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Study of Spatial Variations of Air Pollutants in Ulaanbaatar

Bachelor Thesis

by

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Statutory Declaration

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

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Abstract

Long-term air pollution data with spatial resolutions are needed to aid in the research of Ulaanbaatar's air quality and to discover which residential areas have higher pollutant levels. However, until recently, similar study was rare in Mongolia. This study examines the spatial variations of PM2.5, PM10, CO, SO2, NO2 and O3 in 13 monitoring stations in Ulaanbaatar between January 2014 and December 2020. For the overall averaged pollutant values in all stations, they exceeded the Mongolian National Standard for PM10, PM2.5, SO2, and NO2, while O3 and CO were provided that standard (MNS 4585:2016) and their highest occurrences were 94.7%, 95.6%, 50.6%, 42.4%, 90.5%, and 34.75%, respectively, higher than the daily average MNAQS.

According to the characteristics of pollutants at different site, the highest concentrations of PM10, PM2.5, SO2, and CO were mostly researched in Ger areas. Whereas the concentrations of O3 and NO2 were highly occurred in traffic areas. The seasonal analysis was investigated that the hazardous levels are reached in winter and then the concentrations were decreased for until autumn, not including with ozone. Because there hasn't been a solid link between ozone levels and seasonal changes. Even though pollutant concentrations were decreased in the summer, some contaminants in categorized groups remained high and did not meet the allowed threshold, especially in PM10.

According to the distribution analysis, 66 percent of air pollutants from the ger area come from there. However, in residential areas, the highest figure in the measurement of NO2 pollution was observed in all of the stations from the evaluation. Despite the fact that the most harmful pollutants, the highest evaluation PM10 and SO2, were studied in ger areas, the pollutants' distribution at all places generally identical.

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Chapter 1: INTRODUCTION

1.1 Problem

Ulaanbaatar, the capital city of Mongolia, is one of the cities with the worst air quality. The United Nations International Children's Emergency Fund (UNICEF) has mentioned that daily average PM2.5 pollution levels reach 687 $\mu g/m^3$ on the coldest days of the year which is 27 times greater than the level WHO recommends as safe [1] and also Mongolia is ranked 20th out of 118 countries about the worst air quality measured in air quality index [2]. The city has the highest concentration of respirable particulate matter (PM10 and PM2.5) in the country, making it one of the most polluted cities in the world for several years [3]. High-concentration particulate matter is generated from stove stacks in Ulaanbaatar's ger region due to incomplete combustion in traditional low-efficiency stoves. According to a study on recent improvements in particulate matter pollution in Ulaanbaatar [4], the highest PM2.5 and PM10 concentrations in Ulaanbaatar were reduced by 46% and 55%, respectively, when compared to the average maximum values from 2014 to 2020. Despite a decrease in PM pollution over the winter of 2019–2020, the concentrations are still high, above the Mongolian national limit. As a consequence of the substantial air problem, human health has worsened and been influenced. It has been claimed by [5]. which noted that air pollution, metals, tobacco smoke, and toxic chemicals are environmental risk factors for the Mongolian population reflected in the development of cardiopulmonary diseases in adults and neurodevelopmental and respiratory disorders in children. Moreover, children living in a highly polluted region of central Ulaanbaatar were found to have 40% worse lung function than children living in a rural location, according to UNICEF data [6]. Air pollution has also been related to ailments like bronchitis and asthma, which can be extremely harmful to children and pregnant women, individuals. Accurately planned management is required for future air quality enhancement and a collection of various acts. Therefore, the study of air investigation and analysis is necessary at that time.

1.2 Aim

The main goal of this study is to investigate how the air pollutants are varied over the area of Ulaanbaatar. Thus, characteristics of spatial variations of air pollutants in Ulaanbaatar are looked into in this study.

There are several reasons to investigate: Spatial variations of air pollution in Ulaanbaatar have been investigated previously [7]. However, in the last few years, the sources of air pollution have largely changed. From the winter of 2019/2020, the Mongolian government declared a prohibition of raw coal usage for most of the city’s districts and a significant reduction in particulate matter pollution was seen [8]. Thus, it is therefore necessary to investigate spatial variations of air pollutants and their relationship with contributing factors for the last few years.

The objective of this study is to investigate the spatial variations of PM2.5, PM10, NO_2, SO_2, CO, and O_3 in Ulaanbaatar based on the six-year data from January 2014 to December 2020 measured at 13 air quality monitoring sites.

1.3 Introduction

Ulaanbaatar is found in Mongolia’s center locale, within the Tuul waterway valley, at a height of 1350 meters over ocean level [9]. According to census data from 2021, the city's population was estimated to be around 1.5 million inhabitants. Ulaanbaatar is now the country's principal political, economic, business, scientific, and cultural hub. The city also houses the central government and its bureaucratic structure, as well as the most prestigious public and private institutions of higher learning and the greatest medical services. The city has a population of almost 1,6 million people, making it home to nearly half of Mongolia's population. Because of the nomadic tradition, 60% of the population lives in ger regions. Rapid population increase in Ulaanbaatar, Mongolia, along with a household reliance on coal for heating and cooking, has resulted in one of the world's most severe examples of air pollution. Due to those reasons, the population of Ulaanbaatar city has been constantly increasing for the last few decades.

Coal burning in Gers, industries, particle emissions of creation, power stations, improved stoves, home heating systems, public and private transportation, road particle transformation, and waste incineration are all sources of air pollution in Ulaanbaatar. From Table 1, there are 411 thousand households living in Ulaanbaatar, of which 22.2 percent live in traditional Mongolian gers, 77.3 percent in houses and apartments, and 0.5 percent in other types of housing [10]. Thus, 54.4 percent of Ulaanbaatar's population lives in Ger regions [11]. It is considered as the main source of air pollution in Ulaanbaatar. The city’s other major air pollution source includes 3 waste incineration points, 4 power plants, and over 600 thousand vehicles. Of these, especially, during wintertime, smog of ger districts, motor vehicles and power plants produce a very large amount of air pollutants. Different attempts have been made to reduce the air pollution, but there is very little change.

Table 1.Statistical information in Ulaanbaatar[12]

Population	1’539’810

Household number in UB	411’400
Household number in Ger	91’249
Household number in House	317’944
Traffic	662’644
Waste incineration point	3
Power plant	4

The main reason for air pollution in Ulaanbaatar is not only coal burning in ger areas, power stations, industries, and vehicles. Additionally, it is influenced by climate conditions and geographical location. In wintertime, a lot of coal is burned, especially households living in the ger area that burn tons of coal every winter, creating 60% of air pollution in the city. Total coal consumption in Mongolia is 81750.74 m3 of coal per capita every year [13] (based on the 2016 population of 3,056,364). For the geographical location, the city is surrounded by a valley of mountains which means pollution sources tend to be concentrated, and in the weather phenomenon known as a temperature inversion, a layer of cooler air is trapped near the ground by a layer of warmer air above not allowing for any dispersion of pollutants. In such a case, normal air mixing almost ceases, and pollutants are trapped in the lower layer. In winter, the effects of temperature inversion are enhanced.

Air pollution in Ulaanbaatar reflects increasing curiosity by the people as well as scientific researchers and policymakers due to hazardous occurrences of air pollution events, especially in wintertime. Accordingly, the spatial variations of the air pollutants in Ulaanbaatar are studied previously using the data from air quality measurement sites and numerical models. However, there is a lack of recent studies in spatial variations of the air pollution in Ulaanbaatar.

According to studies and literature, average concentration levels of particulate matter and sulfur dioxide in Ulaanbaatar between December 2015 and January 2016 were up to 10 times higher than the limits recommended by the World Health Organization [14]. To address this issue, the government adopted the National Program for Reducing Air and Environmental Pollution in March 2017, with the ultimate target of 80% air pollution reduction by 2025 [15].

Chapter 2: STATE OF ART

During the last decade, Ulaanbaatar is considered one of the most polluted cities in the world, especially in the wintertime. The ger area contributes to the worst situation since each household consumes about 5 tons of coal previously or 2-3 tons of upgraded briquette fuel since 2019 winter, firewood, and other combustible materials per winter season. In particular, this leads to very high concentrations of particulate matter and other primary pollutants. Raw coal was the most important energy source in Ulaanbaatar in 2014, according to the World Data Atlas, accounting for 93.2 percent of total energy production [16]. Such high coal consumption, which Mongolia consumes 8,823,724 tons of coal per year as of the year 2016 and is ranked 41st in the world for coal consumption [17], induced a large number of pollutants, including SO_2, NO_2, and PM2.5. Many articles, news, and media stated that during winter times Ulaanbaatar's air quality was dozens of times higher than international standards. Most typical urban pollutants include particulate matter (PM), sulfur dioxide (SO_2), volatile organic compounds (VOCs), lead (Pb), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), and ozone (O_3). Carbon monoxide, nitrogen oxides, sulfur dioxide, ozone, particulate matter, and lead are called criteria pollutants meaning that these six pollutant concentrations are useful indicators of overall air quality. Combustion of fossil fuels (in particular, coal) can lead to simultaneous concentrations of PM2.5, SO_2, and NOx. Among these pollutants, PM2.5 is the pollutant with the highest risk for public health and may influence the national economy.

Air pollutants

In this study, six pollutants, which include PM10, PM2.5, SO2, NO2, CO and O3 are studied. General description and adverse impacts of the air pollutants are briefly described in this chapter.

1. *PM10*

PM10 are very small particles, with a diameter of 10 micrometers (0.01 mm) or smaller. For comparison, human hair is, on average, 50 to 70 µm in diameter. High levels of PM10 can make you cough, your nose run and eyes sting. Common factors of PM10 particles include dust from unsealed roads, smoke from fires, sea salts, car and truck exhausts and industry [18]. The permissible amount of 24 hours average is 100 µg/m3 in MNS 4585:2016 from Table 2.

2. PM2.5

The term fine particles, or particulate matter 2.5 (PM2.5), refers to tiny particles or droplets in the air that are two- and one-half micrometers or less in width which about larger particles in the PM2.5 size range would be about thirty times smaller than that of a human hair.

Particles in the PM2.5 size range are able to travel deeply into the respiratory tract, reaching the lungs. Exposure to fine particles can cause short-term health effects such as eye, nose, throat and lung irritation, coughing, sneezing, runny nose and shortness of breath. People with breathing and heart problems, children and the elderly may be particularly sensitive to PM2.5.

There are outdoor and indoor sources of fine particles.

- The outdoor sources:

1. Car, truck bus and off-road vehicle;
2. The burning of fuels such as wood, heating oil or coal and natural sources such as forest and grass fibers;
3. The reaction of gasses or droplets such as power plants.

- The indoor sources:

1. Fine particles are tobacco smoke, cooking, burning candles or oil lamps, and operating fireplaces and fuel-burning space heaters [19].

In the Mongolian air quality standard from Table 2, the permissible level for 24 hours average is 50 µg/m3.

3. CO

CO is a colorless, odorless gas that is toxic when inhaled in large quantities. When something burns, CO is released. The largest sources of CO in the outdoor air are vehicles that burn fossil fuels, trucks and other vehicles or machinery. Many items in your home, such as unventilated kerosene, gas heaters, leaking chimneys, stoves, and gas stoves, emit CO and affect indoor air quality.

Inhalation of air with a high content of CO reduces the amount of oxygen delivered to vital organs such as the heart and brain by the bloodstream. These people already have a reduced ability for getting oxygenated blood to their hearts in situations where the heart needs more oxygen than usual. Also, it can cause various diseases, including brain, central nervous system, and heart damage, and can be fatal. They are especially vulnerable to the effects of CO when exercising or under increased stress and also it results in the heart accompanied by chest pain also known as angina [20]. (The permissible level for 8 hours average is 10000 µg/m3 MNS 4585 2016 from Table 2)

4. SO_2

Sulfur dioxide (SO_2) is a gaseous air pollutant composed of sulfur and oxygen. SO_2 forms when sulfur-containing fuel such as coal, oil, or diesel is burned. The largest sources of SO_2 emissions are burning fossil fuels, electricity generation, industrial boilers, and other industrial processes such as petroleum refining and metal processing. Diesel engines are another major source, including old buses and trucks, locomotives, ships, and off-road diesel equipment [21].

SO_2 causes a range of harmful effects on the lungs, as the EPA's most recent review of the science concluded [22]:

- Wheezing, shortness of breath and chest tightness and other problems, especially during exercise or physical activity.
- Continued exposure at high levels increases respiratory symptoms and reduces the ability of the lungs to function.
- Short exposures to peak levels of SO_2 in the air can make it difficult for people with asthma to breathe when they are active outdoors.
- Rapid breathing during exercise helps SO_2 reach the lower respiratory tract, as does breathing through the mouth.
- Increased risk of hospital admissions or emergency room visits, especially among children, older adults and people with asthma.

