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ORIGINAL PAPER

Air pollution levels and $PM_{2.5}$ concentrations in Khovd and Ulaanbaatar cities of Mongolia

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Abstract

Ulaanbaatar, the capital of Mongolia, is one of the world's leading cities in terms of air pollution. However, due to a lack of detailed research on air pollution in other urban settlements of Mongolia, they might be more polluted than Ulaanbaatar city. Thus, Khovd city, known as an urbanized center in the Western region of Mongolia, has been chosen as one of our study sites besides Ulaanbaatar. The purpose of the study was to compare the $PM_{2.5}$ concentrations of these two cities. We focused on the $PM_{2.5}$ concentration levels of Ulaanbaatar city from 2017 to 2020 and the $PM_{2.5}$ of Khovd city in 2020. The study results show that the $PM_{2.5}$ concentrations of Ulaanbaatar have been declining since 2018. However, the $PM_{2.5}$ of Ulaanbaatar from January through March 2020 was 129 ± 57, 71.1 ± 32.9 and 33.1 ± 12.4 µg/m^3, respectively. Meanwhile, the $PM_{2.5}$ concentrations of Khovd from January to March 2020 were 175.6 ± 59 µg/m^3, 101.2 ± 47.3 µg/m^3 and 20.8 ± 18.9 µg/m^3 respectively. $PM_{2.5}$ of Khovd city has a lower concentration than Ulaanbaatar in the semi-heating and non-heating periods while Khovd has a higher concentration and longer duration of pollution than Ulaanbaatar in the heating season. The firing hours of ger areas coincide with the increase of $PM_{2.5}$ concentrations in Khovd and further research is necessary to identify other contributing factors. Our study results also suggest that there is an urgent need to implement a national program to reduce air pollution in Khovd city.

Keywords Khovd city · Ulaanbaatar city · $PM_{2.5}$ · Comparison

Introduction

The concentration and composition of $PM_{2.5}$ or less than $PM_{2.5}$, one of the air pollutants, can be toxic and can impact human health (Brunekreef and Holgate 2002). $PM_{2.5}$ has numerous adverse effects such as cardiovascular disease, chronic pulmonary disease, oxidative stress, pneumonia (Miller and Xu 2018; Dominici et al. 2006; Feng et al. 2016) and the birth effect (Shang et al. 2019). According to the US study, long-term exposure to ambient $PM_{2.5}$ is associated with increased risks of adult mortality (Franklin et al. 2008). In 2019, the average concentration of $PM_{2.5}$ was 62 µg/m^3; Mongolia ranked third in the world for air pollution after Bangladesh and Pakistan (IQAir. 2020). These countries belong to the developing countries of Asia, and a recent study shows that developing countries are more prone to air pollution than developed countries (Shisong et al. 2018).

Ulaanbaatar city is located in a valley with mountains to the north and south (Kottek et al. 2006). The topography, extensive pollution emissions and frequent temperature inversions have combined to cause high concentrations of $PM_{2.5}$ in the winter months (Allen et al. 2013). The population growth caused mainly by rural to urban migration has led to the expansion of air pollution in the capital of Mongolia. The population in the early 1960s was 150,000, but it increased rapidly after democratization reached 580,000 i n the 1990s and was recently reported to have exceeded 1.5 million (Mongolian statistical information service 2021).

Another contributing factor to increasing air pollution is a temperature inversion, frequently observed in mountainous urban areas and can cause severe air pollution problems, especially in wintertime (Ganbat and Baik 2016; Hou and Wu 2016). The study showed that the impact of coal

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combustion particles was high in winter, particularly condensed particles composed of organic carbon used by the PMF model. However, the impact of soil dust on the source of $PM_{2.5}$ was dominant in the autumn and spring (APRD JICA, 2017). The result of coal-burning used for heating in the winter season accounts for a considerable proportion (60–70%) of air pollutant emissions of Ulaanbaatar (World Bank Sustainable and Alternative Energy Program 2009). As reported by a 2013 analysis, ambient $PM_{2.5}$ provided 29% of cardiopulmonary deaths, 40% of lung cancer deaths and nearly 10% of all-cause mortality in Ulaanbaatar (Allen et al. 2013). The government of Mongolia has accomplished enormous actions to reduce air pollution in the last 13 years. One of the recent actions had banned the usage of raw coal in the capital city starting from 15 May 2019 (Minister of Nature, Environment and Tourism & Governor of the Capital City and the Mayor of Ulaanbaatar 2019). However, Khovd city, another study area, is still using raw coal.

Khovd city covers landscapes of the Great Lake Basin in the northeast, and it has a sheltered, extremely continental and dry climate. In winter, extensive temperature inversions involving warm air mass in lower mountain regions superimpose above cold air mass in the plains, leading to relatively warm conditions on the winter pastures at approx. 2000 m a.s.l (Zemmrich 2008). In 2019, more than 90,000 people lived in Khovd province, and 30,000 of them lived in Khovd city. In the city, there are 5200 households, and many organizations have low-pressure stoves that use raw coal (Mongolian statistical information service, 2021).

Ulaanbaatar city is a cultural, economic and political center of Mongolia. Likewise, Khovd is the central city of the western region of Mongolia. As mentioned earlier, there are several similarities between Ulaanbaatar and Khovd cities. Although several studies have been conducted on air pollution in Ulaanbaatar, there is a lack of research on air quality in other cities of Mongolia. Therefore, we aimed to compare the concentration of $PM_{2.5}$ in Ulaanbaatar city and Khovd city. The overall objectives of the present study are (i) an analysis of $PM_{2.5}$ variation in Ulaanbaatar in recent years; (ii) a comparison of $PM_{2.5}$ of Ulaanbaatar and Khovd cities in 2021; (iii) factors affecting $PM_{2.5}$ in Khovd city and approaches to reduce the concentration.

Materials and methods

Study area

The study area is located at NUM (106°55′6.30"E, 47°55′25.41"N) in the central part of Ulaanbaatar and at KhU (91°38′41.33"E, 48° 0′10.16"N) in central part of Khovd city. Both cities lie in a valley surrounded by mountain slopes. Sampling was conducted at Ulaanbaatar and Khovd cities (Fig. 1).

