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Evaluation of Dry Deposition Fluxes of Atmospheric Particulate Matters Observed in Denizli, Turkey in Winter and Spring

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Abstract **–** The particulate matters in ambient air were sampled in Denizli, Turkey in winter and spring using Bergerhoff Method. The average dry deposition fluxes were calculated as 152.1 ± 30.7 mg m^{-2} day^{-1} and 333.9 ± 214.2 mg m^{-2} day^{-1} in spring and winter, respectively. The minimum dry deposition flux was observed as 115.4 mg m^{-2} day^{-1} on May 4-6, 2015 period, while the maximum flux was determined as 733.3 mg m^{-2} day^{-1} on November 7-9, 2016. No significant relation was observed between the dry deposition fluxes and the values of the temperature and the wind speed. It has been determined that the dry deposition fluxes in winter were approximately twice of the fluxes in spring. It can be said that the concentrations of particulate matters sourced from domestic heating in winter have higher concentrations than spring.

Keywords – Air pollution, ambient air, Bergerhoff method, dry deposition, flux, particulate matter

I. Introduction

Dry deposition is the transport of gaseous and particulate species from the atmosphere onto surfaces in the absence of precipitation. The factors that govern the dry deposition of a gaseous species or a particle are the level of atmospheric turbulence, the chemical properties of the depositing species, and the nature of the surface itself. The level of turbulence in the atmosphere, especially in the layer nearest the ground, governs the rate at which species are delivered down to the surface. For gases, solubility and chemical reactivity may affect uptake at the surface. For particles, size, density, and shape may determine whether capture by the surface occurs. The surface itself is a factor in dry deposition. A nonreactive surface may not permit absorption or adsorption of certain gases; a smooth surface may lead to particle bounce-off. Natural surfaces, such as vegetation, whereas highly variable and often difficult to describe theoretically, generally promote dry deposition [1].

Dry deposition and wet deposition are the ultimate paths by which particulate matters and trace gases are removed from the atmosphere.

The relative importance of dry deposition, as compared with wet deposition, for removal of a particular species depends on the following factors; whether the substance is present in the gaseous or particulate form; the solubility of the species in water; the amount of precipitation in the region; the terrain and type of surface cover [1].

Particulate matter (PM) is a pollutant of great environmental concern due to its association with increased mortality (from non-accidental and cause-specific diseases). There have been numerous efforts to demonstrate a strong relationship between mortality and particulate matters. PM is also known to exert significant effects on the alteration of the earth's radiative balance. However, the mechanism and the extent of such an association still remain unknown for further investigation [2].

The process of dry deposition of gases and particles is generally represented as consisting of three steps:

1. Aerodynamic transport down through the atmospheric surface layer to a very thin layer of stagnant air just adjacent to the surface
2. Molecular (for gases) or Brownian (for particles) transport across this thin stagnant layer of air, called the quasi-laminar sub layer, to the surface itself
3. Uptake at the surface [1].

In this study, dry deposition of particulate matters in ambient air was determined using Bergerhoff Method at two different seasons in Denizli, Turkey. The sampling periods were April 2015-May 2015 and November 2016-December 2016. Particulate matter analyses of dry deposition samples were performed at the laboratory and dry deposition fluxes were calculated. The data of dry deposition fluxes were compared with the data of PM_{10} concentrations. Statistical relations between dry deposition fluxes and meteorological parameters were investigated.

II. Materials and Method

A. Dry Deposition Sampling

Denizli has dense population, advanced industrialization, and heavy traffic. Therefore air pollution problems can be occurred as well as the other environmental problems in Denizli.

Dry deposition samplings were carried out at Pamukkale University, Kinikli Campus (37.44 N, 29.06 E) in Denizli, Turkey.

Dry deposition sampling site is an urban area under the effect of residential heating in winter and has moderate traffic (Fig. 1).

The samplings were performed at two different periods:
- Spring, between April 2015 and May 2015
- Winter, between November 2016 and December 2016

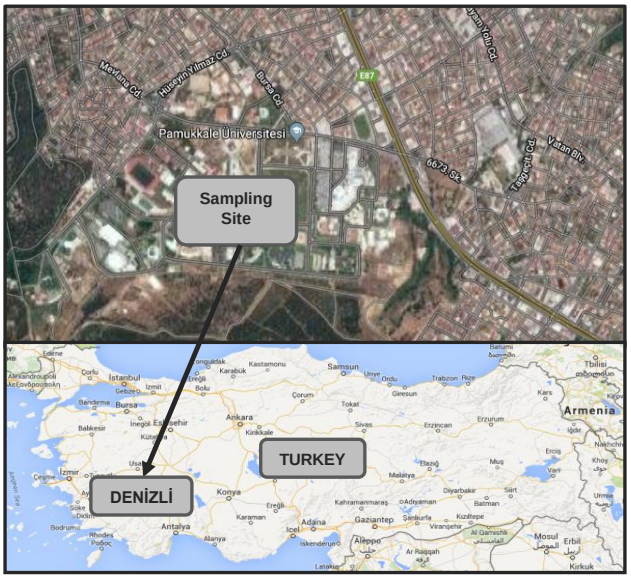

Fig. 1 The location of sampling station in Denizli, Turkey

B. Dry Deposition Sampling Method

Dry deposition sampling of particulate matters was performed using Bergerhoff Method.