The permissible level of 24 hours average is 50 μg/m^3 in MNS 4585:2016 (see Table 2).

5. O_3

Ozone is a colorless, odorless gas composed of three oxygen atoms. Good ozone usually occurs 34-100 km from the Earth's surface and is in the form of a protective layer that absorbs harmful radiation from the sun. Surface ozone is formed as a result of chemical reactions of sunlight with pollutants emitted from internal combustion engines, power plants, industrial furnaces, oil refineries and chemical plants. Photochemical oxidation products are highly dependent on the intensity of sunlight and ambient temperature.

Tropospheric, or ground level ozone, is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC). This happens when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight.

Ozone in the air we breathe can harm our health, especially on hot sunny days when ozone can reach unhealthy levels. People at greatest risk of harm from breathing air containing ozone include people with asthma. For environmental effect, elevated exposures to ozone can affect sensitive vegetation and ecosystems, including forests, parks, wildlife refuges and wilderness areas. In particular, ozone can harm sensitive vegetation during the growing season [23].

6. NO_2

Nitrogen dioxide, or NO2, is a gaseous air pollutant of nitrogen and oxygen and is one of a group of related gasses called nitrogen oxides, or NOx. NO2 forms when fossil fuels such as coal, oil, gas or diesel are burned at high temperatures. NO2 and other nitrogen oxides in the outdoor air contribute to particle pollution and to the chemical reactions that make ozone. Car, trucks, and buses are the largest sources of emissions, followed by power plants, diesel-powered heavy construction equipment and other movable engines, and industrial boilers [23].

Nitrogen dioxide causes a range of harmful effects on the lungs, including:

- Increased inflammation of the airways;
- Worsened cough and wheezing;
- Reduced lung function;
- Increased asthma attacks.

It is one of six widespread air pollutants that have national air quality standards to limit them in the outdoor air. NO2 can also form indoors when fossil fuels like wood or natural gas are burned. Table 2 shows the maximum permissible levels of the air pollutants described in the Mongolian air quality standard.

Table 2.Maximum permissible levels of the air pollutants in the "MNS 4585:2016 Air quality. General technical requirements"

Names	Average time of measurements	Unit	Maximum permissible level
Sulfur dioxide (SO2)	Average of 20 minutes Average of 24 hours Annual average	µg/m^3	450 50 20
Carbon monoxide (CO)	Average of 20 minutes Average of 1 hour Average of 8 hours	µg/m^3	60000 30000 10000
Nitrogen dioxide (NO2)	Average of 20 minutes Average of 24 hours Annual average	µg/m^3	200 50 40
Ozone (O3)	Average of 8 hours	µg/m^3	100
Total particles	Average of 20 minutes Average of 24 hours Annual average	µg/m^3	500 150 100
Particulate matter 10	Average of 24 hours Annual average	µg/m^3	100 50
Particulate matter 2.5	Average of 24 hours Annual average	µg/m^3	50 25
Lead (Pb)	Average of 24 hours Annual average	µg/m^3	1 0.25
Benzo[e]pyrene (C20H12)	Average 24 hours	µg/m^3	0.001

From assessment of air quality in Ulaanbaatar in 2020 [25], the maximum of annually averaged SO_2 pollution around the "5 buudal" which is included in ger area station is 5.7 times higher than the maximum permissible level specified in the newly approved national air quality standard. Other stations also had higher levels of pollution at most locations. Also, the average daily concentration of sulfur dioxide from the air quality data of the stationary guards in Ulaanbaatar during the measurement period is noted that in the vicinity of the airport (belongs to ger area) was three times higher than the permissible amount. NO_2 is a by-product of combustion at higher temperatures than the combustion of nitrogen-containing fuels, and is usually the result of a heat-absorbing reaction during combustion and causes environmental pollution. The main sources of pollutants are all types of vehicles, and these pollutants alone and in the form of acid precipitation and surface ozone generation. The city center and near the main road are exposed to nitrogen dioxide pollution, which exceeds the maximum permissible level specified in the standard. For the entire observation period in 2020, the average annual maximum concentration was around the western “Baruun 4 zam”, reaching 110 $\mu g/m^3$, 2.8 times higher than the maximum permissible level, while it was close to the permissible level at other locations, except for a slight increase during the heating period. Within the air quality monitoring network of Ulaanbaatar, particles with a particle size of less than 10 microns at 10 monitoring sites and dust masses with a particle size of less than 2.5 microns at 6 monitoring sites are continuously determined by beta radiation absorption and laser scattering. The average annual maximum concentration of dust less than 10 microns in the city reached 136 $\mu g/m^3$ around “Mongol Gazar” (industrial area) and was 2.7 times higher than the maximum permissible level, depending on the location. For the maximum concentration of PM2.5 in the air was measured at around 56 $\mu g/m^3$ at “Zuragt” which is included ger area. This is 2.2 times the annual average permissible maximum specified in the standard. Moreover, O_3 is monitored at 5 points in Ulaanbaatar, and the total observations do not exceed the maximum permissible levels. During the measurement period, it is the highest around the “Nisekh” area (belongs to ger) and tends to increase during the warm season. Finally, Last year's air quality measurements did not show any higher levels of CO than allowed.

Chapter 3: DATA AND METHODS

3.1 Data

Data on air pollutants used in this study is gathered from the national monitoring network, which includes the stations operated by the National Agency for Meteorology and Environmental Monitoring (NAMEM) and the Agency Against Air Pollution (AAAP) of the Municipality. In addition, for PM2.5, measurement data at the US Embassy air quality monitoring site is used [26]. Pollutants (PM2.5, PM10, SO_2, NO_2, CO, and O_3) and weather parameters were measured every hour from January 1st, 2014 to December 31st, 2020. Figure 1 shows the location of Ulaanbaatar, Mongolia, and the location of 13 air quality monitoring sites. The stations are divided into 5 groups differentiating by their location as follows:

- Ger area — UB3, UB5, APRD1, APRD2, APRD4, and APRD6
- Industrial area — UB1 and UB7
- Traffic area — UB2 and APRD3
- Remote area — UB8
- Residential area — UB4

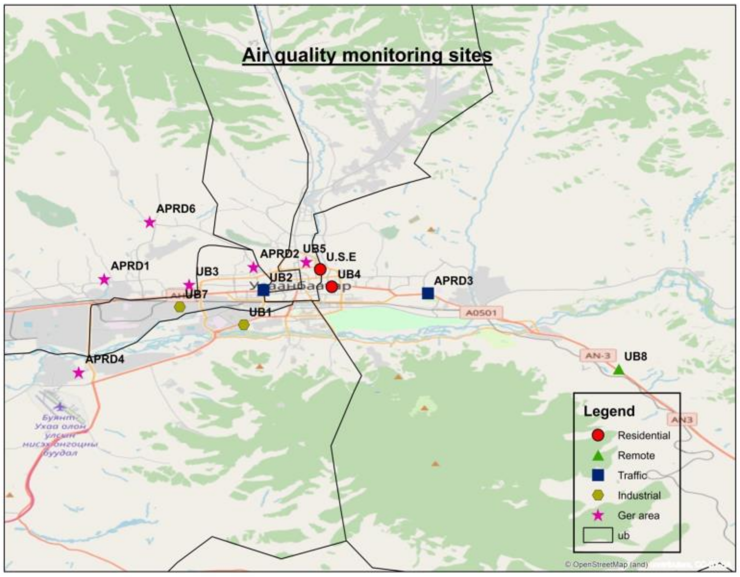


Figure 1.Air quality monitoring sites

However, measurements up to six criteria air pollutants are measured, not all sites measure all the pollutants and there is unavailability in data for various reasons. Figure 3 provides a quick graphical and numerical summary of data with summary statistics and plots of variable distributions for the overall stations. A detailed summary for each type of station is provided in Appendix 1.

Table 2 demonstrates the location classifications and information of measured parameters at monitoring stations. For instance, all six criteria pollutants (SO_2, NOx, CO, O_3, PM2.5, and PM10) are measured at Baruun 4 zam site and PM2.5 is observed at the US Embassy site.

The following standardized devices measure air pollutants at the sites are regularly calibrated based on standard methods:

- ***Ozone (O342e)***: UV photometry LED (US-EPA-Automated Equivalent Method: EQOA-0515-225). An air sample is taken into the device's ‘mixing chamber,' where it is subjected to UV radiation with a wavelength of 254 nm. When compared to an air sample without ozone, ozone absorbs UV radiation in proportion to its quantity (and other characteristics). Some gaseous hydrocarbons and other substances that absorb UV light with a wavelength of 254 nm, such as mercury, will interfere. Few possible substances will interact with this approach since O_3 is distinctive in its absorption of light at 254 nm. Furthermore, using very similar technology, this method may be utilized to measure a variety of contaminants. It had a Teflon sample inlet filter, automated temperature and pressure compensation, a flow rate of 1 liter/min, and a zero/span external solenoid valve, and worked in a range of 0–0.5 ppm in an atmosphere of 0–35°C [27].
- ***Carbon Monoxide (CO12e)***: Non Dispersive InfraRed CO analyzer (US-EPA-Automated Reference Method: RFCA-0915-228.). The amount of infrared light absorbed by the sample gas as it travels through a multi-reflection chamber is used to measure the CO sample concentration. Because the absorption spectrum is not continuous, for extremely selective sample gas measurement, a gas filter called a correlation wheel is utilized in conjunction with the optical filter. The correlation wheel is made up of two sealed chambers of equal volume, one filled with carbon monoxide (CO) and the other with nitrogen (N2). The light beam passes through the CO cell and the N2 cell alternately as the wheel rotates, then via interference optical filters before reaching the detector. If the sample includes CO, the reference beam will not be attenuated since the CO in the reference cell has already attenuated it. The e-Series of analyzers has been completely eco-designed, with special attention paid to the product's environmental impact during its entire life cycle. The unique «inside the box» foam modular design makes the product more durable, energy-efficient, easier to service, and environmentally beneficial. The measurement range of CO12 is 0-50 ppm (or 0-300 ppm on custom basis request). It had 4 independent analog inputs and output, 4 remote control inputs, and 6 dry contacts outputs, and serviced 24 V power supply and enhanced temperature range up to +50ºC for use without the air conditioner [28].

- ***Sulfur Dioxide (AF22e)***: UV Fluorescence SO_2 analyzer (US-EPA-Automated Equivalent Method: EQSA-0802-149). When sulfur dioxide is exposed to UV light with a wavelength of 190-230 nm, it produces a distinctive glow. While most other contaminants in the air do not absorb this wavelength of light, the molecule does. As a result, in the U.V. fluorescence systems, a beam of radiation is sent through a sample. A filter and photomultiplier tube pass the decay radiation through, allowing a concentration to be determined. At certain wavelengths, water vapor and oxygen can interfere with sulfur dioxide's characteristic fluorescence. To limit inaccuracy, water vapor must be evaporated using a dryer or by selecting specific wavelengths. Nitrogen can be used to dilute an air sample, lowering the oxygen concentration and minimizing inaccuracy. One of the most sensitive ways for assessing concentrations is ultraviolet fluorescence. The technology can measure highly specific samples, and any interferences or potential overlaps can be avoided with the use of additional U.V. lasers. It worked with a complete scale range of 0 - 0.50 ppm, at any temperature between 5 and 40 degrees Celsius, with a Line Setting of "MEASURE," an Analog Output Setting of "MOMENTARY VALUE," and any of the following choices [29].

- ***NOx & NO_2 (AC32e):*** Chemiluminescent NO-NOx & NO_2 analyzer. The chemiluminescence technique is used to automatically analyze the amounts of NO, NOx, and NO_2 in a gaseous sample. The CLD (Chemiluminescence detector) is based on the reaction NO and O_3, which releases photons (light) that are detected by a cooled photomultiplier tube (PMT). Some gaseous hydrocarbons and other substances that absorb UV light with a wavelength of 254 nm, such as mercury, will interfere. The e-Series of analyzers has been completely eco-designed, with special attention paid to the product's environmental impact during its entire life cycle. The unique «inside the box» foam modular design makes the product more durable, energy efficient, easier to service, and environmentally beneficial. The measurement range of AC32e is 0-1 ppm (user selectable and programmable). It had 4 independent analog inputs and output, 4 remote control inputs and 6 dry contacts outputs, and serviced 100-250 V power supply and operating temperature was 0-40ºC [30].