Study instrument

The National University of Mongolia (NUM) was selected as the one of the study areas for the PM2.5 sensor to measure PM2.5 in Ulaanbaatar in 2017. The other one is at Khovd University (KhU), and its measurement data have been collected since 2020. To measure $PM_{2.5}$, we used sensors of Panasonic model GA1 with a thermal resistor to induce an internal upward air flow to facilitate continuous sampling. This sensor unit has an accuracy of ± 10% from low to high concentrations (~ 1,000 μg/m^3) (Motlagh et al. 2020), and its average flow rate in the detection region was estimated to be 65 mm/sec (Nakayama et al. 2018). Briefly, the particle size distribution was estimated by measuring the scattering intensities of single particles. The output of the $PM_{2.5}$ sensors was calibrated using nearly monodisperse polystyrene latex (PSL) particles (Ly et al. 2018). One of the main features of light-scattering particles relates to their low power consumption (Cheng et al. 2014; Chowdhury et al. 2018). The sensor devices are also equipped with a Wi-Fi module and mobile phone connectivity for data logging and visualization.

Methods

Sampling

Over the last four years, the PM2.5 concentration data had collected every 10-s interval through the PM2.5 sensor. Data consists of 120, 92 and 151 data points (daily average of $PM_{2.5}$ concentration) from every heating season, semi-heating season and non-heating season, respectively. Monthly data of temperature and the wind speed were obtained from the web of University of Wyoming (University of Wyoming 2021).

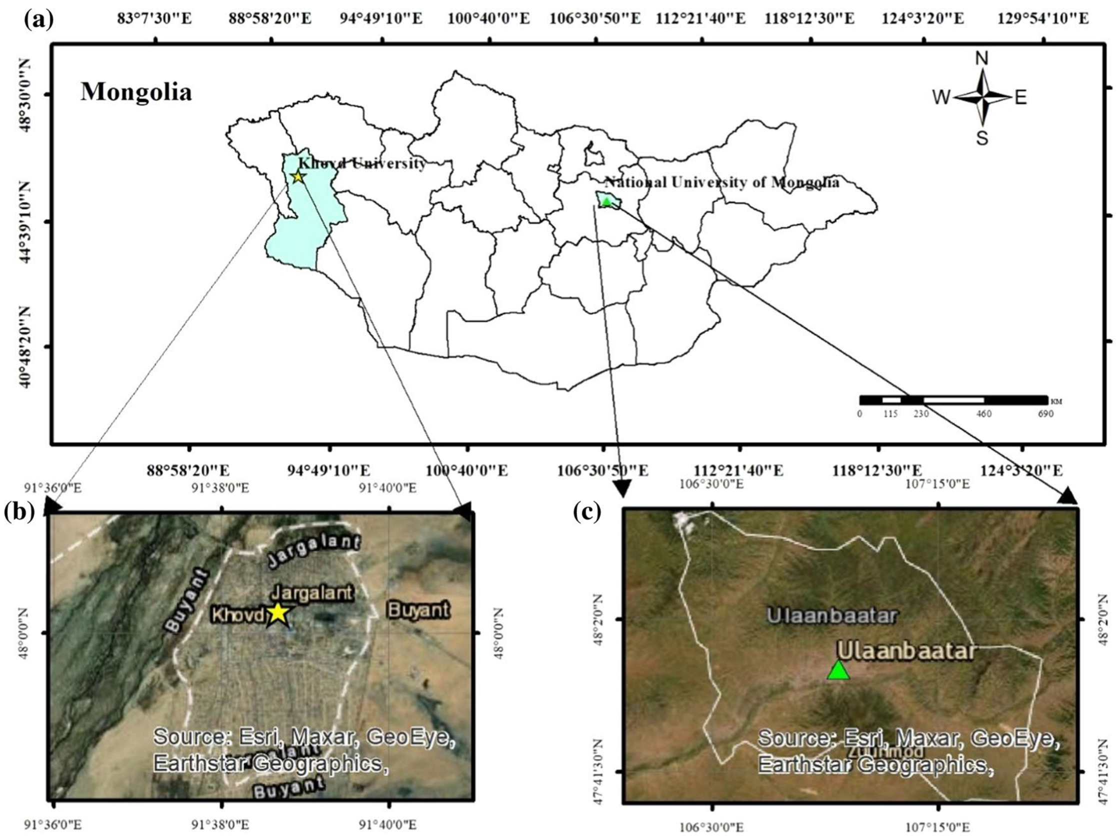

Fig. 1 **a** Location of Khovd and Ulaanbaatar, Mongolia. **b** Air quality monitoring site in Khovd. **c** Air quality monitoring site in Ulaanbaatar

Table 1 AQI levels and associated health impacts

AQI categories (index values)	Breakpoints from the PM2.5 (µg/m3) 24-h	AQI value actions to protect your health
Good (Up to 50)	0.0 – 12.0	None
Moderate (51—100)	12.1 – 35.4	Unusually sensitive people should consider reducing prolonged or heavy exertion
Unhealthy for Sensitive Groups (101—150)	35.5 – 55.4	People with heart or lung disease, older adults, children and people of lower socioeconomic status should reduce prolonged or heavy exertion
Unhealthy (151—200)	55.5—150.4	People with heart or lung disease, older adults, children and people of lower socioeconomic status should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion
Very Unhealthy (201—300)	150.5—250.4	People with heart or lung disease, older adults, children and people of lower socioeconomic status should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion
Hazardous (301—400)	250.5—350.4	Everyone should avoid all physical activity outdoors; people with heart or lung disease, older adults, children and people of lower socioeconomic status should remain indoors and keep activity levels low
Hazardous (401—500)	− 500.4	

Statistical analyses

Firstly, the R program which is free software environment for statistical computing, and graphics supported by the R Foundation for Statistical Computing was used to analyze the data. Also, we calculated the number of long-term data using OriginLab, scientific graphing and analysis software, in this study.

