. On the other hand, the maximum concentration occurs around 11:00 a.m. This is a reasonable pattern for the winter period because heating begins during the early morning hours and proceeds with an increasing rate till noon. The heating rate decreases due to the increase in ambient air temperature during the afternoon hours. This pattern is followed by another increase in the concentration levels of SO_2 between 6:00 p.m. and 10:00 p.m. when people arrive home. Moreover, unequal cooling rates of the earth and the air above the earth may cause fewer dispersion problems. This is a nocturnal phenomena and it may break up with the rays of the morning sun (Peavy et al., 1985).

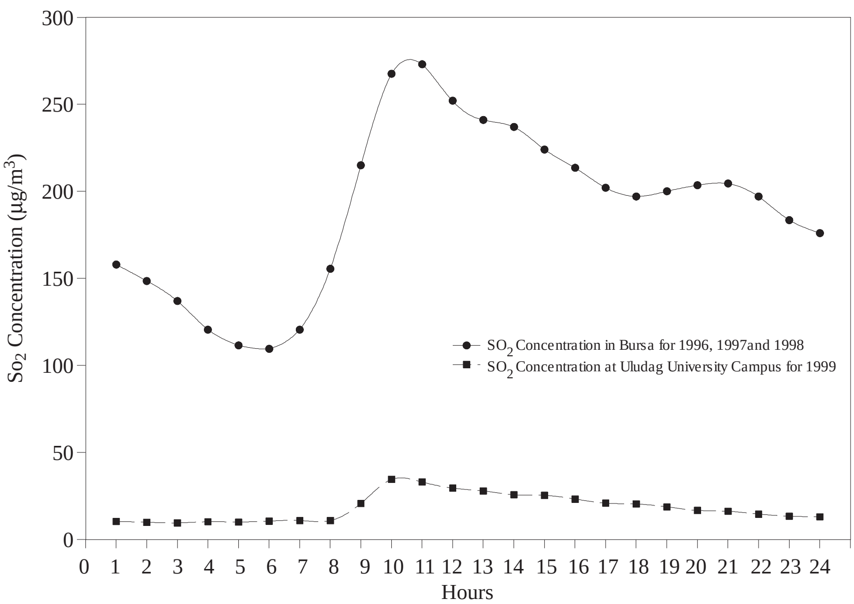

Figure 2. Average Daily SO_2 Concentration Fluctuations in Bursa and on Uludağ University Campus.

A comparison between Tables 3 and 4 shows the differences between the winter season and annual averages of some cities. This difference in SO_2 concentrations probably indicates the effects of fuels used for heating. In Turkey, sulfur-containing fuels are generally used for residential heating, except in some cities that had air pollution problems previously. Therefore, when the temperature gets colder, the SO_2 concentration in the atmosphere increases. For example, as shown in Table 4, Erzurum and Sivas, having very cold winter seasons, have much higher SO_2 concentration levels than Antalya and Adana, located in southern Anatolia, which has a very mild winter season. Since the winter temperature in Bursa is between these two cases, the measured SO_2 concentrations for Bursa are between the values of these two cases.

If sulfur-containing fuels are used for residential heating in a place, high SO_2 concentrations in the atmosphere are to be expected during the winter season with increasing populations in the city. For instance, Ordu and Tunceli have the smallest populations of all the cities listed in Table 4, and they have the lowest SO_2 concentrations. However, other factors such as the type and amount of fuel used, industrial and commercial activities, topographic and climatologic conditions are also important factors for SO_2 concentrations. For example, even though İstanbul and Ankara have the highest populations they have reasonably low SO_2 values. This is mainly due to the type of fuel used, which is natural gas. Therefore, authorities not only in Bursa but also in other cities, such as Erzurum and Sivas, should encourage the use of natural gas.

Table 2 shows some limits for ambient SO_2 concentrations. Based on the Turkish AQPR, the values given for the long-and short-term limits (LTL and STL) of SO_2 are 150 and 400 $\mu g/m^3$, respectively. The average of winter season SO_2 concentrations determined for Bursa has exceeded the LTL, even though the LTL set by the Turkish AQPR is higher by a factor of up to 3 compared to other limits suggested by the USA, Canada and WHO given in Table 2. Data gathered by Tuncel (1995) showed that between the years 1990 and 1995, Bursa had an average winter SO_2 concentration of 198 $\mu g/m^3$, which is in agreement with the values found in this study. Tuncel (1995) has determined that the daily average SO_2 concentrations of Bursa exceeded the STL of the Turkish AQPR 119 times during this period. Based on the results presented in this study and by Tuncel (1995), the winter SO_2 concentrations for Bursa violated both LTL and STL.