- ***PM10 and PM2.5 (MP101M):*** Suspended particulate beta gauge monitor. The MP101M enables regulatory monitoring of PM10 and PM2.5, with an alarm if the threshold is exceeded. The analyzer uses a beta ray attenuation measurement approach to calculate fine dust concentrations by detecting how much radiation a sample collected on a fiber tape collects when exposed to a radioactive source. Collisions with electrons, whose number is proportional to density, absorb low-energy beta rays. It has high accuracy (not influenced by the physicochemical nature of particles), no need for factory recalibration, and is not sensitive to vibration, humidity and temperature. Reduces evaporation artifacts of volatile chemicals by continually regulating the sampling flow rate to the ambient temperature and pressure. Its measuring range is up to 10000 µg/m3 (user-programmable) and also the low detectable limit is 0.5 µg/m^3 (24h average). The operating temperature and power supply are +10 to +40°C and 230V, respectively [31]

Table 3.Monitoring site information

	Site name(ID)	Location	Latitude,longitude	Weather parameter	Measuring parameter					
					SO2	NOx	CO	O3	PM2.5	PM10
1.	**MIsheel (UB1)**	Industrial	47°53'38.4" N 106°52'55.92" E	◦	◦	◦	◦	◦	-	◦
2.	**Baruun 4 zam (UB2)**	Roadsite	47°54'55.8" N 106°53'40.2" E	◦	◦	◦	◦	-	◦	◦
3.	**1-r horoolol (UB3)**	Ger area	47°55'7.68" N 106°50'52.08" E	◦	◦	◦	◦	◦	◦	◦
4.	**Bukhiin urguu (UB4)**	Residential	47°55'3.36" N 106°56'15" E	◦	◦	◦	◦	◦	◦	◦
5.	**100 ail (UB5)**	Ger	47°55'58.8" N 106°55'17.04" E	◦	◦	◦	◦	◦	-	◦
6.	**Mongol gazar (UB7)**	Industrial	47°54'18.36" N 106°50'30.84" E	◦	◦	◦	◦	-	-	◦
7.	**Urgakh naran (UB8)**	Remote	47°51'59.4" N 107°7'4.8" E	◦	◦	◦	◦	◦	-	◦
8.	**Tolgoit (APRD1)**	Ger area	47°55'20.28" N 106°47'39.84" E	◦	◦	◦	◦	◦	◦	-
9.	**Televiz (APRD2)**	Ger area	47°55'47.28" N 106°53'17.88" E	◦	◦	◦	◦	◦	◦	-
10.	**Amgalan (APRD3)**	Roadside	47°54'48.6" N 106°59'52.8" E	◦	◦	◦	◦	◦	◦	-
11.	**Nisekh (APRD4)**	Ger area	47°51'51.84" N 106°46'41.88" E	◦	◦	◦	◦	◦	◦	◦
12.	**Bayankhoshuu (APRD6)**	Ger area	47°57'28.08" N 106°49'22.8" E	◦	◦	-	-	-	◦	◦
13.	**US Embassy**	Residential	47°55'42.0213" N 106°55'48.8498"E	-	-	-	-	-	◦	-

Figure 3.3 shows the street view of seven selected monitoring stations and their surroundings. "Baruun 4 zam" is classified as a roadside location, "100 ail", "Televiz", and "Tolgoit" are classified as ger locations, "Mongol Gazar" is classified as an industrial location, and "Urgakh Naran" is classified as a distant location.

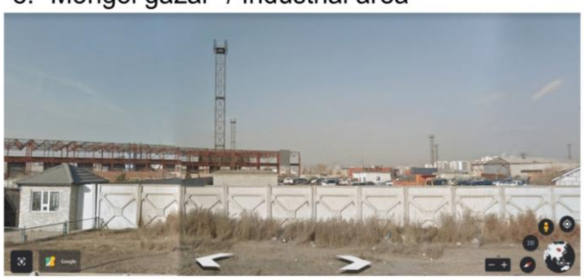
a. “Baruun 4 zam” / Roadside area

b. “Bukhiin Urguu” / Residential area

c. “100 ail” / Ger area

d. “Televiz” / Ger area

e. “Mongol gazar” / Industrial area



f. “Urgakh Naran” / Remote area

g. “Tolgoit” / Ger area

Figure 2.Selected monitoring locations and surroundings

3.2 Methods

Measurement is the foundation for all study and research. To be sure of types of errors such as random which involve unpredictable fluctuations in external conditions, one hundred percent accurate detection by sensing and monitoring instruments is not possible with any method. Owing to this reason, the analysis is based on an immense amount of raw data, which means the first stage has been analyzing unprocessed data. Without this, the study and processing would be inaccurate and erroneous. That helps us to understand unknown numbers. The following steps are included:

- The data is provided excel file with “exl” file extension;
- To verify minus values and then remove it from;
- To examine over ranged values, such CO value with greater than 10000 µg/m3 has been eliminated, due to some random errors.

Figure 3.2 provides a quick graphical and numerical summary of data with summary statistics and plots of variable distributions for the overall stations. As shown in Figure 3.3, the summary of data which are include:

1. Percentage and number of missing data: Red intervals reveal where the error is. For example, the number of missing data is 710 which is 1.2 percent of the total data.
2. Min, max, median and median are calculated in the SummaryPlot function.
3. Histogram of overall data: Which values are the most overlapped.

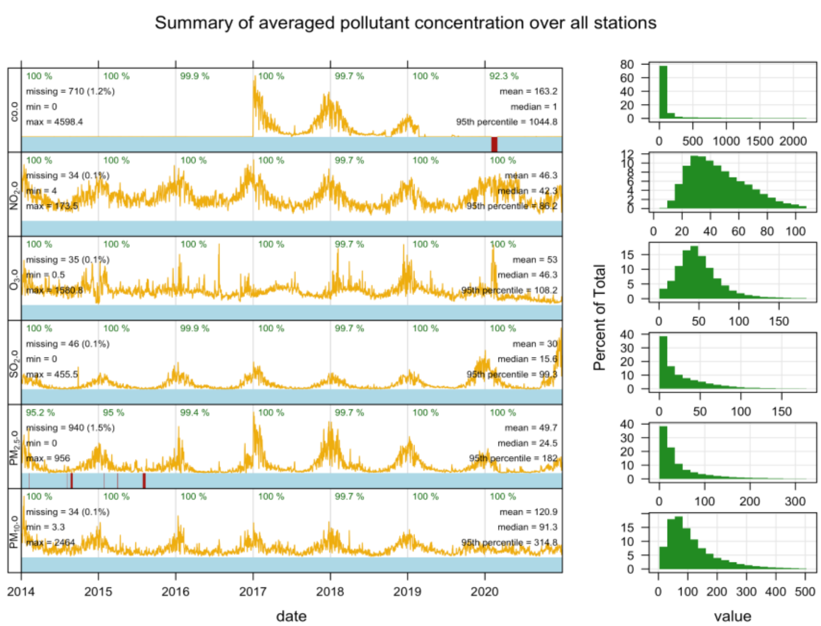


Figure 3.Summary of pollutant concentration data averaged over all stations

Chapter 4: Results

4.1 General characteristics of air pollutants

Due to the pollutant sources because of the population and the rapid urban development, industrialization, traffic ingestion, and coal consumption, the Ulaanbaatar city experiences air pollution sometimes far exceeding the Mongolian national air quality standard MNS 4585:2016. Figure 4.1 shows the time series of monthly mean concentrations of air pollutants (PM10, PM2.5, NO_2, SO_2, CO, and O_3) averaged over all monitoring sites between 2014 and 2020 in Ulaanbaatar. To extend Figure 4, Table 4 and Figure 5 summarizes the quantitative information of pollutant concentrations. The overall mean concentrations are 117.64, 49.47, 46.26, 29.99, 163.23, and 52.99 $\mu g/m^3$ for PM10, PM2.5, NO_2, SO_2, CO, and O_3, respectively. It is seen that PM10 exceeds the Mongolian National Air Quality Standard (MNAQS), which is 100 $\mu g/m^3$ daily average, while other pollutants do not exceed the permissible level in general. During the study period, the highest overall mean $PM_{2.5}$ concentration of 956 $\mu g/m^3$, which is ~19 times higher than the national air quality daily mean standard level, occurred on January 15th, 2016, while the highest overall mean PM_{10} concentration of 2464 $\mu g/m^3$ (~24 times the national air quality standard level) occurred on January 11nd, 2014. In addition, the hourly maximum concentration of SO_2, NO_2, O_3, and CO was recorded as 455.48 $\mu g/m^3$ (December 24th, 2020), 173.5 $\mu g/m^3$ (May 27th, 2020), 1580.75 $\mu g/m^3$ (December 26th, 2014), and 4598.44 $\mu g/m^3$ (January 12th, 2017), respectively (Table 4). They are 50.6%, 42.4%, 90.5% and 34.76% higher than the Mongolian national daily mean value in SO_2, NO_2, O_3 and CO. Compared to 2017, in 2020, the concentrations of PM10 and PM2.5 are decreased by 45.8% and 62.5%, respectively, while the concentrations of NO_2, SO_2, and O_3 are slightly increased between 2014 and 2020. It should be highlighted that the SO_2 concentration has been constantly rising for the last two years. The monthly mean pollutant concentrations of six criteria pollutants have regularly and frequently fluctuated in seasons. Seasonal variations are analyzed in Chapter 4.3.