For this study, the following equation was used to construct the air quality index (AQI) of $PM_{2.5}$ (U.S. Environmental Protection Agency 2018). The values of the break points for the AQI function below are given in Table 1.

$$Ip = \frac{IHi - IL}{BPHi - BPLo}(Cp{-}BPLo) + ILo \quad (1)$$

where Ip = the index for pollutant p. Cp = the truncated concentration of pollutant p or P pollutant of concentration. BP_{Hi} = the concentration breakpoint that is greater than or equal to Cp. BP_{Lo} = the concentration breakpoint that is less than or equal to Cp. I_{Hi} = the AQI value corresponding to BP_{Hi}. I_{Lo} = the AQI value corresponding to BP_{Lo}.

Results and discussion

Results

An analysis of $PM_{2.5}$ in Ulaanbaatar from 2017 to 2020

We divided the PM2.5 monitoring period into; heating period, semi-heating period and non-heating period. Heating period, semi-heating period and non-heating period cover between November and February, September and October, and March–April and May–August, respectively. Long-term PM2.5 concentration, air temperature and wind speed values between 2017 and 2020 are given in Fig. 2. In 2017, January, the coldest month of the year, monthly average $PM_{2.5}$ concentration was 162 μg/m^3, with an average temperature of –25 °C and the wind speed of 2.1 m/s. In January of 2018, 2019 and 2020, PM2.5 concentration reached 88.5, 181.4, 88.9 μg/m3, whereas the average temperature was –26.4, –21.7 and –21.8 °C, and the wind speed was 2.4, 2.7 and 1.7 m/s, respectively. On the other hand, July, the warmest period of the year, had monthly average PM2.5 concentration 11 times higher than that of January in 2017, and the average air temperature and wind speed were 20.4 °C and 5.7 m/s, respectively. Whereas July 2018 had a $PM_{2.5}$ concentration of 11.9 μg/m^3, its average temperature was 16.7 °C and the wind speed was 4.9 m/s.

As can be seen from Fig. 2, the measurement of $PM_{2.5}$ was illustrated from January 2017 to December 2020, as well as the temperature and wind speed for those periods. In 2017, in the coldest month, January, monthly average $PM_{2.5}$ concentration was 162 μg/m^3 with an average temperature of -25 °C and the wind speed of 2.1 m/s. In January of 2018, 2019 and 2020, the concentrations of $PM_{2.5}$ were 88.5, 181.4 and 88.9 μg/m^3, average temperatures were -26.4, -21.7 and -21.8 °C and the wind speed was 2.4, 2.7 and 1.7 m/s, respectively. However, in the hottest month, July 2017, monthly average $PM_{2.5}$ concentration was 14.4 μg/m^3 with an average temperature of 20.4 °C and the wind speed of 5.7 m/s, whereas July 2018 had a $PM_{2.5}$ concentration of 11.9 μg/m^3, its average temperature was 16.7 °C and the wind speed was 4.9 m/s. Moreover, in July 2019, the $PM_{2.5}$ concentration was 11.8 μg/m^3 with an average temperature of 18.9 °C and the wind speed of 5.3 m/s. Data collected for July 2020 show a very similar figure to that of July 2019, which had a monthly average $PM_{2.5}$ concentration of 9.3 μg/m^3 with an average temperature of 18.2 °C and the wind speed was 5.1 m/s. According to the chart, the regularity of the temperature and wind speed was approximately equal during study periods, while the $PM_{2.5}$ concentration increased sharply which was 144.1 μg/m^3 during the heating season of 2018–2019. However, concentrations of $PM_{2.5}$ were relatively low in the heating season of 2020. Figures 3, 4 and 5show a boxplot of $PM_{2.5}$ concentration and calculated AQI conveyed as a percentage of each season.

According to Fig. 3, the $PM_{2.5}$ concentration during the heating season was 115 ± 55 μg/m^3 in 2017, 125 ± 70 μg/m^3 in 2018, 107 ± 70 μg/m^3 in 2019 and 59 ± 29 μg / m^3

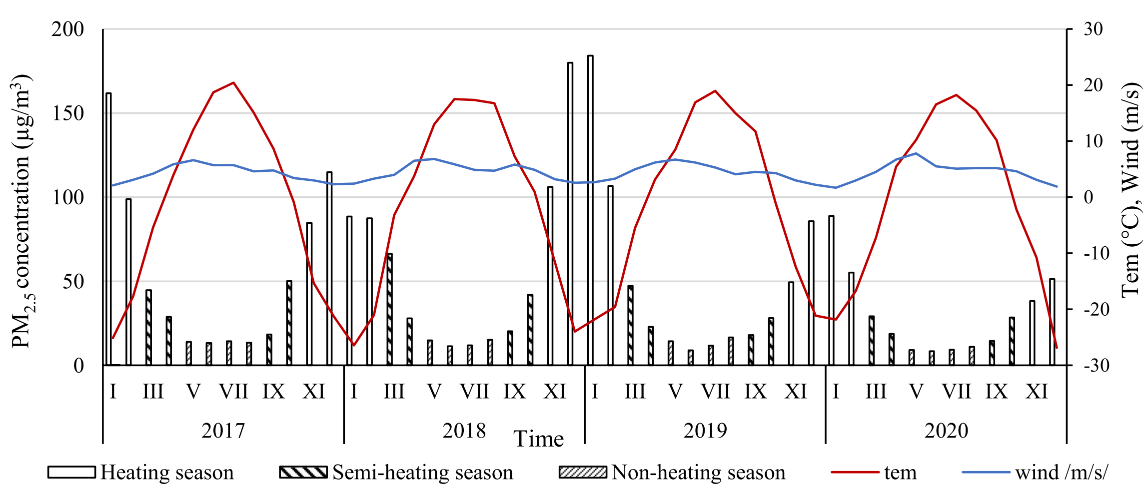

Fig. 2 The monthly average $PM_{2.5}$ concentration in Ulaanbaatar between 2017 and 2020

