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ARTICLES

CHARACTERISING SEASONAL VARIATIONS AND SPATIAL DISTRIBUTION OF AMBIENT $PM_{2.5}$ CONCENTRATION BASED ON SHORT-TERM MONITORING IN DARKHAN CITY

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Abstract: *The purpose of this study was to survey the seasonal variation of fine particulate matter ($PM_{2.5}$) concentration and determine spatial distribution in Darkhan city. Air pollution research and reports have been few and far between in most of parts in Mongolia, especially in Darkhan with respect to quantitative aerosol particle concentration. In this study, we utilized "$PM_{2.5}$sensor" to measure spatial and seasonal variation of particulate matter concentrations in the study area. The monitoring points were chosen by basing on their specific features and set up directly at ambience outdoor. In each season, we carried out measurement at 3 points, which covered the ger district and apartment district areas for one day. Whereas, at one point the ger district was sampled for 4 days in summer. Fine particulate matter concentrations were the highest in the ger district area because there are many households that use coal for their daily heating and cooking, and at the bared surface. As for seasonal variation, in winter pollution reached 400 times higher than other seasons. Furthermore, at the ger district area, $PM_{2.5}$ concentration was as much as 20 times greater than other points and it was observed that this too had its impact on the apartment district as well. As regards the air quality index, the level of particulate matter in the ger district area is extremely unhealthy to hazardous in winter. While, good and moderate indexes were mostly identified at monitoring points during the springtime.*

Keywords: *$PM_{2.5}$; seasonal variation; spatial distribution; air quality index, Darkhan city;*

INTRODUCTION

Air pollution has become a grave problem that requires serious attention because of its harmful impact on human health and environmental quality. A large number of epidemiological studies have shown that air pollution has adverse affects on human health[1,2].
Fine particulate matter ($PM_{2.5}$, particles smaller than 2.5 m in aerodynamic diameter) has been associated with a variety of adverse health effects, including visibility reduction, as well as changes in the Earth's radiation balance. Fine PM may be formed directly from a primary source, such as, motor vehicles, industrial facilities, biomass burning, or indirectly through the conversion of gaseous emissions in to the atmosphere from anthropogenic or

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Vol. 58 No 03 (227) 2018
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https://www.mongoliajol.info/index.php/PMAS

natural sources. As a result, fine atmospheric particles are complex mixtures of primary components (e.g., soot, water, vapor, and dust) and secondary components (i.e., sulfate, nitrate, ammonium, and organic matter). This complexity in composition presents both challenges and opportunities in regard to understanding aerosol physical–chemical processes and elucidating sources of ambient particles[1, 3, and 4].

Despite recent improvements in air quality in large parts of the world, poor air quality remains a challenge in many urban areas worldwide. The World Health Organization's (WHO) International Agency for Research on Cancer (IARC) has recently identified outdoor air pollution as a major cancer agent on a global scale[5], indicating that health impacts due to exposure to air pollution are still of widespread concern. Air pollution can affect the respiratory, cardiovascular, cardiopulmonary and reproductive systems and lead to cancer [5, 6, 7, 8, and 9]. Controlling air pollution not only directly reduces adverse health effects, but also increases general well-being, quality of life, improves public health and can have positive impact on ecosystem services.

Peri-urban *ger* areas are low-income, largely informal settlements on the outskirts of cities where people live in *gers* - traditional Mongolian portable round felt tents, also known as the yurt, and/or in simple terms, detached houses. Basic infrastructure services in these settlements, such as piped water, sanitation, proper roads, public transportation, etc., are poor or non-existent. The unplanned growth of *ger* areas along with the unprecedented pace of urbanization have brought with them many challenges, such as unemployment, traffic congestion, air pollution and adverse environmental impacts[10]. In Ulaanbaatar, the capital of Mongolia, today, more than 60% of the population live in the peri-urban *ger* areas. However, the percentage of *ger* residents is also very high (about 50%) in secondary cities such as Darkhan, Erdenet and Khovd.