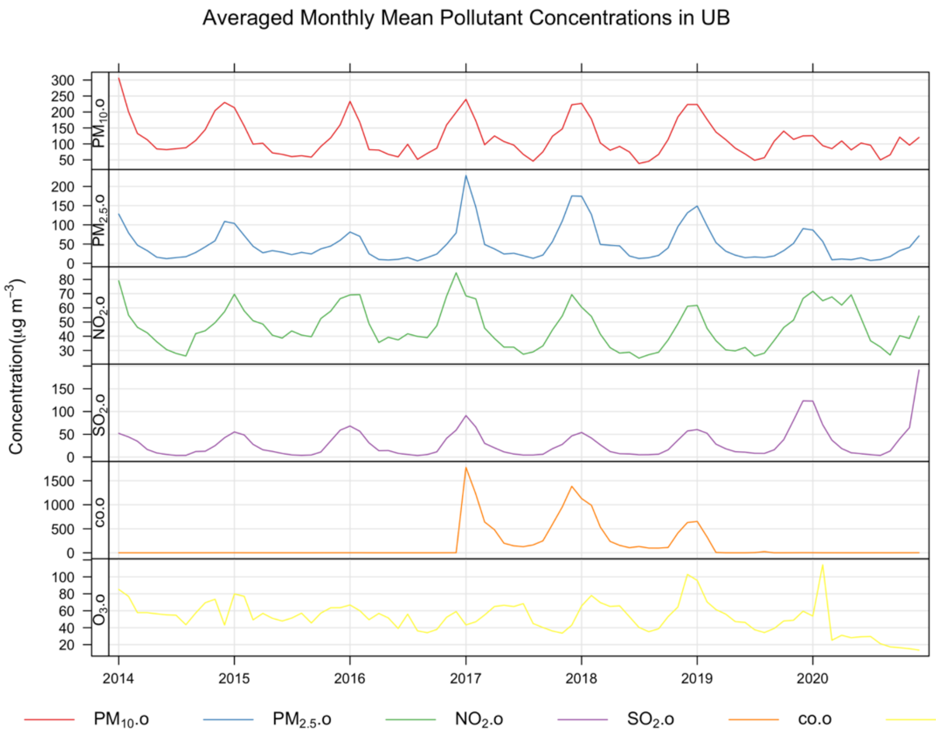


Figure 4.Averaged Monthly Mean Pollutant Concentrations in UB

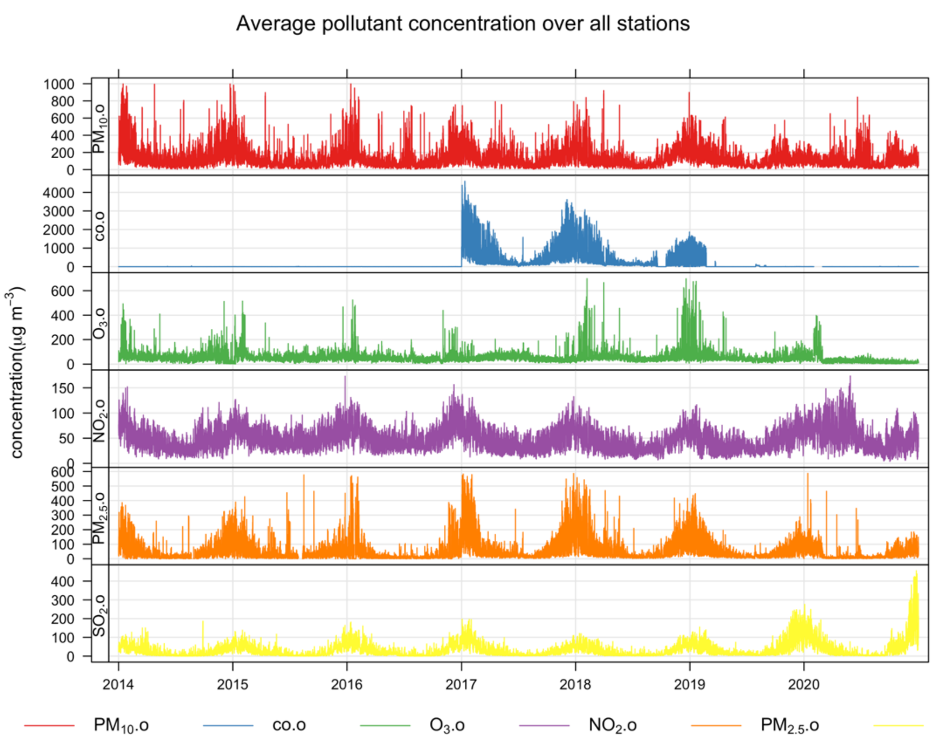


Figure 5.Time series of the averaged pollutant concentrations

4.2 Characteristics of pollutants at different sites

Table 4. shows the average concentrations of air pollutants over different types of sites (ger, traffic, remote, residential, and industrial). The concentrations are averaged over time (2014-2020). PM10 concentration is the highest in ger area sites, while it is the lowest in remote sites. Ratio between ger and remote areas is 53.3% that means PM10 concentration in ger area is almost 2 times greater than that in remote area. In addition, average concentrations of PM2.5, SO_2, and CO in ger area are 82, 42.2 and 305.5 µg/m^3, respectively. It indicates that most pollutants are released from ger area and also interestingly, the CO concentration in ger area is approximately 527 times greater than that in remote area. For NO_2 and O_3, greater concentrations are measured in traffic areas to 71.6 and 103 µg/m^3, respectively, and their average concentration levels are 30.5% and 2.9% higher for NO_2 (24-hour average) and O_3 (8-hour average) are greater than the national standard values, respectively.

Table 4.Average concentrations of air pollutants over different types of sites (ger, traffic, remote, residential, industrial). The concentrations are averaged over time (2014-2020). The thick values indicate the maximum among the different types of sites.

	Average (Max)	Ger	Traffic	Residential	Industrial	Remote
PM10	117.6±95.9 (998)	163.6±183.7 (1998)	77.6±71 (399)	103.5±81.1 (399)	103.8±76 (399.5)	87.2±93. (998)
PM2.5	49.5±65.7 (587.3)	82±105.2 (1269.5)	53.6±61.9 (556.6)	29.5±44.6 (1061)	-	-
SO_2	29.9±38 (455.5)	42.2±65.4 (1002.2)	27.3±31.6 (457.1)	24.9±31.9 (381)	19.6±25.4 (580)	21.2±26.5 (447)
NO_2	46.3±21.3 (173.5)	36.2±22.1 (204)	71.6±34.9 (347)	61.1±27.9 (280)	35.5±24.3 (185)	26.9±24.4 (240)
O_3	52.9±39.7 (1580.7)	38.7±56.2 (2265.2)	103±71 (399)	25.9±28.3 (299)	27.3±22.6 (200)	36.5±23.3 (164)
CO	163.2±424.9 (4598.4)	305.5±759 (7957.7)	156.6±480.6 (9749.9)	0.8±1.0 (12.7)	0.8±0.9 (17.1)	0.5±1.5 (92.5)

These below Figure 6 reveal the averaged pollutant concentration over 5 grouped area between 2014 and 2020.

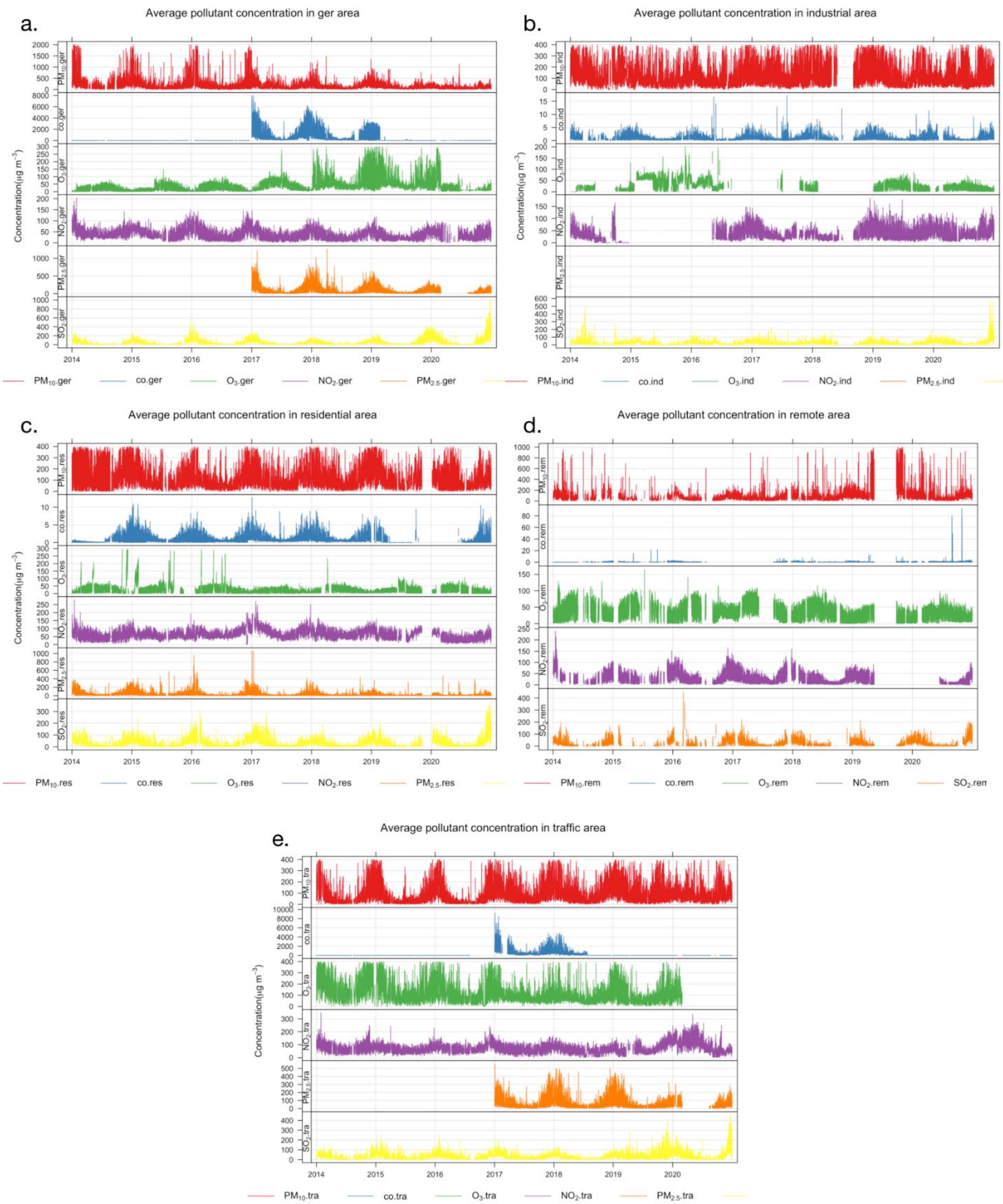


Figure 6.Pollutant concentrations over different types of sites in Ulaanbaatar

Detailed characteristics of each criteria pollutant are further described.

4.2.1 Carbon Monoxide (CO)

Time series of monthly mean pollutant concentrations of CO at sites of five different categories during 2014-2020 were shown in Figure 7 and Figure 8. The highest monthly mean concentration of CO was at ger sites and the lowest level was found in remote area. Due to high values at ger and traffic sites, the time series of monthly mean CO concentration is separated into two figures, which are (figure 7) industrial, remote and residential and (figure 8) traffic and ger areas, respectively. In addition, it was revealed that CO in ger and traffic sites are steadily fluctuated until December 2016 and then they have sharply increased January 2017 that have approximately raised from 5.6 to 2850 in ger, and from 4 to 2150 µg/m^3 traffic area, which have increased by 99.8% and 99.8%, respectively. But after that CO concentrations have regularly decreased and returned to normal level since March 2019. As for residential, remote and industrial groups, 3 lines and limits have indicated normal CO concentrations which have maximum value at 2.4 (November 2016) and 1.95 (November 2017), 1.9 (August 2020) µg/m^3 in residential and industrial, and remote sites, respectively. Generally, the concentration starts to rise from August and peaks in November or December (winter months).

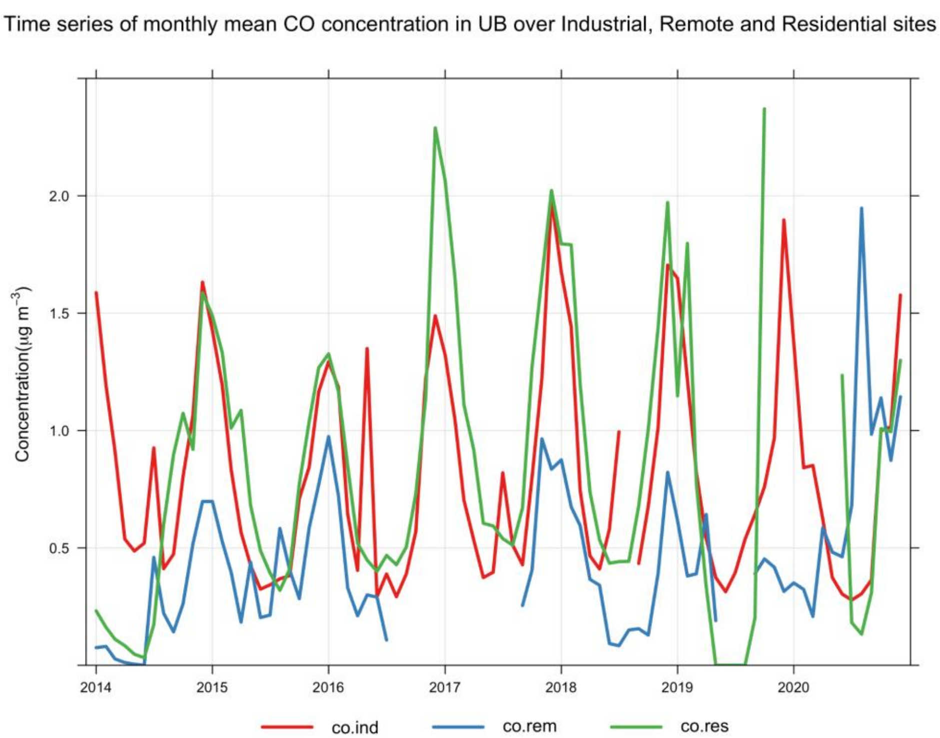


Figure 7.Time series of monthly mean CO concentrations at industrial, remote, and residential sites

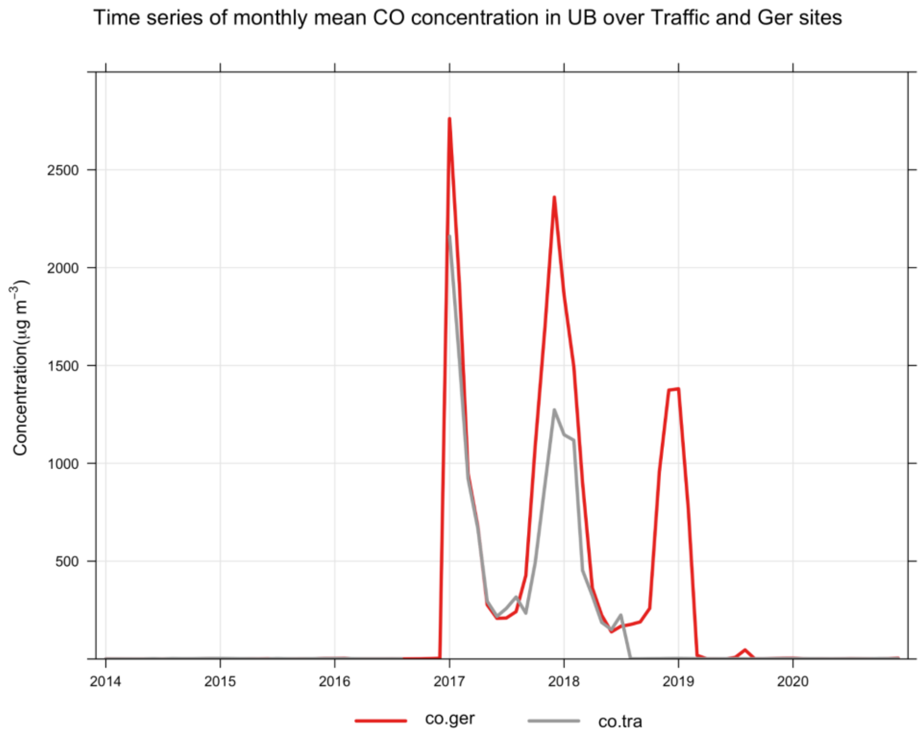


Figure 8.Time series of monthly mean CO concentrations at traffic and ger site

Monthly, weekly, and daily variations in CO concentrations averaged across the air quality monitoring sites during the study period are depicted in Figure 9. We can see the analysis of ger and remote areas, while other categorized groups indicate zero values because they (almost 420 less than) can not reach the value of red and blue lines. On weekdays, the daily mean concentrations were somewhat greater than that on weekends. The weekend, especially on Saturday, shows the lowest concentrations of 280 µg/m^3 in the ger area and 142 µg/m^3 in the traffic area. The daily variations in concentrations in ger and traffic areas were nearly identical - the largest CO concentrations occurred on Thursday (320 µg/m^3 and 168 µg/m^3 , respectively). In general, the CO concentration at ger sites was maximum from Tuesday to Thursday, and minimum on Monday. The procedure of increasing traffic sites occurred from Monday to Thursday. For the hourly variation of CO concentration, the lowest value in ger and traffic sites emerged around 4 p.m. before the evening peak reaching 105 µg/m^3 and 99 µg/m^3, respectively. Afterwards, CO concentration in ger and traffic areas were constantly increased until 11 p.m. (425 µg/m^3) and 9 p.m. (205 µg/m^3), respectively. The maximum values in ger and traffic sites for monthly mean variation happened in January which are 960 and 490 µg/m^3, respectively, while lowest values occurred in June which are both approximately 55 µg/m^3. For generally, CO concentrations were dropped January to June, and then were raised until December (middle of winter months).