The sampler was transparent, polyethylene and cylindrical. Dimensions of the sampler were 13 cm of diameter and 26 cm of height. It was set at a stand approximately 0.5 m high from ground level.

The samplers and laboratory materials were washed with 1:1 HNO_3 acid, then rinsed with tap water and deionized water and dried prior to use. The same procedure was replicate using 1:1 HCl acid [3].

Ultra-pure water of 500 mL was put to the sampler. The sampler was hold on throughout 2 days. At the end of the sampling, dry deposition samples were transferred to cleaned sample storage containers and brought to the laboratory.

C. Particulate Matter Analyses of Dry Deposition Samples

Analyses of particulate matters were made at the Research Laboratory of Environmental Engineering Department, Pamukkale University. The volumes of the samples were measured and recorded. The amount of total suspended solids (TSS) and the amount of total dissolved solids (TDS) were added to each other to determine the total solid matter in the sample.

To analyse suspended solids, the conditioned 0.45 µm cellulose acetate filters (Sartorius) were weighed with analytical balance. The deposition samples of 50 mL were filtered by filtration apparatus. The filter was put to the oven at 103-105 ^{0}C for one hour. Then the filter was cooled for half an hour in the desiccator and weighed with the analytical balance.

TSS value was calculated by the following formula:

$$TSS\ (mg\ L^{-1}) = \frac{A-B}{V} \qquad (1)$$

A: Weight of the filter paper and the residue (mg)
B: Weight of the clean filter paper (mg)
V: Volume of sample (L)

To measure total dissolved solids, a clean evaporating dish was conditioned and weighed with analytical balance. After the sample has been filtered, the filtrate was transferred to the evaporating dish and weighed with analytical balance. The filtrate was put to the oven at 103-105 ^{0}C for one hour. Then it was cooled for half an hour in the desiccator and weighed with the analytical balance.

TDS value was calculated as follows:

$$TDS\ (mg\ L^{-1}) = \frac{A-B}{V} \qquad (2)$$

A: Weight of the evaporating dish and the residue (mg)
B: Weight of the clean porcelain evaporating dish (mg)
V: Volume of sample (L)

D. Calculation of Dry Deposition Fluxes

Dry deposition fluxes of the samples were calculated by the following formula:

$$F\ (mg\ m^{-2}\ day^{-1}) = \frac{m}{A \times T} \qquad (3)$$

m: Mass of total solid matter (mg)
A: Surface area of the sampler (m^2)
T: Sampling time (day)

E. Quality Control

Field and laboratory blanks were collected along with the dry deposition samples to determine the contaminants occurred during the sampling, handling, and filtration steps. Particulate matter analyses of these samples were also performed.

F. Statistical Analysis

Statistical analysis of the data was performed using Microsoft Excel program. Statistical relations were determined at the $p < 0.01$ level.

III. Results

A. Dry Deposition Fluxes

The average dry deposition fluxes of particulate matters in spring and winter were determined as 152.1 ± 30.7 mg m^{-2} day^{-1} and 333.9 ± 214.2 mg m^{-2} day^{-1}, respectively.

The minimum dry deposition flux was observed as 115.4 mg m^{-2} day^{-1} on May 4-6, 2015 period, while the maximum flux was determined as 733.3 mg m^{-2} day^{-1} on November 7-9, 2016 throughout the entire sampling period.

In spring, the minimum and maximum fluxes were observed as 115.4 mg m^{-2} day^{-1} in May 4-6, 2015 and 200.0 mg m^{-2} day^{-1} in May 14-16, 2015, respectively (Table 1).

Table 1. Dry deposition fluxes of particulate matters in spring in Denizli, Turkey

Sampling Period	Flux (mg m^{-2} day^{-1})
12-14.04.2015	123.1
27-29.04.2015	176.9
02-04.05.2015	153.8
04-06.05.2015	115.4
06-08.05.2015	184.6
12-14.05.2015	161.5
14-16.05.2015	200.0
16-18.05.2015	130.8
18-20.05.2015	123.1

In winter, the minimum flux was determined as 116.2 mg m^{-2} day^{-1} in November 19-21, 2016, while the maximum flux

was observed as 733.3 mg m^{-2} day^{-1} in November 7-9, 2016 (Table 2).