Darkhan is one of the largest 3 cities and covers a territory of 103 sq. km. It is situated in the north-central part of the country at an elevation of about 650-700 meters above sea level in the Kharaa River basin. The city was founded in 1961 and as of 2017, it had a population of 84.2 thousand. The climate in Darkhan is strongly influenced by the extreme continental and prevailing north-westerly winds. Darkhan is in a semi-arid zone with an annual temperature of -1.1°C. It has an annual precipitation of approximately 380 mm a year. Administratively it borders with Selenge aimag only. It is 200-220 km north of Ulaanbaatar [11, 12].The pollution is at its severest in winter, when an estimated more than 3,648 *gers* fire their stoves overtime to offset the frigid outdoor temperatures that can dip as low as 40 degrees below zero - where Fahrenheit and Celsius overlap. In addition to generating heat, the *ger* stoves spew a hazardous type of pollution called particulate matter (PM) in the form of soot. Other sources, such as coal-fired power plants and vehicles, also contribute to the city's pollution problem [13].

The purpose of this study was to survey the seasonal characterization of fine particulate matter ($PM_{2.5}$) in Darkhan city. For this purpose, we set the following objectives.

1. To measure the $PM_{2.5}$ concentration for a day each season, and,
2. To determine seasonal and spatial difference of $PM_{2.5}$ concentration in outdoor air ambient.

MATERIALS AND METHODS

The study area is Darkhan, a highly industrialized province, which is one of the largest cities of Mongolia. The city is located at the intersection of the Ulaanbaatar-Altanbulag roadway and the Ulaanbaatar Railway line. The city is divided into 2 new and old Darkhan, where the apartments districts are surrounded by the *ger* districts. The industrial

Vol. 58 No 03 (227) 2018
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https://www.mongoliajol.info/index.php/PMAS

facilities are situated in the southern part of the city. Each season we chose 3 points that can represent the special features of the settlement zones. Briefly, the *ger* district area was chosen for the main air polluting source, while the apartment districts were chosen to determine the difference with the source point. Study area with monitoring points are shown in Figure 1. Fine particle was collected with a "$PM_{2.5}$ sensor" which measures the concentration of ambience $PM_{2.5}$ every 10 seconds and whereby then=8640 data for the day are derived from $PM_{2.5}$ sensor. 52mm x 45mm x 22mm $PM_{2.5}$ Sensor has been invented and developed by the Panasonic Corporation and Nagoya University of Japan. $PM_{2.5}$ concentration was determined by dispersing the mass distribution, and expressing fine particle size directly to μg/m³[14].