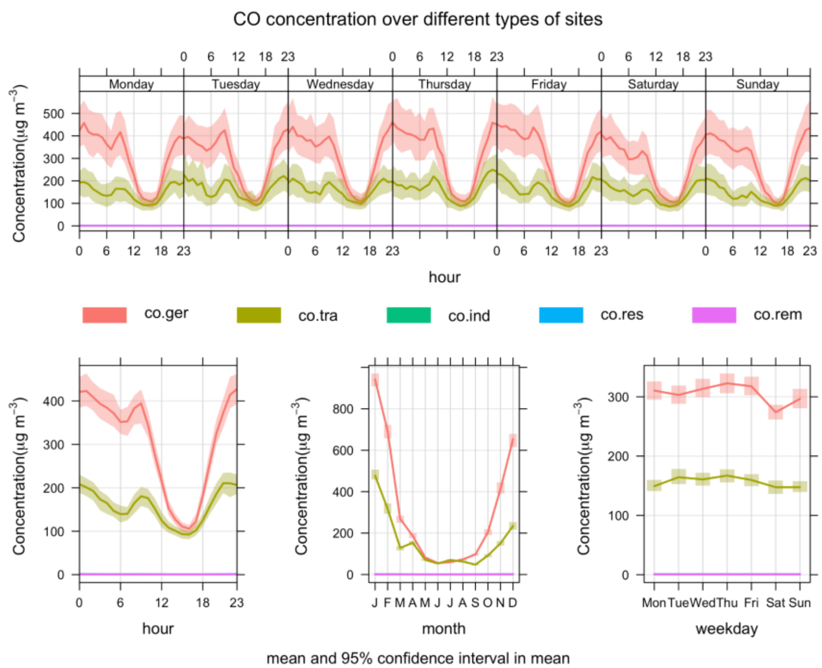


Figure 9.Time variations of CO concentrations over different types of sites

The bellow Figures 10 and 11 demonstrate the frequency of carbon monoxide over ger and roadside locations, as well as industrial, distant, and residential areas, respectively, to highlight which sites and areas are the most common. Due to the huge number of differences, CO Histogram analysis is divided into two figures, as shown in Table 4, where carbon monoxide average concentrations in ger and residential are 305.47 and 0.8 µg/m^3, respectively.

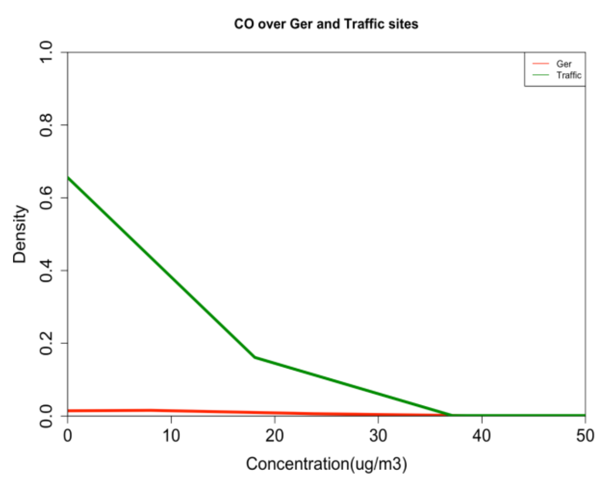


Figure 10.Histogram of CO over Ger and Traffic sites

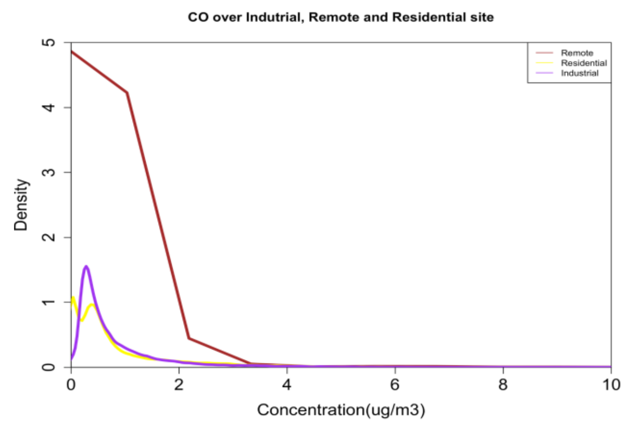


Figure 11.Histogram of CO over Industrial, Remote and Residential sites

4.2.2 Sulfur Dioxide (SO_2)

Figure 12 shows the monthly mean SO_2 concentrations in five distinct areas, indicating that the ger area is a major source of SO_2, whereas the industrial area has the lowest concentration. In the ger area, SO2 concentrations decreased from 2016 to 2018 and reached its peak in October 2020, its pattern is the same as in residential areas. The peak values of ger (residential) site in 2016, 2018, and 2020 is 154 µg/m^3 (87.5 µg/m^3) in January, 68.5 µg/m^3 (40 µg/m^3) in January, and 200 µg/m^3 (129 µg/m^3 in November) in October, respectively. The green line reveals industrial sites that are regularly fluctuating, but the highest point and increasing rate appeared in November 2020. For example, the maximum level in 2014 (48 µg/m^3) is less than 58.2% from 2020 (115 µg/m^3). In the overall picture of Figure 12, SO2 concentrations in residential, rural, industrial, and traffic sites are increased dramatically in 2020, with values about twice as high as in 2019.

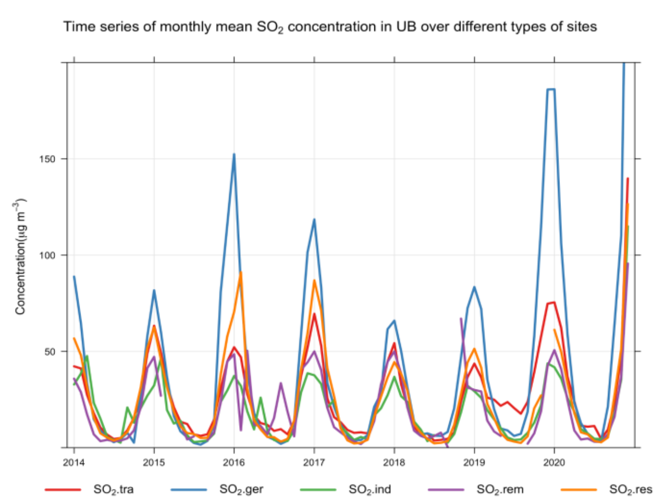


Figure 12.Time series of monthly mean SO2 concentrations over all stations.

Figure 13 provides hourly, weekly, and monthly variations of SO_2 concentration. SO_2 concentration is the greatest in ger area. The following highlights are revealed reveals at different sites:

1. Ger: The greatest SO_2 concentration is found. The peak value reaches on Friday which is 43.5 µg/m^3 and then decreased until the end of the weekend (40.8 µg/m^3).
2. Traffic: The second highest SO2 concentration among different types of sites is found in traffic area. The area's greatest concentration was noted (38 µg/m^3) on Thursday. The lowest concentrations are shown on weekends with a minimum of 26.5 µg/m^{3}on Saturday. From Monday through Wednesday, SO_2 varies little.
3. Residential: Residential sites follow the same pattern as the traffic area. 26 µg/m^3 (on Thursday) was the highest number, while 24 µg/m^3 (on Saturday) was the lowest. The maximum concentration at residential sites is 1.6 times lower than that at ger sites.
4. Remote: Its figure was the same as the ger area, but the value of the remote area was 2 times lower than the ger area. The maximum concentration occurs on Friday and the minimum on weekends.
5. Industrial: The maximum level of 20.5 µg/m^3 reaches on Wednesday, and thereafter the readings declined till Saturday (18.3 µg/m^3).

The daily variation of SO_2 concentration showed a "W"-like shape. The minimum SO_2 concentration occurs at approximately 5 p.m., 7 a.m., 7 a.m., 6 a.m., and 6 a.m. at ger (29.8 µg/m^3), traffic (21 µg/m^3), residential (16 µg/m^3), remote (10 µg/m^3)and industrial (9 µg/m^3) sites, respectively. Daytime peaks of SO_2 concentration in ger, traffic, residential, remote, and industrial areas appeared between 11 a.m. (53 µg/m^3), 12 p.m. (33.5 µg/m^3), 1 p.m. (31 µg/m^3), 12 p.m. (25 µg/m^3), and 1 p.m. (26.5 µg/m^3), respectively, as well as around midnight. The morning increase might be attributed to a "rush hour" caused by cooking and space heating, as well as traffic resuspension and particle emissions (ger area), whereas primary emissions played a significant role at night.

For the monthly variations, its shape resembles an "U"-like shape and the lowest value at all sites occurred simultaneously approximately 6-10 µg/m^3 in August. During summer months, the traffic sites experience higher SO_2 compared to other sites. The reason can be explained by SO_2 source emissions being higher emission from vehicle fuels and reduced emissions in other areas.

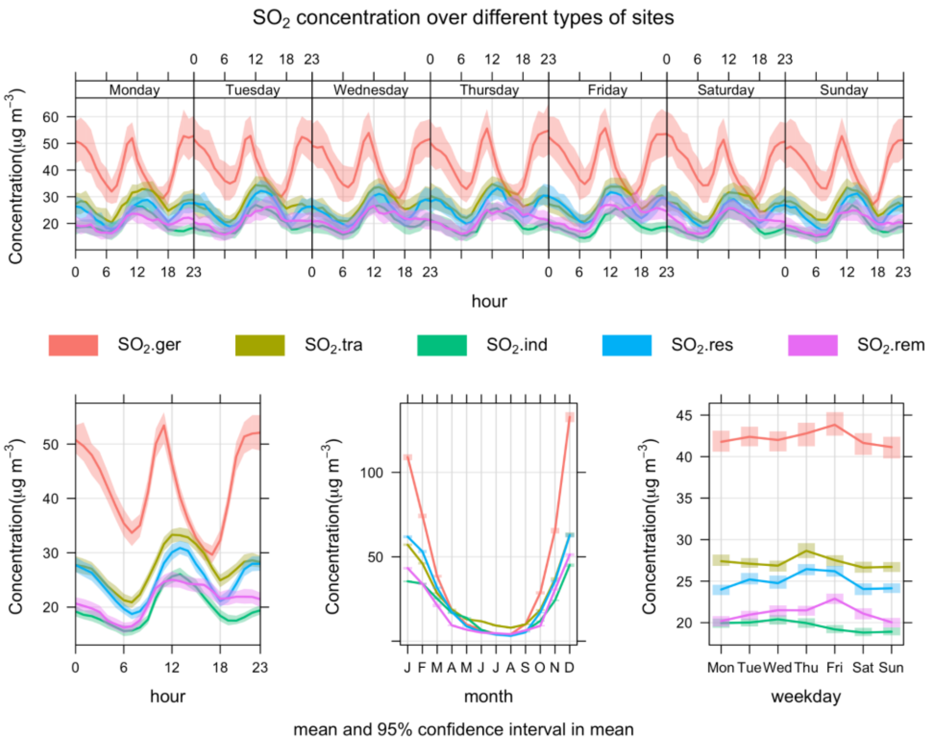


Figure 13.Time variations of SO2 concentrations at different types of sites

In this Figure 14, you can see occurrences of SO_2 concentrations in all over areas. For all categorized areas, the maximum density happened between 4 to 9 µg/m^3 concentration and the relationship between density and concentration were inversely proportional to each other. From this information, SO_2 convention is generally constant in all stations.