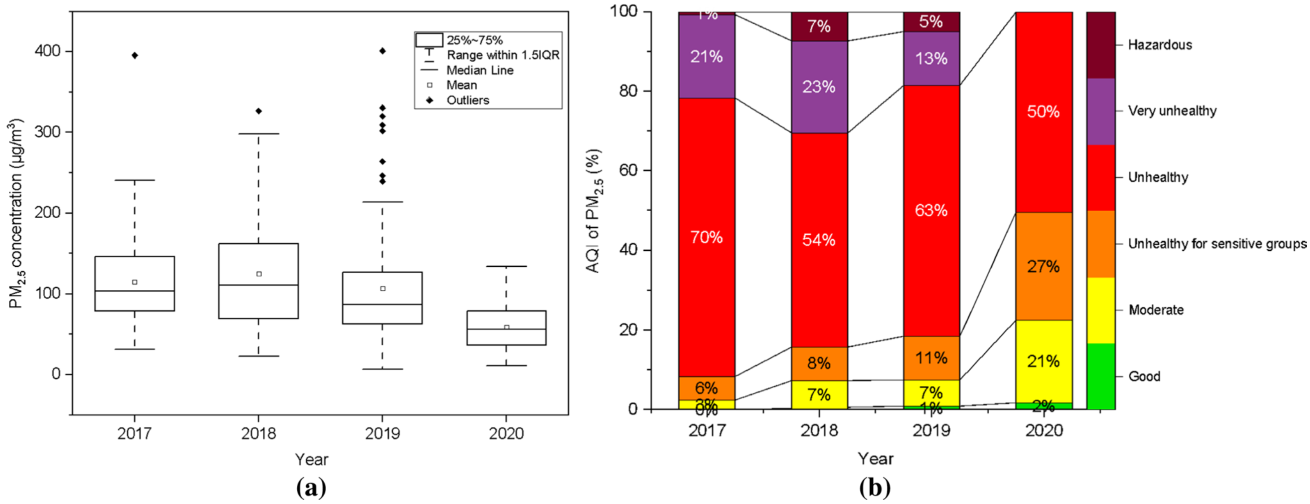

Fig. 3 **a** Boxplot of $PM_{2.5}$ concentration during the heating season; **b** AQI of $PM_{2.5}$ in the heating season

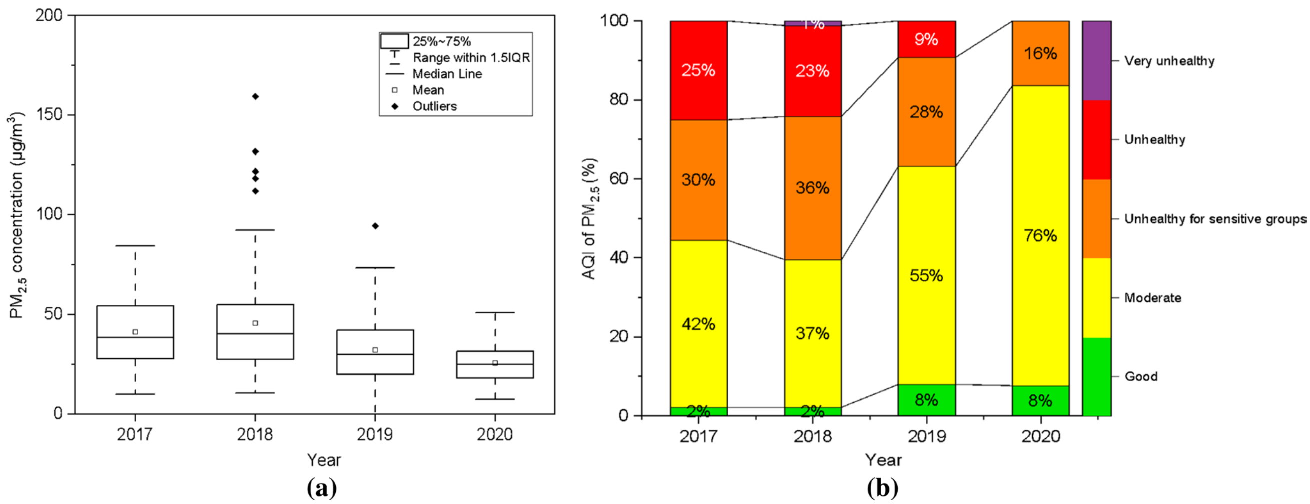

Fig. 4 **a** Boxplot of $PM_{2.5}$ concentration during the semi-heating season; **b** AQI of $PM_{2.5}$ in the semi-heating season

in 2020. In the last four years until 2020, $PM_{2.5}$ was a high level in the heating season of 2018, and in 2020 it was the lowest. During the study period, the maximum concentration was 401 μg/m^3 in 2019, and the lowest concentration was 6.7 μg/m^3 in 2019. However, the AQI of $PM_{2.5}$ was 2%, 21% and 27%, 51% in "good", "moderate" and "unhealthy for sensitive groups" and "unhealthy", respectively, during the heating period of 2020. Nevertheless, in the 2017 heating season, 3% were "moderate", 6% were "unhealthy for sensitive groups", 70% were "unhealthy", 21% were "very unhealthy", and 1% were "hazardous".

Figure 4 illustrates a distribution of numerical data, skewness and an average of $PM_{2.5}$ for the semi-heating season from 2017 to 2020. The maximum value was in the 2018 semi-heating season and was 45.6 ± 27.8 μg/m^3, and the minimum value was in 2020 and was 25.6 ± 9.9 μg/m^3. In the semi-heating season of 2018, 1% of AQI was in the "very unhealthy" category, while this category was not in 2020. The calculated AQI categories were as follows: 2% "good" category, 42% "moderate" category, 30% "unhealthy for sensitive groups" category and 25% "unhealthy" category, in the semi-heating season of 2017. However, the AQI categories