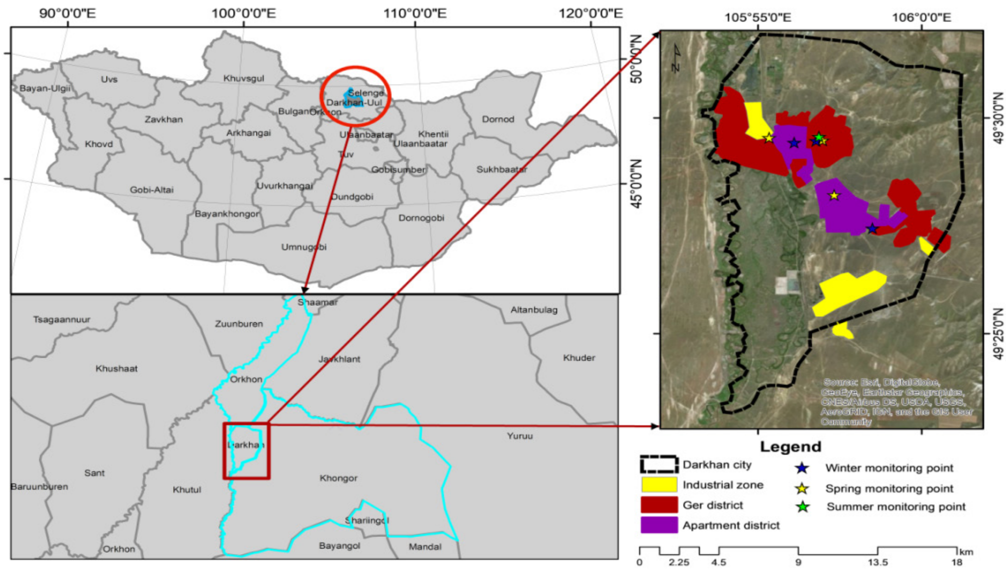

Figure 1. Location of Monitoring Points

Measurement: $PM_{2.5}$ samples were carried out at 3 points for one whole day in the winter and spring of 2018. In addition, for 4 days in summer we carried out measurements at the point where the pollution level was very during the previous seasons.

Measurement data (15 minutes on an average) were compared with the MNS 4585:2016 national standard and the results were based on comparing the data to each site and each season. Air pollution level is shown by a chart with the relevant air quality index for every two hours in as much as the air quality index changes during the course of an entire day depending on human activities.

This study data was processed using analytical research method. In 2018, analytical researches were carried out on 27-28 January, 7-8 April, and 1-5 June respectively.

Vol. 58 No 03 (227) 2018
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https://www.mongoliajol.info/index.php/PMAS

Table 1. Study point and duration

№	Name of monitoring point	Frequency	Date	Duration (hour)	Type of settlement area
1	*Ger* district area	3	27- 28 January 7- 8 April 1- 5 June	24 24 96	*Ger* district
2	Central Hospital of Darkhan (CHD)	2	27- 28 January 7- 8 April	24 24	Apartment district
3	Micro block	1	27-28 January	24	Apartment district
4	Dreven district	1	7- 8 April	24	*Ger* district

RESULTS

Winter measurements were carried out in the ger district area, the Central Hospital of Darkhan city and the Micro-block, and the measurement data are shown in figures 2, 3, 4 and 5.

In figure 2, the $PM_{2.5}$ level exceeds (greater than 2-20 times) the MNS 4585:2016 air quality standard for one day, despite the fact that the measurement was carried out between 4 am and 6 pm. Diurnal average concentration was 215 µg/m^3.

At the Central Hospital of Darkhan city (figure 3), measured data are higher than MNS 4585:2016 during some periods (from 03:00 to 05:00 hours and from 07:00 to 11:00 hours) while figure is lower than the standard for the day at the Micro-block district (figure 4).

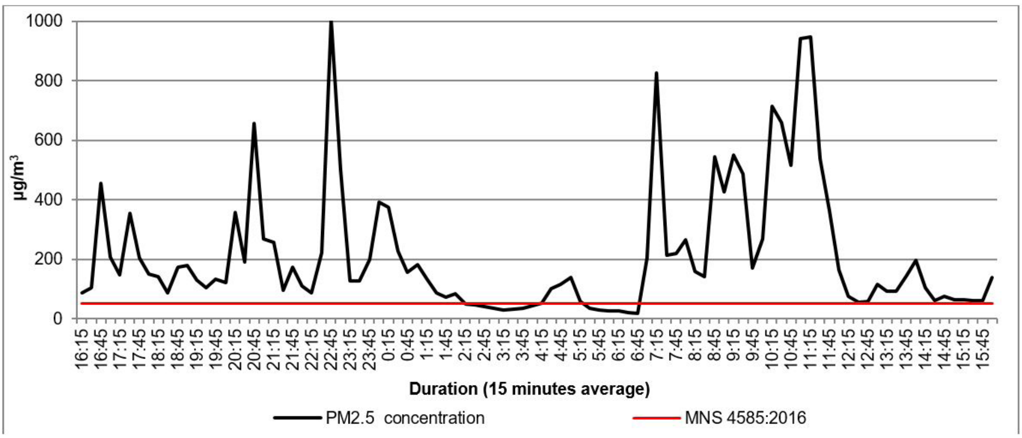

Figure 2. $PM_{2.5}$ measurement in the ger district area in winter

PMAS
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https://www.mongoliajol.info/index.php/PMAS