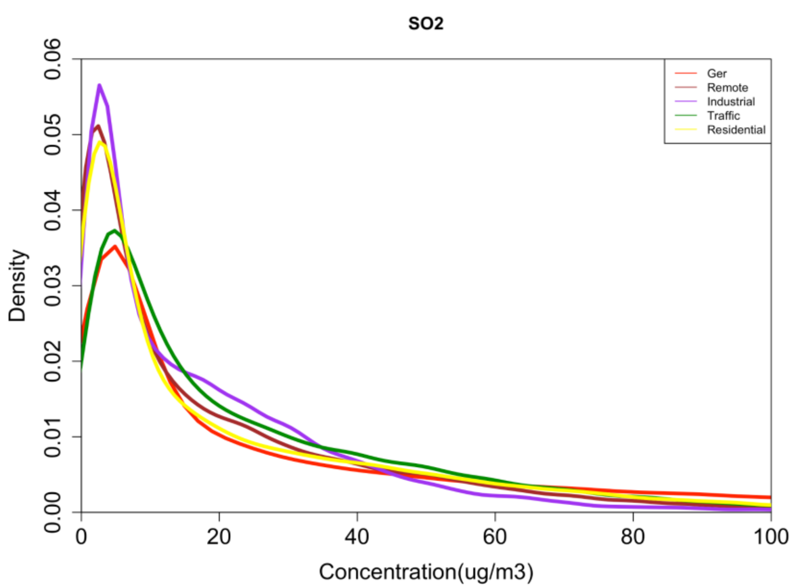


Figure 14.Histogram of SO2 over all stations

4.2.3 Nitrogen Dioxide (NO_2)

Figure 15 shows the time series of monthly averaged NO_2 concentrations at different locations. The greatest NO_2 concentrations were found at traffic sites (the highest peak value is 142.86 µg/m^3) while the lowest levels were found in remote areas (the lowest peak value is 32.47 µg/m^3), indicating substantial NO_2 pollution in traffic area. General overview of this figure, the yearly maximum values were reached in December and January, whereas the lowest values were observed in summer months (June, July, and August). NO_2 concentrations at remote and residential sites have risen from 2015 to 2017 and subsequently fell until 2020, with the greatest value in remote sites being 52.9 µg/m^3, 76.38 µg/m^3, and 32.47 µg/m^3 (for residential, 68.48 µg/m^3, 132.53 µg/m^3, and 77.82 µg/m^3). The ratio between 2017 and 2020 is 1:2.35 and 1:1.7 for remote and residential, respectively. As for the ger and industrial areas, the NO2 concentrations appeared to be stable. In 2016, 2017, 2018, 2019, and 2020, the maximum of monthly mean value of ger (industrial) area is 71.82 (68.6) µg/m^3, 58.53 (60.1) µg/m^3, 53.16 (64.4) µg/m^3, 54.04 (63.97) µg/m^3, and 53.1 (63.31) µg/m^3, respectively. NO2 concentration at traffic location is 142.86 µg/m^3 and 144.2 µg/m^3 in January and April 2020, respectively, were much higher than in other months such as the top value in January 2020 was 1.6 times higher than in January 2018 (86.1 µg/m^3).

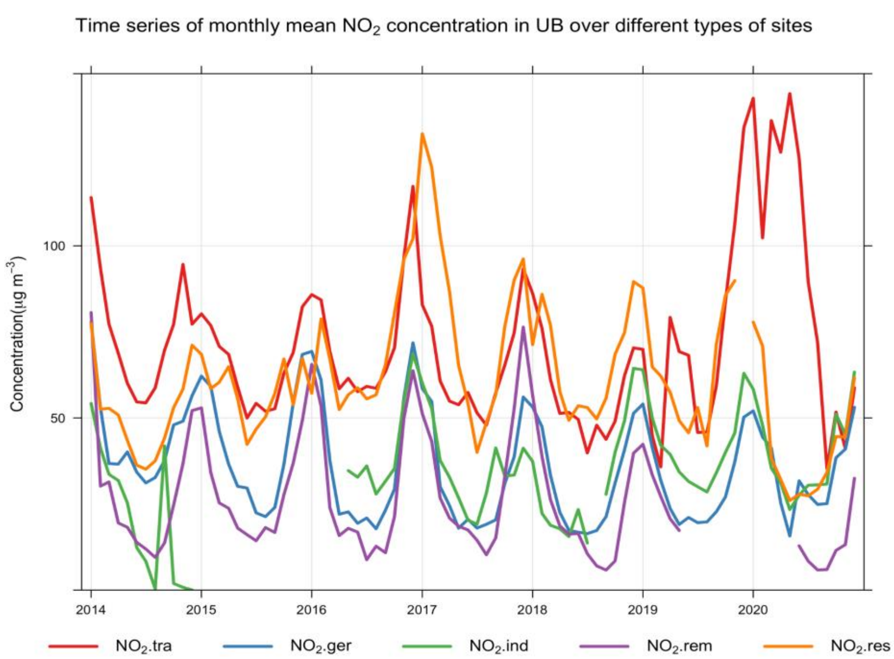


Figure 15.Time series of monthly mean NO2 concentrations over all stations

The variations of hourly, weekly, and monthly averaged NO_2 concentrations are illustrated in Figure 16. The greatest values for traffic, residential, ger, and industrial sites were found typically on Thursday or Fridays being 75 μg/m^3 (Friday), 65 μg/m^3 (Friday), 47.3 μg/m^3 (Friday), and 46.9 μg/m^3 (Thursday), respectively. In remote areas, the weekly maximum was 38 μg/m^3 on Wednesday. On weekends, the lowest NO_2 concentrations were found at all locations. NO_2 concentrations in traffic, residential, ger, industrial, and rural places were 68.5 μg/m^3 (Sunday), 58.5 μg/m^3 (Sunday), 44.5 μg/m^3 (Sunday), 43 μg/m^3 (Saturday), and 34.8 μg/m3 (Saturday), respectively. They were then gradually raised till the peak days. Ger, industrial, and remote areas meet the 24-hour mean permissible value of national standard MNS 4585:2016 (50 μg/m^3) while the rest two groups do not meet the national standard value. For the hourly averaged NO_2 concentration in 2014 to 2020, it shows maximum at 9-11 p.m. NO_2 levels at all sites shows at two peaks:

- Traffic: 11 a.m. and 9 p.m., 73 and 87 μg/m^3, respectively.
- Residential: 10 a.m. and 10 p.m., 61.5 and 76 μg/m^3, respectively.
- Ger: 10 a.m. and 10 p.m., 40 and 49.7 μg/m^3, respectively.
- Industrial: 7 a.m. and 11 p.m., 36 and 50 μg/m^3, respectively.
- Remote: 9 a.m. and 10 p.m., 26.5 and 38.5 μg/m^3, respectively,

They are Indicating which can be attributed to shifts in traffic hours in the city.

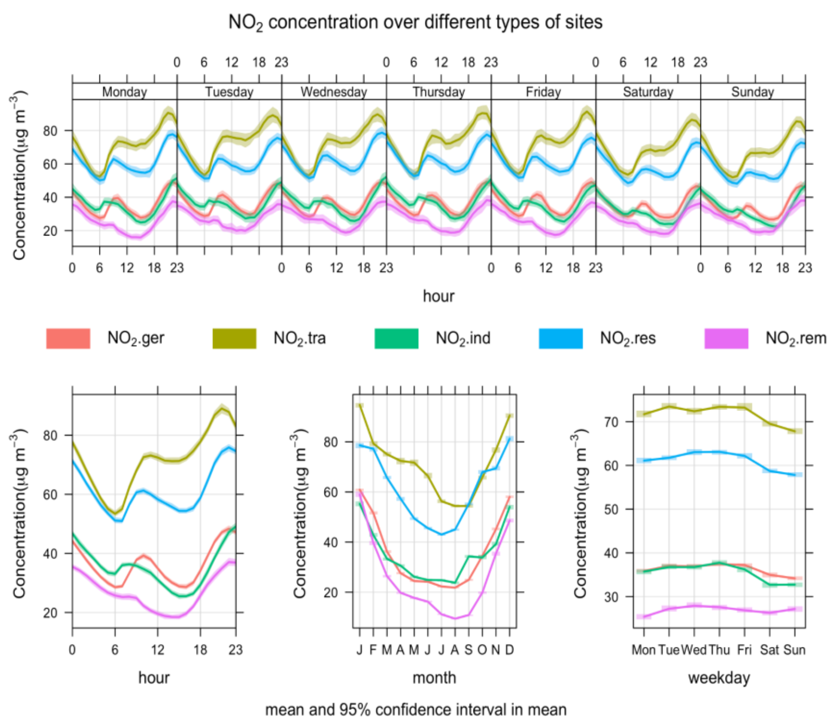


Figure 16.Time variations of NO2 concentrations over different types of sites

As you can see Figure 17, Histogram of averaged NO_2 concentrations in all areas from 2014 to 2020. In this study, the maximum occurrences of ger, industrial, traffic, residential and remote were approximately 15, 15, 56, 48 and 11 µg/m^3 respectively.

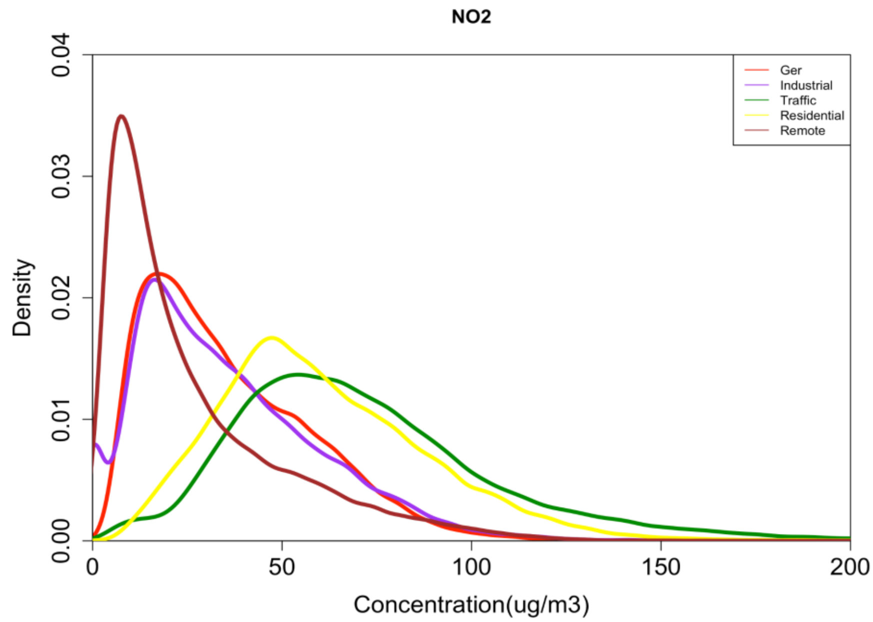


Figure 17.Histogram of NO2 over all stations

4.4.4 Particulate Matter (PM10 and PM2.5)

The purpose of this section is to give an overview of Ulaanbaatar's monthly mean PM pollutant characteristics. Monthly averaged PM2.5 and PM10 concentrations from 2014 to 2020 are shown in Figures 18 and 19, respectively. Measurement of PM2.5 are done at three locations - ger, traffic, and residential. Both PM2.5 and PM10 concentrations occurred dominantly in ger areas which are 316.99 µg/m^3 (January 2017) and 565.8 µg/m^3 (January, 2014). For the national standard MNS 4585:2016, the daily annual permissible level are 100 µg/m^3 (PM10) and 500 µg/m^3 (PM2.5). For the study period, the concentrations of PM10 and PM2.5 are 5.15 and 7.2 times higher than the Mongolian National Standard, respectively. Due to several monitoring reasons, PM2.5 data were not measured in ger and traffic stations between 2014 and 2020. The lowest peak values of PM10 (100.47 µg/m^3 in December 2020) and PM2.5 (25.71 µg/m^3 in December 2020) were investigated in traffic and residential areas, respectively. From 2014 to 2019, the overall trend of PM10 in traffic, residential, and industrial settings was constantly oscillating, and then they were considerably reduced in 2020, with greatest peak values of 159.55 µg/m^3, 185.41

μg/m³, 181.58 μg/m³ and lowest peak values of 100.47 μg/m³, 128.82 μg/m³, and 116.92 μg/m³, respectively. As for the Figure 19, it is clearly seen that PM2.5 is steadily decreasing in ger, traffic, and residential sites for the last few years. Between 2017 and 2020, their peak values in ger , traffic and residential areas dropped from 316.9 μg/m³ to 140.5 μg/m³, 81.7 μg/m³ to 113.7 μg/m³ and 78.4 μg/m³ to 25.7 μg/m³, respectively. According to this data, the ger area has the lowest levels of PM10 and PM2.5 from 2017 to 2020, the decreasing rates are 57.1% and 64.1%, respectively.