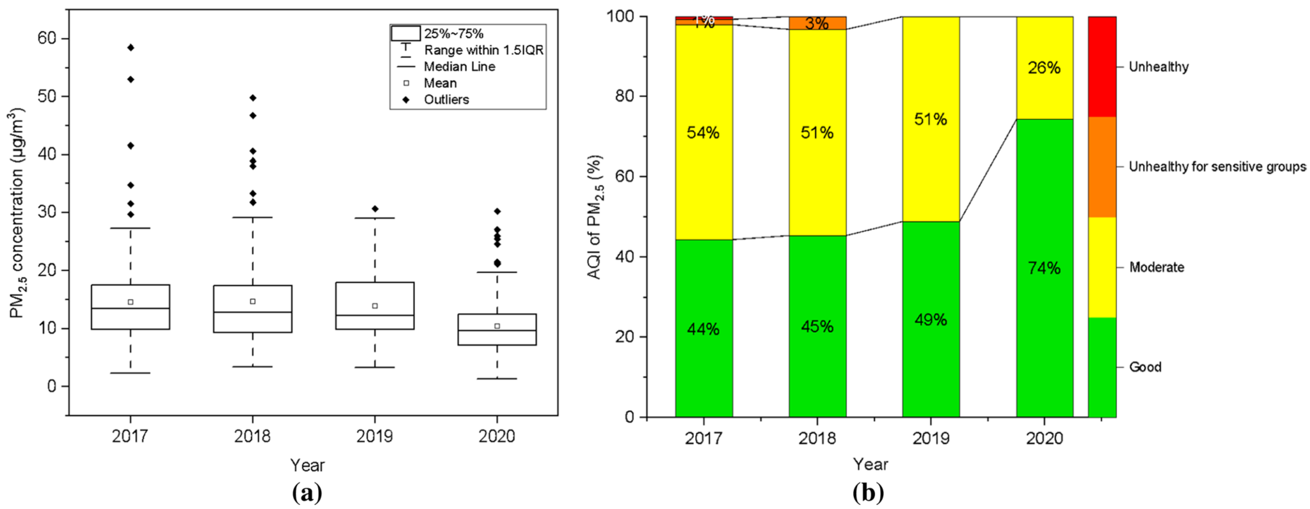

Fig. 5 **a** Boxplot of $PM_{2.5}$ concentration during the non-heating season; **b** AQI of $PM_{2.5}$ in the non-heating season

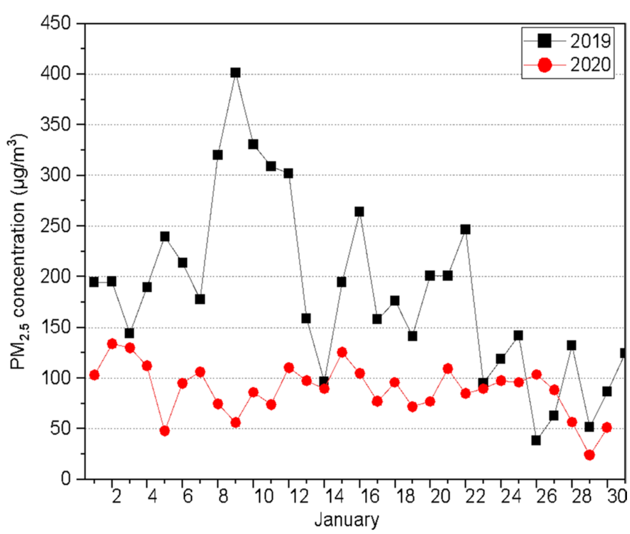

Fig. 6 $PM_{2.5}$ concentration of Ulaanbaatar in January 2019 and 2020

have been estimated in 8% as "good", 76% as "moderate" and 16% as "unhealthy for sensitive groups" in 2020.

Figure 5 shows $PM_{2.5}$ concentration of non-heating season from 2017 to 2020. In 2017, regarding $PM_{2.5}$ parameter is 7.7 ± 14.6 μg/m^3, 7.9 ± 14.7 μg/m^3, 5.9 ± 13.9 μg/m^3 and 5 ± 10.5 μg/m^3 in 2017, 2018, 2019 and 2020, respectively, in non-heating period. During the non-heating season of 2017, 44% of the AQI was in the "good" category, but in 2020 it increases to 74%. However, AQI of $PM_{2.5}$ was in the "moderate" category which is 54% and dropped to 26% in the non-heating season of 2020. The comparison of $PM_{2.5}$ concentrations between 2019 and 2020 shown in Fig. 6 illustrates the difference in the usage of raw coal and improved fuel.

Figure 6 shows the total measurements of $PM_{2.5}$ in the most polluted month (January) of 2019 and 2020. According to the study, $PM_{2.5}$ concentration reached 1100 μg/m^3 several times in 2019, which means 73 times more than the suggested level by the WHO air quality guidelines (15 μg/m^3 24-h mean) (World Health Organization 2021). However, in 2019, the maximum concentration of $PM_{2.5}$ decreased by 2 times, reaching 540 μg/m^3. The mean concentrations of $PM_{2.5}$ were 184.6 ± 172.3 μg/m^3 and 88.9 ± 72.8 μg/m^3 in January 2019 and 2020, respectively.

Comparison of $PM_{2.5}$ between Ulaanbaatar city and Khovd city

The result was based on the measurement data of $PM_{2.5}$ concentrations in Ulaanbaatar and Khovd from January to September 2020. The PM2.5 data was interrupted due to technical conditions from October to December. To show the comparison of $PM_{2.5}$ in Ulaanbaatar and Khovd city, the mean concentration, minimum and maximum measurement, and standard deviation were calculated (Table 2).

Table 2 compares the $PM_{2.5}$ concentrations of Ulaanbaatar and Khovd city from January to September in 2020. During the heating season from January to February, the average $PM_{2.5}$ concentration exceed the WHO air quality guidelines, which is 129 ± 57 μg/m^3, 71.1 ± 32.9 μg/m^3, respectively, in Ulaanbaatar city and 175.6 ± 59 μg/m^3, 101.2 ± 47.3 μg/m^3, respectively in Khovd city. In comparison with the non-heating period, the $PM_{2.5}$ concentration was 10.1 ± 3.9, 7.3 ± 1.7, 7.6 ± 3.4, 9 ± 5.1 and 12.1 ± 4.5 μg/m^3 of May, June, July, August and September in Ulaanbaatar city. However, the measurement of $PM_{2.5}$ was 3 ± 5.9, 1.1 ± 1.1, 0.6 ± 0.9, 2.1 ± 6.8 and 12.7 ± 13.2 μg/m^3 in May through September, respectively in Khovd city.