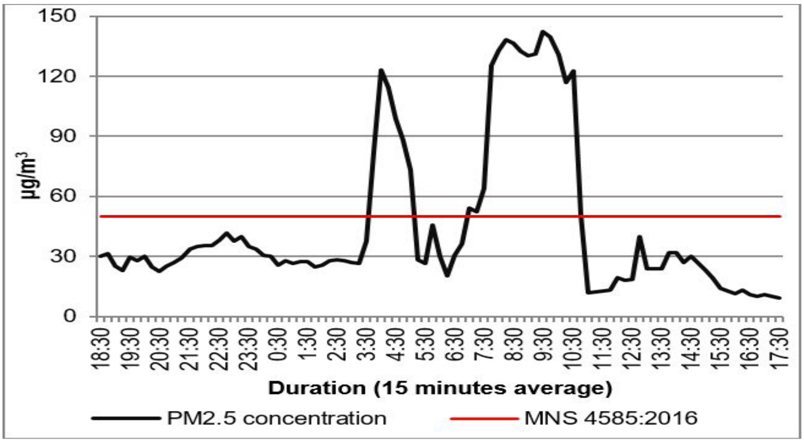

Figure 3. $PM_{2.5}$ measurement at CHD in winter

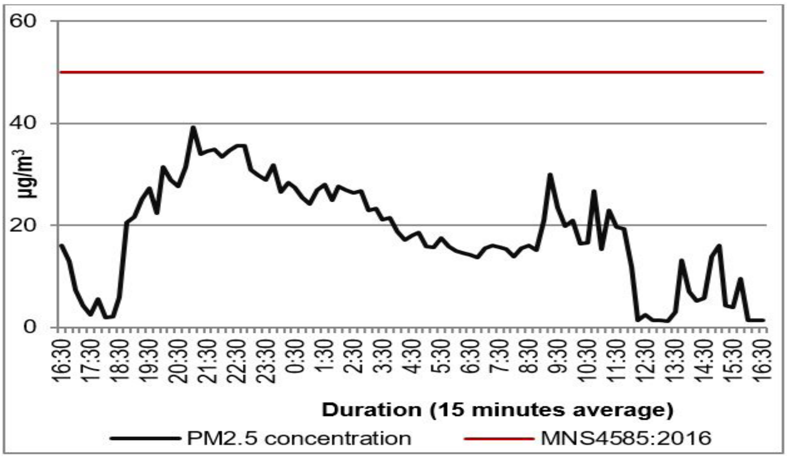

Figure 4. $PM_{2.5}$ measurement at Micro-block in winter

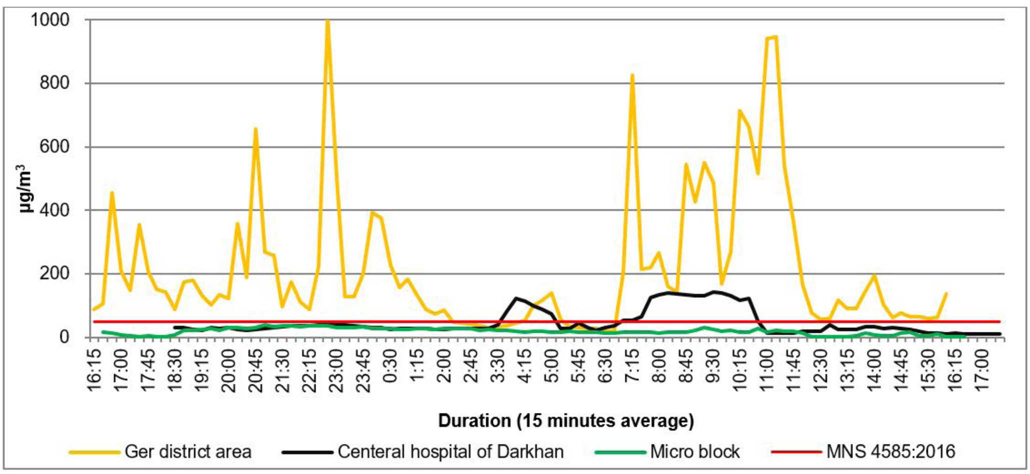

Figure 5. Comparative result of the winter season

Vol. 58 No 03 (227) 2018
DOI: https://doi.org/10.5564/pmas.v58i3.1031
https://www.mongoliajol.info/index.php/PMAS

The above figure shows the $PM_{2.5}$ concentration at each monitoring point. In the ger district area, the $PM_{2.5}$ concentration is higher than in other points because there are many households that use coal for their daily heating and cooking.

Spring measurements were carried out in the ger district area, Central Hospital of Darkhan city and Dreven district. Measurement data are shown in figures 6, 7, 8 and 9.

In figure 6, the $PM_{2.5}$ level is 2-3 times more than the MNS 4585:2016 air quality standard from 6 pm. to 11 pm. Conversely, pollution level during other periods is lower than the air quality standard. The daily average concentration was 28 µg/m^3. Upward trends were observed from 18:00 to 23:00 hours and from 06:00 to 11:00 hours.

At Central Hospital of Darkhan city and Dreven district areas, the daily average concentration is in approximate value (15µg/m^3 in figure 7 and 20µg/m^3 in figure 8), furthermore, the peak of pollution was observed between 19:00 hours and midnight, whereas, pollution exceeding the air quality standard occurred only between 18:45 and 19:00 hours at these sites.