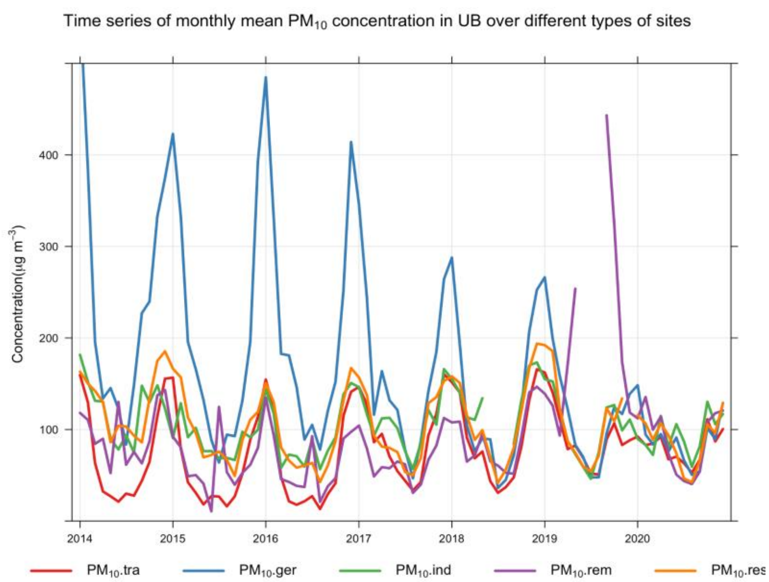


Figure 18.Time series of monthly mean PM10 concentrations over all stations

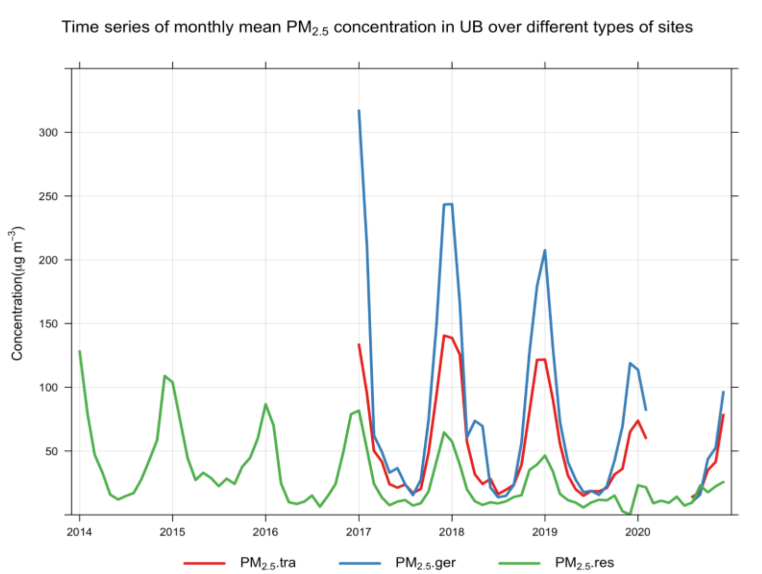


Figure 19.Time series of monthly mean PM2.5 concentrations over all stations

Hourly, daily, and monthly PM2.5 and PM10 concentrations are illustrated in Figures 20 and 21, respectively. The maximum of the hourly mean PM2.5 and PM10 concentrations were 111 μg/m^3 and 215 μg/m^3, respectively, at ger sites at 10 p.m. The general characteristics of 5 sites show "W"-like variation with following oscillations:

- First oscillation: The reduction between early morning and morning (12-1 a.m. to 6-8 a.m.)
- Second oscillation: The rise between morning and early late morning (6-8 a.m. to 10-11 a.m.)
- Third oscillation: The reduction between late morning and early evening (10-11 a.m. to 17-19 p.m.)
- Fourth oscillation: The rise between early evening and late evening (17-19 p.m. to 10-11 p.m.)

During the study period, daily mean PM2.5 and PM10 concentrations considerably exceeded national air quality standards. Workdays had higher average daily mean concentrations than weekends. The lowest concentrations were recorded during the weekend - 148 μg/m^3, 100 μg/m3, 100 μg/m^3, 86 μg/m^3, and 48 μg/m^3 for PM10 at ger, industrial, residential, remote and traffic sites, respectively, and 77.5 μg/m^3, 53 μg/m^3 and 20 μg/m^3 for PM2.5 at ger, traffic and residential sites, respectively. The variations in day-by-day peaks of PM2.5 and PM10 concentrations were same, the largest PM2.5 and PM10 occurred on Thursday or Friday:

- PM2.5: 87.5 μg/m^3 (Ger), 56 μg/m^3 (Traffic), and 31 μg/m^3 (Residential).
- PM10: 171 μg/m^3 (Ger), 108.5 μg/m^3 (Residential), 100 μg/m^3 (Industrial), 90 μg/m^3 (Remote), and 80 μg/m^3 (Traffic).

Industrial, remote, and traffic areas meet the national standard permissible level for PM10, while only residential area meets the national standard permissible level for PM2.5. The greatest value was found in January from monthly and seasonal analysis, followed by December. In addition, both PM2.5 and PM10 concentrations in winter months were much higher than those in other months, with average values in the ranges of 75-230 μg/m^3 for PM2.5 and 120-375 μg/m^3 for PM10. While the lowest levels were found in summer months and then increased after late summer months.

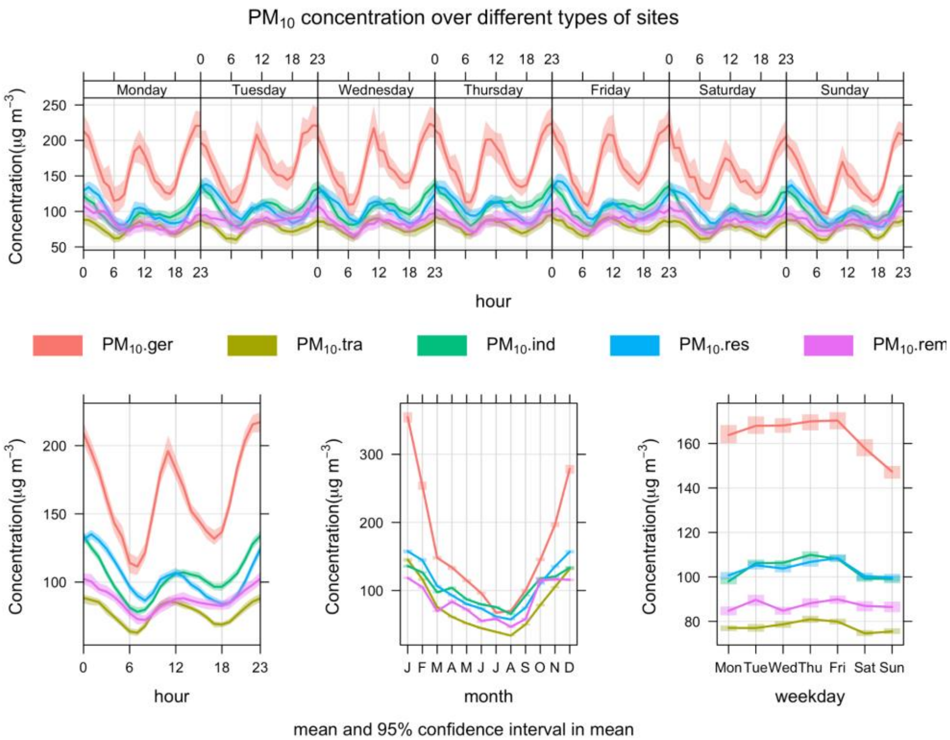


Figure 20.Time variations of PM10 concentrations at different types of sites

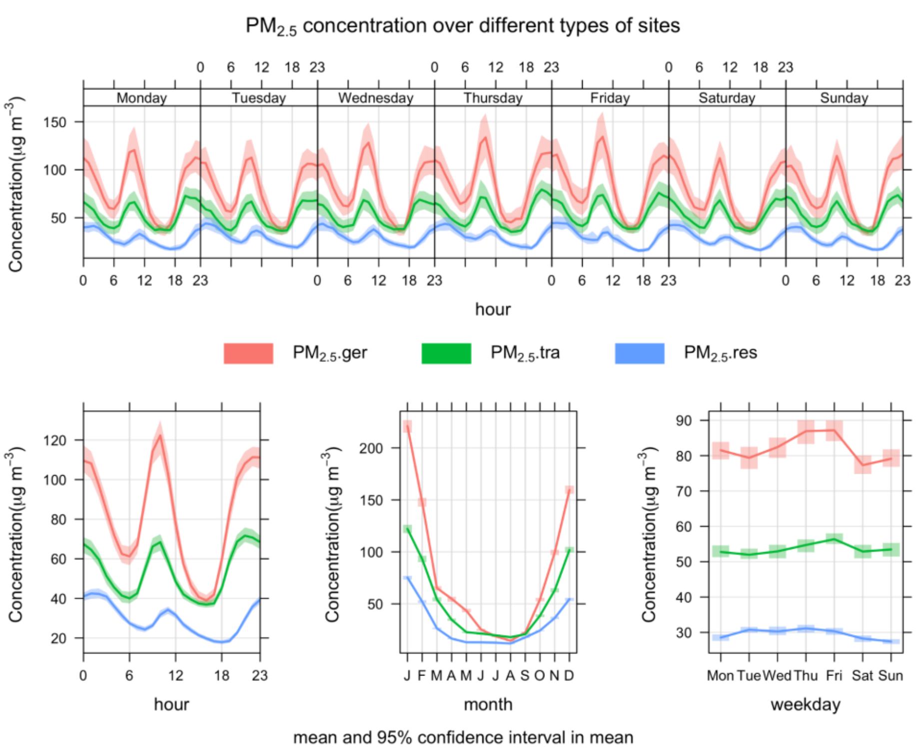


Figure 21.Time variations of PM2.5 concentrations at different types of sites

The frequency of PM10 concentrations from 2014 to 2020 are investigated in Figure 22. In ger, industrial, residential and remote areas, the greatest densities were between 46 to 49 µg/m^3, while for the traffic area it was 25 µg/m^3. For PM2.5 pollutant concentration from Figure 23, the high occurrences in traffic and ger areas were 16 µg/m^3. In the residential site, it was 7 µg/m^3.