Table 5 demonstrates the ambient air concentrations reported for non-urban areas. The values presented for this study were collected from the Uludağ University campus, which could be considered a semi-rural area. The average measured SO_2 value is smaller than the values suggested by the U.S. EPA, Ontario (Canada) and WHO Guidelines.

Table 5. Ambient Air Concentrations for Some Non-Urban Areas

Place	Concentration ($\mu g/m^3$)	Reference	Duration
Clean troposphere	2.8-28^a	Seinfeld, 1986	N.A.
Rural region, Canada	213 (max)	Henry and Heinke, 1996	1 h
Uludağ University, Turkey	18	This study	Jan-March 1999
Non-urban	10	Goudie, 1986	N.A.
Town (Population: 10000)	18	Goudie, 1986	N.A.
Mount Uludağ, Turkey	16^a	Tuncel et al., 1996	1993-94

^{a}: Concentrations are reported in ppb and they are converted to $\mu g/m^3$ using 5°C and 1 atm.
N.A.: Not available.

Sulfur dioxide concentration measurements were evaluated half hourly and the gathered data were used to determine daily and monthly averages. Three months (January, February and March) were considered because these months were the coldest months of the year, with maximum space heating requirements. The calculated average SO_2 concentration for 1999 is 18.1 $\pm$ 7.9 $\mu g/m^3$ for these three months. The calculated average agreed well with the values given in Table 5. The non-urban area SO_2 concentration reported by Goudie (1986) was smaller than that reported in the present study. One reason for this difference might be the closeness of the campus to residential areas. Therefore, the campus may receive some SO_2 residuals transported from residential areas by wind. Another reason might be the season, because this study was done during the winter when the highest possible SO_2 concentrations are expected in the atmosphere. On the other hand, Gouide's (1986) values are yearly averages and they are expected to be lower than the winter season measurements. Yet, when the ambient air has a concentration between 2 and 28 $\mu g/m^3$, it is already defined as 'clean air' in the troposphere according to Seinfeld (1986).

The average SO_2 concentration determined on the Uludağ University campus was very low compared to the average concentration determined in the Bursa city center. The difference was about 10 times. The main reason for this concentration fluctuation is the sulfur emissions into the atmosphere. The sulfur dioxide (SO_2) sources for the campus air are probably the heating units and atmospheric transport from the residential places near the campus. Unlike the campus, Bursa has significantly high numbers of SO_2 sources contributing high amounts of emissions.

Another reason for the concentration difference between Bursa and the campus may be the ventilation or dispersion effects. The dilution of air pollutants in Bursa may be smaller than that on the Uludağ University campus. The rougher surface reduces the wind velocity inside valleys and subsidences. Buildings in downtown Bursa may cause a powerful frictional drag on air moving over and around them. The average speed of the winds is lower in built-up areas than in rural areas, and for higher wind speeds (>1.5 m/s) this difference is more than two times (Gouide, 1986). While the campus is free from the effects of high mountains, high buildings or other objects, the measurement location in Bursa has quite limited air circulation. Therefore, the dispersion is thought to decrease the SO_2 concentration level in the campus.

Conclusions

1. The average of SO_2 measurements for the years 1996, 1997 and 1998 from Bursa was about 189.5 ± 48.3 $\mu g/m^3$. The average value of SO_2 measurements for the Uludağ University campus was 18.1 ± 7.9 $\mu g/m^3$ in 1999.

2. The average concentrations for both places were comparable to the other places cited in the literature.

3. The average values of SO_2 concentrations decreased from January to March for both places. This is mainly due to an increase in ambient temperatures.

4. Diurnal fluctuations of the average hourly SO_2 concentration levels showed a close relationship with the ambient air temperature changes. The peak SO_2 concentrations for both places occurred before the noon hours when heating had started.

5. The average of winter season SO_2 concentrations determined for Bursa exceeded the long-term limit (LTL) of Turkish air quality regulations, which is 150 $\mu g/m^3$. However, the average SO_2 concentration level on the campus was much lower than the LTL value.

6. The average SO_2 concentration determined on the Uludağ University campus was about 10 times lower than the average concentration determined in the city of Bursa. The main reason for this difference was the sulfur emission sources. Another reason is thought to be the dispersion effects, which were very limited in the city center where high buildings and hills exist.

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