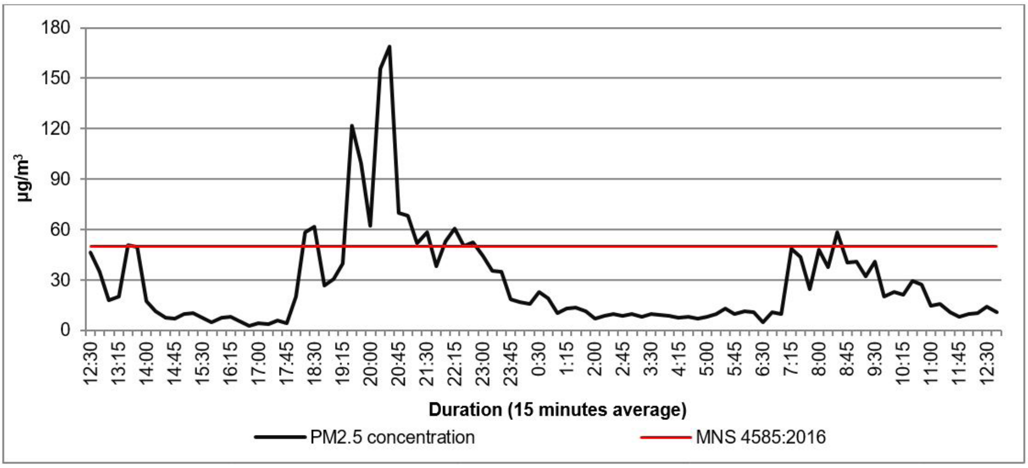

Figure 6. $PM_{2.5}$ measurement at ger district area in spring

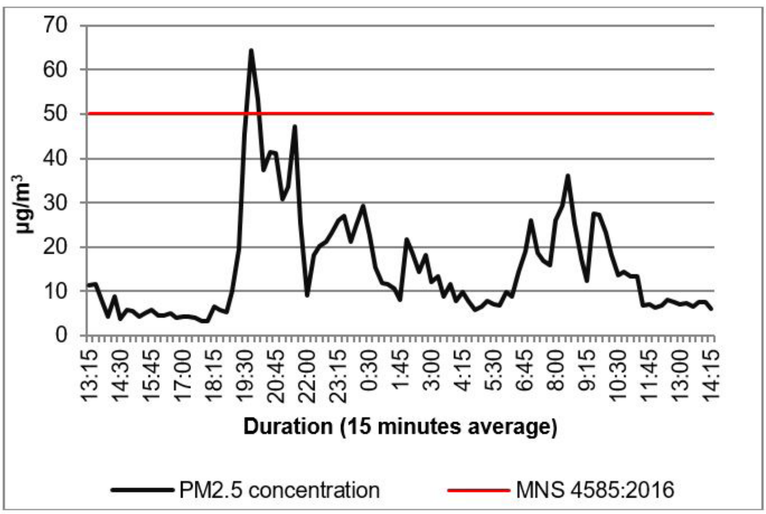

Figure 7. $PM_{2.5}$ measurement at CHD in spring

PMAS
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https://www.mongoliajol.info/index.php/PMAS