Dry deposition fluxes seen in spring were close to each other, while the fluxes observed in winter were different from each other (Fig. 2).

Table 2. Dry deposition fluxes of particulate matters in winter in Denizli, Turkey

Sampling Period	Flux (mg m^{-2} day^{-1})
02-04.11.2016	200.0
07-09.11.2016	733.3
17-19.11.2016	155.6
19-21.11.2016	116.2
21-23.11.2016	400.0
23-25.11.2016	177.8
05-07.12.2016	533.3
07-09.12.2016	488.9
14-16.12.2016	200.0

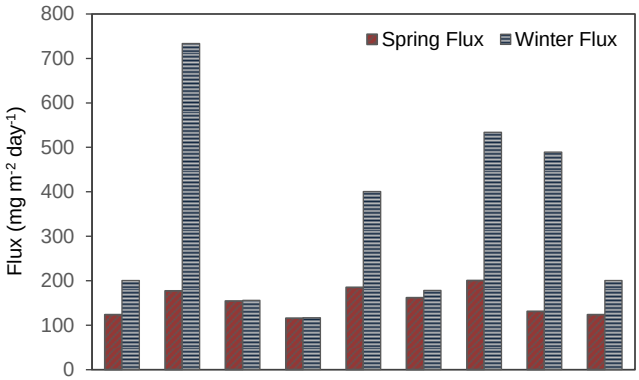

Fig. 2 Comparison of dry deposition fluxes of particulate matters in spring and winter in Denizli, Turkey

B. *Dry Deposition Fluxes and PM_{10} Concentrations*

PM_{10} concentrations and daily dry deposition fluxes related to each sampling period were investigated in terms of interpretation the pollution level of particulate matter. PM_{10} concentrations were obtained from the Air Pollution Measurement Station, Republic of Turkey Ministry of Environment and Urbanization.

The average PM_{10} concentrations in spring and winter were determined as 76.2 ± 14.2 mg m^{-3} and 149.2 ± 40.6 mg m^{-3}, respectively.

No significant relations were observed between the dry deposition fluxes and PM_{10} concentrations during the sampling periods (Fig. 3, Fig. 4).

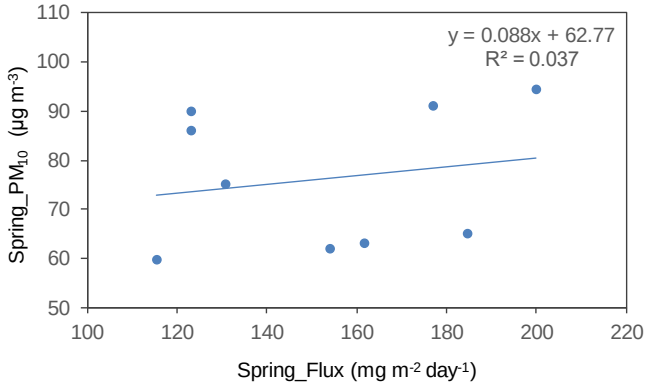

Fig. 3 Statistical relation between dry deposition fluxes and the PM_{10} concentrations in spring

C. *Dry Deposition Fluxes and Meteorological Parameters*

Temperature and wind speed values were provided from the General Directorate of Meteorology, Republic of Turkey Ministry of Forestry and Water Management.

The average temperature values in spring and winter were determined as 20.4 ± 3.6 ^{0}C and 12.4 ± 2.5 ^{0}C, respectively.

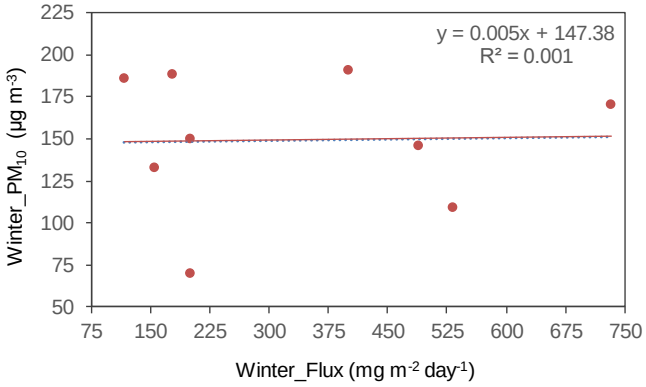

Fig. 4 Statistical relation between dry deposition fluxes and the PM_{10} concentrations in winter

The average wind speed value was observed as 1.4 ± 0.2 m s^{-1} in spring, while the average wind speed was determined as 3.3 ± 1.3 m s^{-1} in winter.