Table 2 Comparison of $PM_{2.5}$ monthly concentrations between Ulaanbaatar city and Khovd city, in 2020

Month	Ulaanbaatar city					Khovd city				
	Max	Min	Mean	SD	N*	Max	Min	Mean	SD	N*
I	226.1	17.0	129.0	57.0	175,327.0	316.8	95.5	175.6	59.0	228,252.0
II	127.8	15.9	71.1	32.9	234,659.0	216.3	26.7	101.2	47.3	249,476.0
III	63.3	14.5	33.1	12.4	263,714.0	68.8	2.4	20.8	18.9	238,661.0
IV	31.4	4.8	20.6	6.8	114,782.0	9.2	1.2	4.1	2.0	250,949.0
V	23.7	5.2	10.1	3.9	207,088.0	31.6	0.0	3.0	5.9	267,378.0
VI	10.4	4.3	7.3	1.7	252,018.0	6.0	0.0	1.1	1.1	251,768.0
VII	22.1	3.7	7.6	3.4	265,942.0	3.2	0.0	0.6	0.9	204,675.0
VIII	26.1	3.2	9.0	5.1	248,201.0	37.7	0.0	2.1	6.8	258,952.0
IX	22.3	4.7	12.1	4.5	168,479.0	51.0	1.6	12.7	13.2	228,227.0

*N = number of total $PM_{2.5}$ measurement

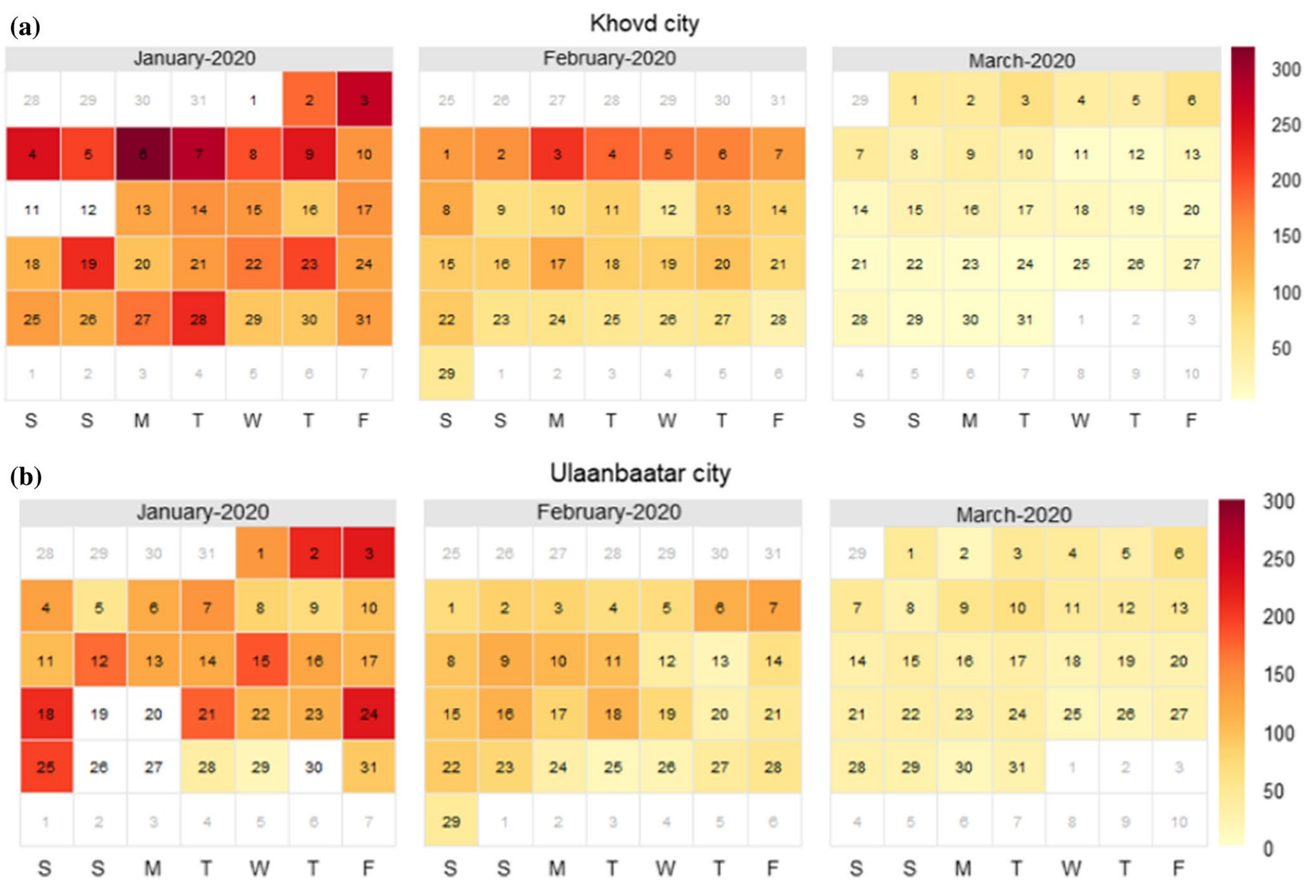

Fig. 7 **a** Khovd city, **b** Ulaanbaatar city, the daily mean concentrations of $PM_{2.5}$ from January to March, 2020

In Fig. 7, the measurement of $PM_{2.5}$ is illustrated day by day from January to March in 2020. The outdoor $PM_{2.5}$ concentration was extremely high, and every day of January and February exceeded the WHO air quality guidelines. Air quality has improved dramatically since March 19 so that March 11 and March 14 did not exceed WHO air quality recommendations.

On the other hand, the total measured 26 days in January 2020 exceeded the 50 μg/m^3 in Ulaanbaatar, while in February, only one day out of 29 days was below 15 μg/m^3. The PM2.5 concentrations of March dropped sharply; however, 2nd, 25th and 30th of March met the air quality recommendations of WHO (Fig. 7).

Factors affecting $PM_{2.5}$ concentrations of Khovd and Ulaanbaatar city

The highest $PM_{2.5}$ concentration of Khovd and Ulaanbaatar city occurred in January, which needs to be analyzed further to determine the contributing factors. Therefore, the working day (Monday, 6^{th} of January) and weekend day (Sunday, 5th of January) were selected from the January data of Ulaanbaatar and Khovd city in order to explore differences between weekends and weekdays (Figs. 7, 8). The colored area of the figure shows a peak of the $PM_{2.5}$ concentration, and it can conduct the frequency with which it increases and decreases over time.