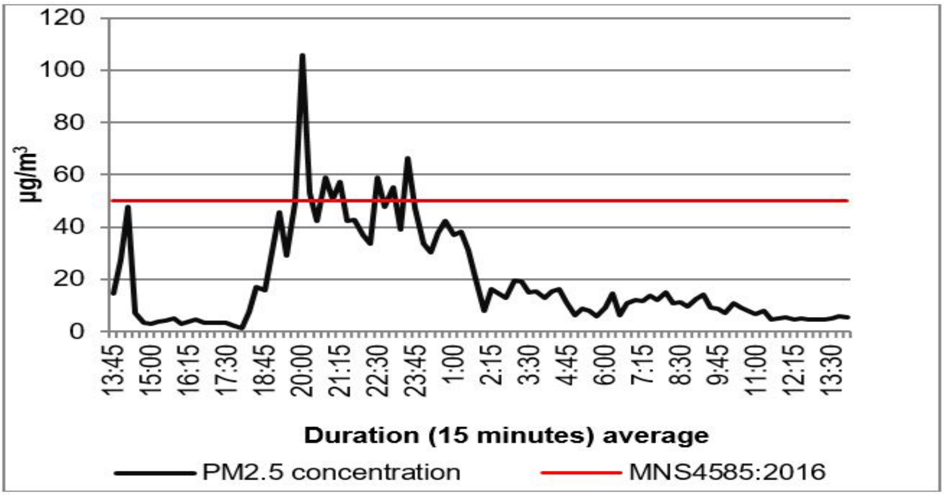

Figure 8. $PM_{2.5}$ measurement at Dreven district in spring

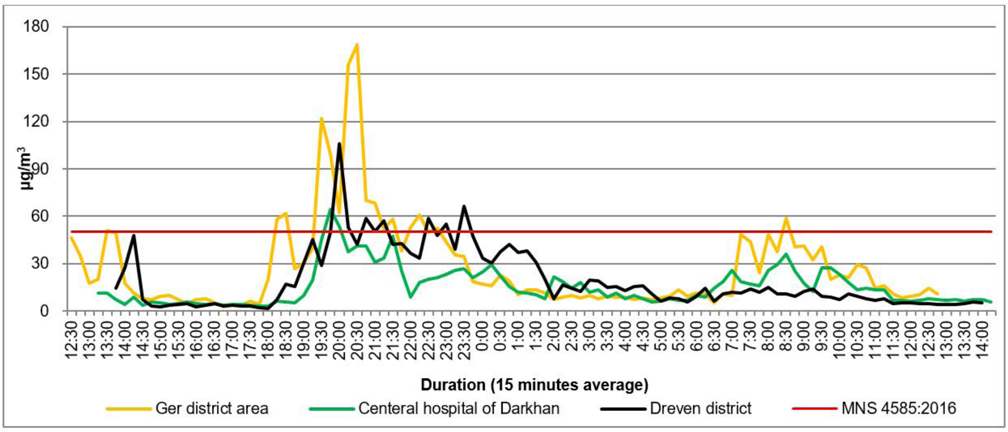

Figure 9. Comparative result of the spring season

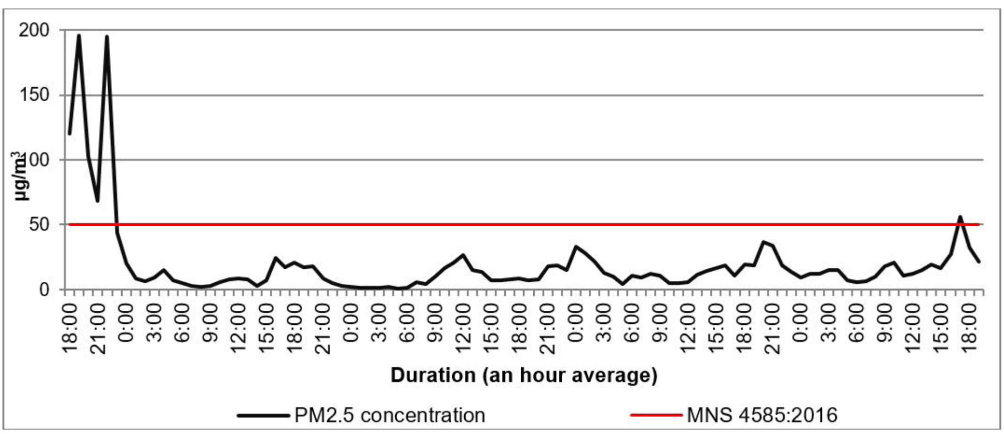

Figure 10. $PM_{2.5}$ measurement at ger district in summer (for 4 days)

Vol. 58 No 03 (227) 2018
DOI: https://doi.org/10.5564/pmas.v58i3.1031
https://www.mongoliajol.info/index.php/PMAS

A glance at the above graph shows that the measurement value exceeds the air quality standard from 1800 hours to11 p.m. at each monitoring point. However, measured values are relatively different at each point, but the fluctuationpatterns are similar. For instance, there was an increase in the $PM_{2.5}$ concentration between 18:00 and 01:00 hours, and from 7 to 9 am.

$PM_{2.5}$ measurement for 4 days are given in figure 10. On 1 June, 2018, it was windy and there was a high level of surface dust and consequently, the $PM_{2.5}$ value was higher than during the other days as well as the MNS 4585:2016 national standard.

Figure 11 shows the seasonal variability at the ger district area monitoring point, which shows that the level ofpollution becomes 400 times higher in winter than in the other seasons. In addition, the maximum level of $PM_{2.5}$ concentration was 1006 μg/m^3 while it was 169 μg/m^3 in spring. Whereas, 53 μg/m^3 is the maximum level in summertime. In short, as the temperature grows warmer, $PM_{2.5}$ concentration decreases in ambient air. This means that fossil fuel and other burning materials, which are used as a source for heating in the *ger* district areas are the main pollution sources in the city of Darkhan, whereas, high speed wind blowing over barren and dry surface raises soot in the warm seasons.