The minimum temperature was observed as 13.3 ^{0}C in April 12-14, 2015, while the maximum temperature was determined as 24.8 ^{0}C in May 18-20, 2015 during the sampling period in spring.

The minimum and maximum wind speeds were 1.2 m s^{-1} in May 16-18, 2015 and 1.8 m s^{-1} in April 27-29, 2015, respectively.

During the sampling period in winter, the minimum and maximum temperatures were determined as 9 ^{0}C in December 14-16, 2016 and 17.0 ^{0}C in November 2-4, 2016, respectively.

The minimum wind speed was 2.1 m s^{-1} in November 23-25, 2016, while the maximum wind speed was 5.8 m s^{-1} in November 7-9, 2016.

The significant statistical relation was not determined between the dry deposition fluxes and the values of the temperature and wind speed during the sampling period in spring (Fig. 5). In winter, no significant relation was observed between the dry deposition fluxes and the values of the temperature and the wind speed (Fig. 6).

IV. DISCUSSION

The dry deposition flux values in Denizli, Turkey were ranged from 115.4 to 733.3 mg m^{-2} day^{-1} during the sampling periods. It has been observed that the dry deposition fluxes in winter were approximately twice of the fluxes in spring. Likewise, the PM_{10} values in winter were about twice as high as the PM_{10} values in spring.

High dry precipitation flux values were also determined in studies performed in different regions. The flux values at Uludag University, Bursa, Turkey by Bergerhoff Method were ranged from 300 to 7860 mg m^{-2} day^{-1} the period of April to June 2001. The daytime flux values (3078 ± 2412 mg m^{-2} day^{-1}) were more than six times the value for night time (524 ± 149 mg m^{-2} day^{-1}) [4].

Dust samples were collected at monthly intervals from three different sites (commercial, residential, and control) of the Jharia coal mining area, India. The yearly average dust

fall was higher for the commercial site (15.5 t km^{-2} month^{-1}) than the residential site (10.7 t km^{-2} month^{-1}) of Jharia coal mining area. The dust deposition rate was highest during summer (March-June), followed by winter (October-February) and lowest in the monsoon season (July-September) [5].

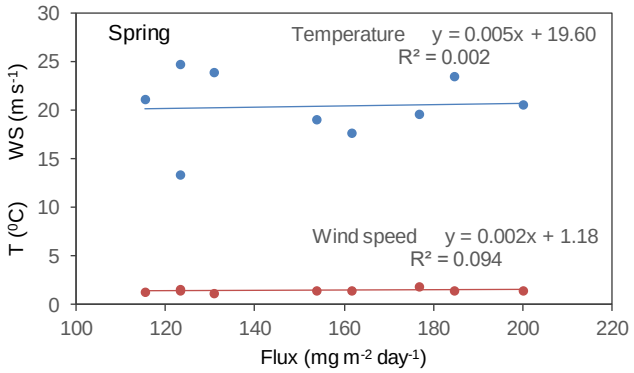

Fig. 5 Statistical relations between dry deposition fluxes and the values of temperature and wind speed in spring

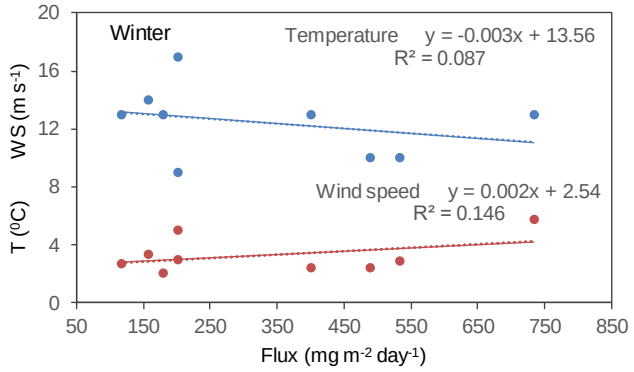

Fig. 6 Statistical relations between dry deposition fluxes and the values of temperature and wind speed in winter

V. CONCLUSION

The higher flux values were observed in winter than in spring in Denizli, Turkey at two sampling periods; April 2015-May 2015 and November 2016-December 2016. The winter season is the season in which fuels for heating start to be used. It can be said that the higher concentrations of particulate matters sourced from domestic heating in winter. This is supported by the higher concentrations of PM_{10} in winter.

The data obtained in this study indicate that dry deposition of particulate matters is important in Denizli. Therefore, effects of dry deposition on environments should be investigated in the future.

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