Figure 8 illustrates the $PM_{2.5}$ concentration of Ulaanbaatar and Khovd as of January 5, 2020. On Sunday or 5th of January, the $PM_{2.5}$ rose between 00:00 and 03:20, 07:37—12:15, and 17:50—00:00 in Khovd city. At 9:30 in Khovd, the $PM_{2.5}$ reached 1065.4 μg/m^3, or the maximum concentration, 70.9 times higher than the WHO air quality guidelines. The increase of $PM_{2.5}$ was painted orange in the figure during 01:40—02:45 and 22:40—00:00 in Ulaanbaatar. The maximum concentration is 232.4 μg/m^3 in Ulaanbaatar at 23:50, which is 15.5 times higher than the WHO air quality guidelines.

Figure 9 presents the $PM_{2.5}$ concentration in Ulaanbaatar and Khovd as of January 6, 2020. On a working day, Monday, the colored area showed that the PM2.5 concentration was excessive between 00:00—05:50 and 07:30—12:30 in Khovd city. On this day, the maximum concentration was 1290.8 μg/m^3, which is 86 times higher than the WHO air quality guidelines. In Ulaanbaatar, $PM_{2.5}$ increased from 00:00 to 03:00 and from 19:10 to 00:00, reaching a maximum of 302.4 μg/m^3, or 20.2 times higher than the WHO air quality guidelines.

The firing hours of ger residential areas coincide with the increased period of $PM_{2.5}$ concentrations in Khovd; therefore, those residential households are considered to be a major source of the pollution.

Discussion

The concentration of $PM_{2.5}$ in Ulaanbaatar and Khovd city

In Ulaanbaatar from 2017 to 2020, the average annual concentrations of $PM_{2.5}$ were 54.8 ± 49.3, 56 ± 51.8, 49.5 ± 52.4 and 30.2 ± 24.7 μg/m^3, respectively. Both natural (meteorological and topographical condition) and anthropogenic (excessive amounts of biomass burning, transportation, etc.,) factors have influence on $PM_{2.5}$ pollution. Ganbat and Baik (2016) suggested that the persistent temperature inversion layer is deep in the valleys and shallow over the mountain slopes in Ulaanbaatar. Local winds, which include urban

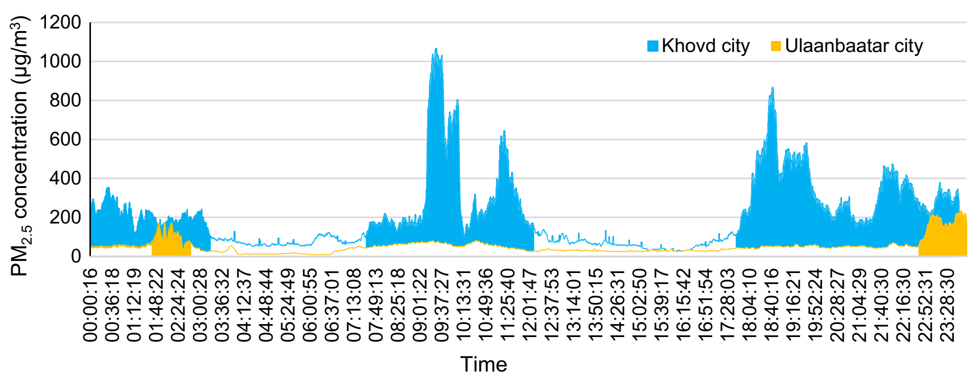

Fig. 8 Sunday, 5th January of $PM_{2.5}$ concentration in Khovd and Ulaanbaatar city (the colored area indicates an increase of $PM_{2.5}$)

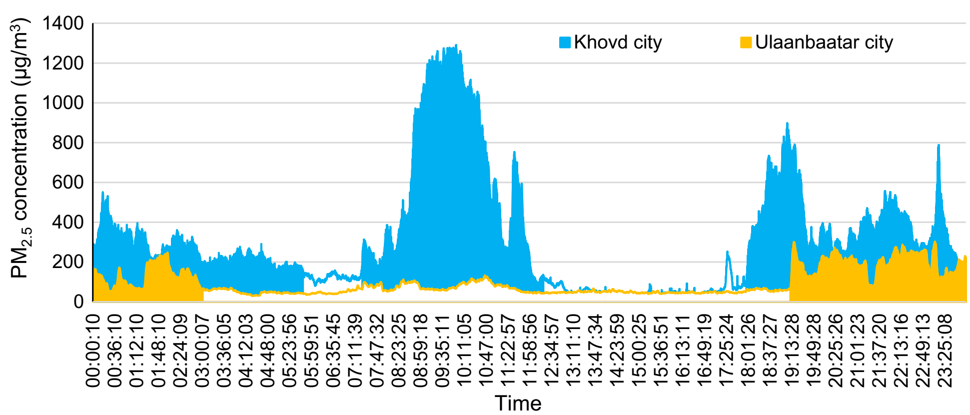

Fig. 9 Monday, 6th January of $PM_{2.5}$ concentration in Khovd and Ulaanbaatar city (the colored area indicates an increase of $PM_{2.5}$)

breezes, mountain slope winds and up-and down-valley winds, were found weak in the presence of the temperature inversion using the mesoscale model coupled with the advanced urban canopy model. By calculating the temperature inversion layer thickness and intensity of Ulaanbaatar for 2008–2016 every winter, a recent study has found a strong correlation between the temperature inversion intensity and $PM_{2.5}$ concentrations (Wang et al. 2018). According to the study, the concentrations of PM_{10} and $PM_{2.5}$ were positively correlated with temperature and relative humidity, respectively, and strongly but negatively correlated with wind speed; wind speed and relative humidity were two key factors affecting the distributions of $PM_{2.5}$ and PM_{10} concentration (Zhao et al. 2014). Considering the relationship between $PM_{2.5}$ level and meteorological factors, geographic conditions need to be studied further to provide more accurate scientific evidence in order to support effective policy actions for reducing air pollution levels.