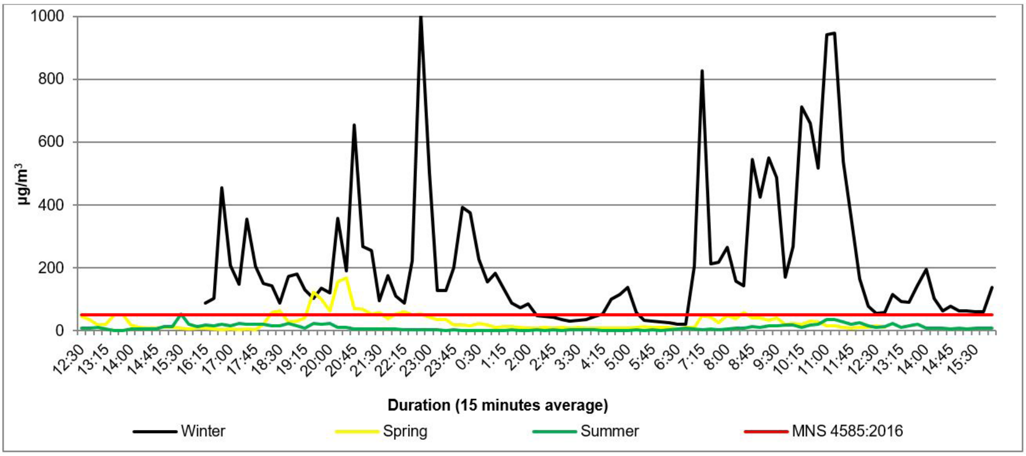

Figure 11. Comparative seasonal result at the ger district monitoring point

Air quality indices assessment

The Minister of Environment and Tourism on 1 March 2001 passed a Ministerial Order No. A/53, under which the "General Procedure on Air Quality Indices and Reporting," was approved under Appendix 1, the "Method of reporting Air Quality Index through Media" was adopted as Appendix 2 and on "The Impact of Pollutants in the Air on Human Health and Methodology of Giving Health Advice" was approved under Appendix 3.

The Air Quality Index is a quantitative data comparing the current concentration of environmental pollutants in the atmosphere to the limits specified in its standards. The Air Quality Index is comprised of five major pollutants. These include: sulfur dioxide (SO_2), nitrogen dioxide (NO_2), less than 10 μm particulate (PM_{10}) and less than 2.5 μm particulate ($PM_{2.5}$), carbon monoxide (CO)[15, 16].

Air Quality Index Classification and Assessment: Air Quality Index is calculated from a range of 0-500 to 6 chapters and shows the air quality level and human health impacts for each category.

Vol. 58 No 03 (227) 2018
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https://www.mongoliajol.info/index.php/PMAS

Numerical values	Air Quality Index levels of health concern
0-50	Good
51-100	Moderate
101-250	Unhealthy for sensitive groups
251-400	Unhealthy
401-500	Very unhealthy
501+	Hazardous

Table 2. Indication of air quality by index

Duration Date		16-18	18-20	20-22	22-00	00-02	02-04	04-06	06-08	08-10	10-12	12-14	14-16	16-18
27-28 January	*Ger* district area	428	268	496	666	330	78	138	448	686	1012	208	158	
	CHD		56	58	74	54	96	126	128	270	90	52	40	22
	Micro-Block	14	40	66	64	54	46	34	30	40	38	8	14	
08-09 April		12-14	14-16	16-18	18-20	20-22	22-00	00-02	02-04	04-06	06-08	08-10	10-12	12-14
	Ger district area	68	16	14	126	166	78	28	18	18	50	74	36	
	CHD	18	10	8	52	66	46	32	26	16	36	50	24	
	Dreven district		28	6	76	96	100	62	32	20	24	20	14	10

CONCLUSIONS

The following conclusions are being made from the study carried out into the seasonal characterization of $PM_{2.5}$ in Darkhan city. These include:

The study shows that the air is relatively highly polluted between 07:00 and 11:00 hours in the morning, and between 18:00 and 22:00 hours in the evening owing to people's lifestyles.

$PM_{2.5}$ in the ger area in winter is relatively high. In terms of heating, households in the ger area primarily depend on fossil fuel. Consequently, pollution from the ger district area effects other settlement areas in the city with a specific pattern.

As for the Air Quality Index, the level of particulate matter in the ger areas is from very unhealthy to hazardous in the winter, while good and moderate indices are mostly present at monitoring points in the springtime.

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