$PM_{2.5}$ concentration levels compared between Khovd and Ulaanbaatar city from January through September of 2020. During the heating season (months of January and February), high concentrations of $PM_{2.5}$ occurred and continued for a considerably long period. The government of Mongolia has banned fossil fuels in Ulaanbaatar since May 2019, whereas raw coal consumption is still acceptable without any restrictions in Khovd city. The $PM_{2.5}$ concentrations of Ulaanbaatar during the heating season of 2019–2020 have declined since the beginning of this regulation.

Comparison of the $PM_{2.5}$ levels in Beijing and Ulaanbaatar cities and policy actions

Among developing countries in Asia, China is one of the countries struggling with air pollution, and the city of Beijing faces similar conditions with Ulaanbaatar city. Table 2 shows the $PM_{2.5}$ levels of Beijing and Ulaanbaatar from 2011 to 2020. Both cities have been pursuing policies to reduce air pollution since 2013. According to Table 2, $PM_{2.5}$ concentrations of Beijing were lower than Ulaanbaatar from 2011 to 2020, while $PM_{2.5}$ concentrations of Ulaanbaatar were lower in 2020.

According to Table 3, $PM_{2.5}$ concentration in Beijing was lower than in Ulaanbaatar in 2011–2012, 2016, and 2018–2019, while $PM_{2.5}$ concentration in Ulaanbaatar was lower in 2013–2015, 2017 and 2020.

Air pollution has now become an increasing source of environmental degradation in the developing countries of East Asia. China, in particular, is experiencing dramatic levels of aerosol pollution over a large portion of the country due to the rapid push to industrialize (Alles 2009). The government of China has been taking major actions to control $PM_{2.5}$ since 2013. These actions include phasing out small and polluting factories, upgrades on industrial boilers, promoting clean fuels in the residential sector, and so on (Zhang et al. 2019). Since 2013, urban and rural households in Beijing have been provided with more subsidies to expedite the replacement of coal with electricity or natural gas. As of 2017, the plurality of Beijing households has become coal-free except for some in remote rural areas. Although enormous actions were taken, approximately 53.4% of all 338 municipal cities in China still did not meet the National Ambient Air Quality Standard in 2017 (Report on the State of the Ecology and Environment in China 2019). Particularly, $PM_{2.5}$ concentrations decreased by an average of 23% during this period for all municipal cities in China (Lu et al. 2020).

In order to combat air pollution in Ulaanbaatar, numerous energy and policy actions have been introduced to ger residential districts, such as replacing traditional heating stoves with advanced models, substituting raw coal-fueled boilers with centralized heating stations, implementing affordable low-cost housing projects and renovating old roadways and intersections with much better technology and designs. Stove replacement was not successful which unfortunately required a special fuel which the marketplace could not fully provide. The electricity charges and zero-cost policy for electricity from 21:00 to 06:00. is not practical (Koo et al., 2020). According to the National Program for Reducing Air and Environmental Pollution (NPRAEP), 20,000 households had to be reinstated into apartments in 2019 (Resolution of the Government of Mongolia 2017). However, a total of 10,287 apartments were commissioned in 2013–2020 (Implementing agency of the Capital City Governor 2020).

Table 3 $PM_{2.5}$ concentration of Beijing and Ulaanbaatar from 2011 to 2020. *Source*: (Statista 2021) $PM_{2.5}$ of Beijing, China, (Enkhjargal et al. 2020) $PM_{2.5}$ of Ulaanbaatar, Mongolia

Year	2011	2012	2013	2014	2015
Ulaanbaatar, Mongolia	133.05 ± 178.09	96.84 ± 119.54	81.84 ± 87.57	64.30 ± 60.02	56.43 ± 52.01
Beijing, China	99.09	90.52	101.56	97.72	82.7
Year	2016	2017	2018	2019	2020
Ulaanbaatar, Mongolia	86.57 ± 90.33	54.8 ± 49.3	56 ± 51.8	49.5 ± 52.4	30.2 ± 24.7
Beijing, China	72.73	58.78	50.7	42.6	38.84

Since 2017, the legal and policy environment on reducing air pollution has been further strengthened, but outcomes are still unacceptable.

To reduce air pollution in Khovd city, a briquette plant was planned to be built in 2021, but construction has not begun yet (The Government of Mongolia 2020). On the other hand, infrastructure improvements and redevelopment of ger areas were planned (Asian Development Bank 2021). Byambajav Ganzorig et al. (2021) studied that in November through February of 2019–2020, $PM_{2.5}$ concentration rapidly decreased by 44% compared to the same period of previous years in Ulaanbaatar (Byambajav et al. 2021). This study shows a positive result of the use of improved fuel instead of raw coal in Ulaanbaatar city. Hence, this quality of improved fuel needs to be implemented in other large cities, such as Khovd. Although progress is underway, there is still a long way to go for Mongolia to optimize its economic and energy structure.

Conclusion

Khovd does not have a $PM_{2.5}$ measurement station, in another words, there is no government oversight. Therefore, this study will be the first and baseline data for long-term measurement of $PM_{2.5}$ in Khovd. Based on the results, a comparative study of $PM_{2.5}$ in Ulaanbaatar for 2017–2020 shows that $PM_{2.5}$ concentration in 2020 is the lowest yet exceeded the WHO air quality standards. According to a comparison of Khovd and Ulaanbaatar city, average $PM_{2.5}$ concentration was 129 ± 57 μg/m^3 in Ulaanbaatar and 175.6 ± 59 μg/m^3 in Khovd in January, the coldest month. In June, the warmest month, the $PM_{2.5}$ concentration in Ulaanbaatar was 7.3 ± 1.7 μg/m^3 and 1.1 ± 1.1 μg/m^3 in Khovd. However, the $PM_{2.5}$ concentration of Khovd is higher than in Ulaanbaatar. Also, it continues to be high concentration from 8 o'clock to 12 o'clock, which is the period of active burning of raw coal in ger areas.

This study was conducted for monitoring purposes, and further research is required. In terms of population concentration, climatic factors and geological formations, Ulaanbaatar should be more polluted, but Khovd's coldest month, January, is more polluted than Ulaanbaatar. Thus, it is suggested that similar monitoring surveys need to be conducted in other cities as well and prompt actions need to be taken in the near future.

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Data availability Not applicable.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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