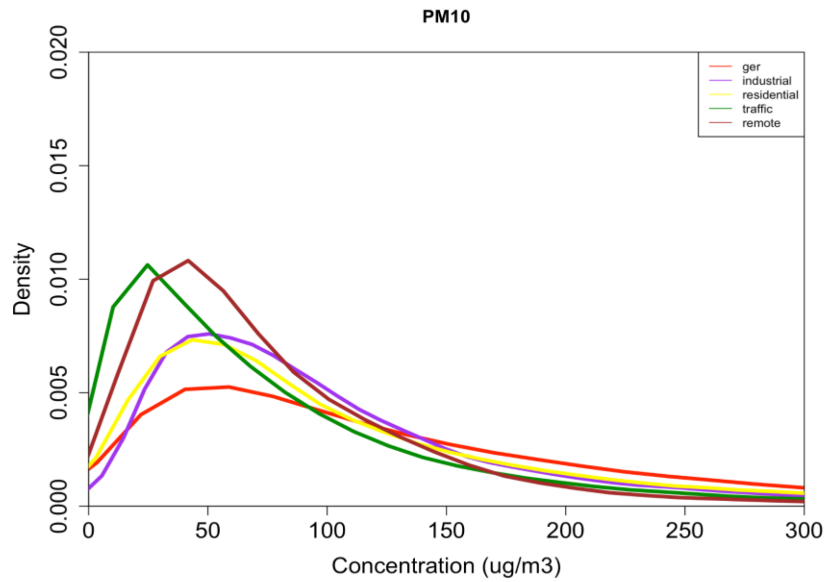


Figure 22.Histogram of PM10 over all stations

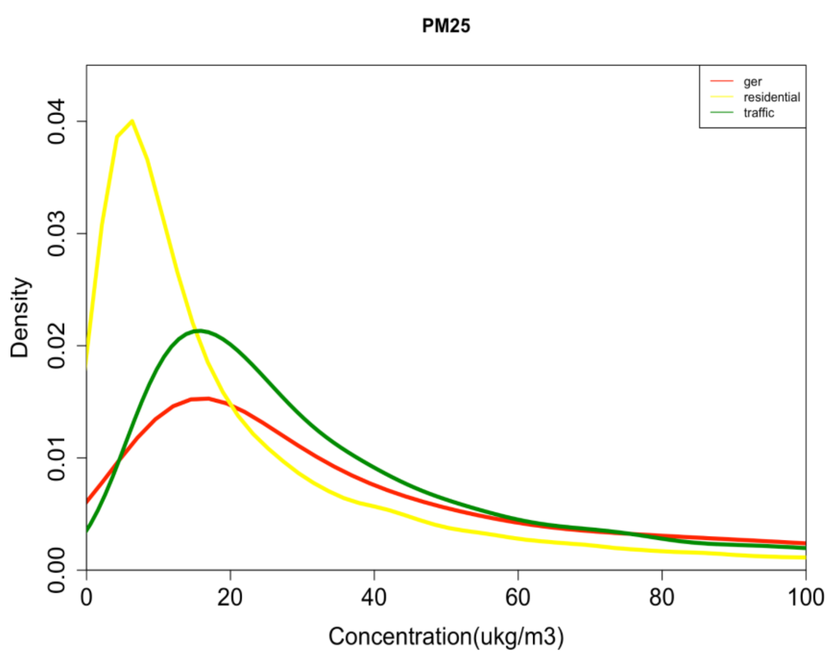


Figure 23.Histogram of PM2.5 over all stations

4.4.5 Ozone (O_3)

Monthly mean ozone concentrations at all different sites between 2014 and 2020 are shown in Figure 24. It is clearly seen that the O_3 concentration is the greatest in traffic area. Its highest values occur in wintertime (December, January and February) and the maximum value is measured in 2014 which is 221.1 µg/m^3 in January. It is almost twice as much as in 2020. In terms of general characteristics, O_3 concentrations decreased between 2014 and 2017, then increased somewhat between 2018 and 2019, after dropping in 2020. Except 2019, O_3 concentrations in the ger area have been steadily increasing for the past seven years. In 2020, the greatest value was 106.0 µg/m^3, which was 71.1% greater than in 2014 at ger areas. Intriguingly, its value declined in winter, and the maximum concentration was discovered in summer of 2014-2017. However, its monthly characteristics were reversed from 2018 to 2020. The highest ozone concentration for remote sites was 87.54 µg/m^3 (in July) in 2015, while the lowest position was 29.56 µg/m^3 (in September) in 2019. Its highest values declined year by year during that time. However, in comparison to 2019, values in 2020 (38.76 µg/m^3 in June) are increased. As you can see, the highest values occurred in early and late summer, not in winter. For the residential areas, 2015 (71.4 µg/m^3 in August), 2016 (62.69 µg/m^3 in July), 2017 (27.1 µg/m^3 in July), 2018 (41.9 µg/m^3 in April), 2019 (45 µg/m^3 in June) and 2020 (38.5 µg/m^3 in June) are all lower than in 2014 (73.6 µg/m^3 in December).

Except in the year 2014, the highest concentrations were seen during summer. The green line shows the lower pattern, which is industrial sites. Between May 2014 (17.6 µg/m^3) and November 2015 (76.7 µg/m^3), O_3 concentrations in this area spiked, then progressively fell from 2016 (51.2 µg/m^3 in April) through 2020. (22.3 µg/m^3 in July). Except for the ger area, O_3 levels decreased from 2014 to 2020, according to this data.

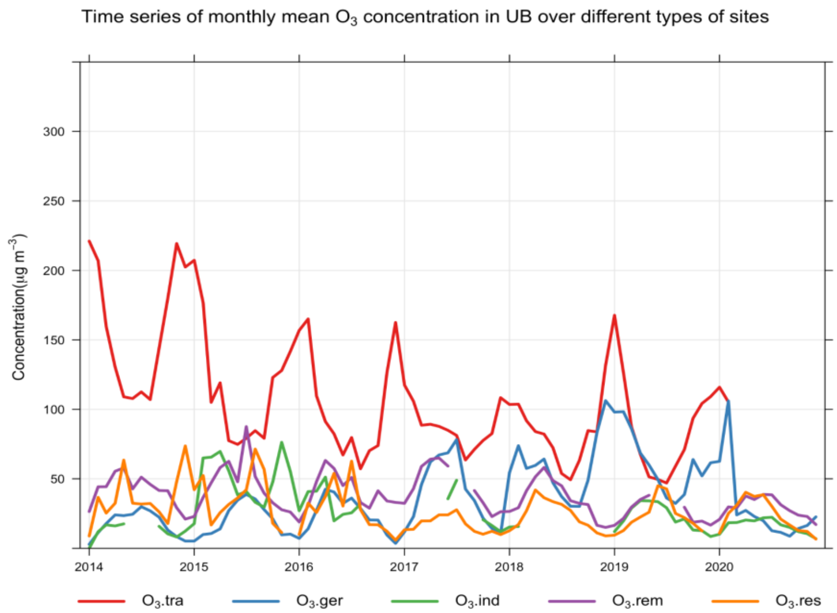


Figure 24.Time series of monthly mean O3 concentrations at all types of stations

Hourly, monthly, and weekly characteristics of O_3 are shown in Figure 25. According to the weekly investigation, the greatest O_3 concentration is found at traffic sites, which fluctuated during weekdays (peaking at 106 µg/m^3 on Thursday) and then fell from Friday to Sunday (99 µg/m^3). The O_3 concentrations at remote and ger sites were almost steady during the weekdays and overlapped each other on Monday, Tuesday, Thursday, Friday, and Saturday. The maximum value was 33 µg/m^3 in the distant area on Wednesday and 35 µg/m^3 in ger area on Sunday, while the lowest value was 31.5 µg/m^3 on Sunday and 29 µg/m^3 on Wednesday, respectively. For the industrial and residential sites, the concentrations were same on Monday and Sunday. The peak level at industrial site was 16.5 µg/m^3 on Thursday, while the lowest concentration at residential site was 9 µg/m^3 on Thursday. Except for the roadside area, none of the regions showed above 40 µg/m^3. Only the ger area had four phases, its “W'-like' shape and peak value at 1 a.m. (122.5 µg/m^3) and then decreased until 8 a.m. (79.5 µg/m^3) (repeated at 3 p.m. (111.5 µg/m^3) and 7 p.m. (94.5 µg/m^3)) for hourly information, while the rest had three. Industrial, remote, and residential areas in the further reaches of the country have similar trends which were elevated from 12 a.m. to 8 a.m. (remote: 25-31 µg/m^3, industrial: 22.5-23.5 µg/m^3, and residential: 18-20 µg/m^3) and then they reached the greatest values at 3 p.m. (52, 35.5, and 38 µg/m^3, respectively) before being reduced until 11 p.m. (27, 21 and 18 µg/m^3, respectively). The most intriguing feature was that in the ger area, the maximum value in January at 150 µg/m^3 (the lowest value occurred in July at 70 µg/m^3) in the monthly analysis was convex, whilst others were concave. The highest points for remote, ger, industrial, and residential occurred in late winter and early spring, with values of 53 µg/m^3 (in May), 48 µg/m^3 (in February), 37 µg/m^3 (in April), and 37 µg/m^3 (in May).

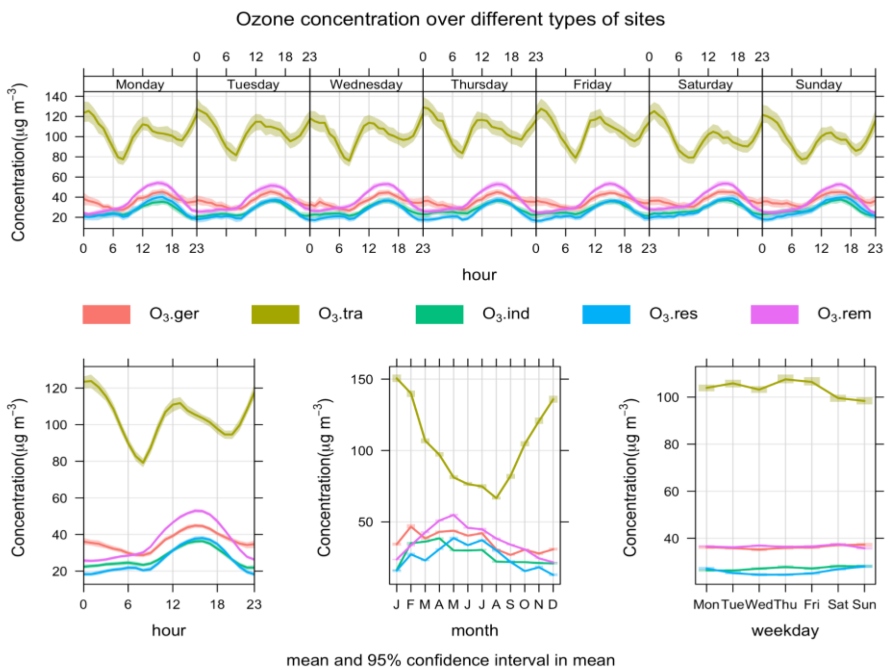


Figure 25.Time variations of O3 concentrations at different types of sites

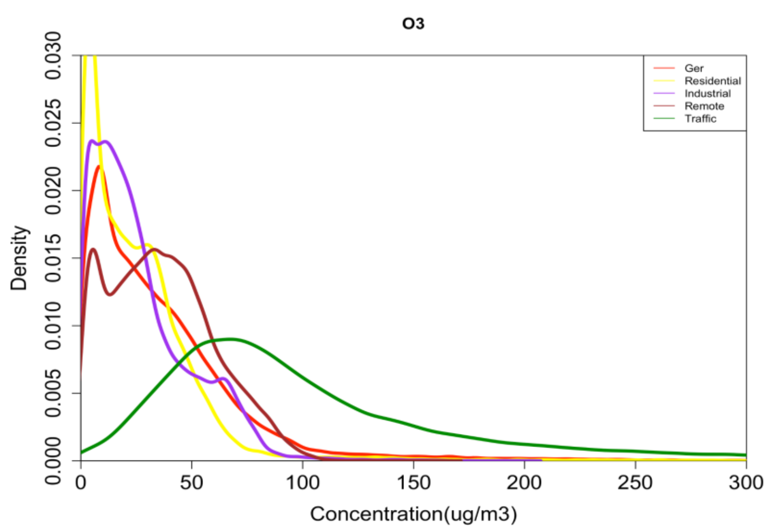


Figure 26.Histogram of O3 over all stations

4.3 Spatial distribution at various locations by seasons

As you can see in Tables 5-9, seasonal averages for all pollutants in the ger, remote, residential, industrial, and traffic areas for the study period were illustrated, respectively. Except for ozone, the highest levels of pollutants were reported in the winter, while the lowest levels were observed in the summer at various locations. For ozone, the averaged maximum concentration in ger, remote, residential, industrial and traffic were 41.53 (spring), 49.42 (spring), 34.84 (summer), 33.97 (spring), and 146.78 (winter) µg/m^3, respectively. Their minimum was 27 (summer), 26.41 (winter), 19.03 (autumn), 20.52 (winter) and 73.94 (summer) µg/m^3, respectively. Ger locations had the highest concentrations of PM10 (298.54), PM2.5 (175.9 µg/m^3), SO2 (105.95 µg/m^3), and CO (664.49 µg/m^3) in the tables, whereas their lowest values were shown in summer which are 3.98, 9.34, 21.1, and 11.58 lower than the highest occurrence, respectively. The greatest concentrations of nitrogen dioxide and ozone were found in the traffic area, at 88.08 and 146.78 µg/m^3 in winter, respectively, whereas the lowest amounts were 1.49 (summer) and 1.98 (summer) lower than the maximum, respectively. PM10 and PM2.5 concentrations for seasonal variation in five categories were not acceptable for the annual average Mongolian National Air Quality Standard. The yearly average MNAQS for sulfur dioxide was delivered at the permitted level to remote, residential, and industrial areas in the spring, summer, and fall, while SO2 concentrations were within annual allowable levels in the ger region in the summer and spring and summer for the roadside area. As for NO2 concentrations in ger, remote and industrial areas, the annual permissible values were investigated in spring, summer and autumn. Unfortunately, remote and traffic areas were not between the annual NO2 allowable amount in all seasons. In MNS 4595:2016, the allowable limit of ozone is 100 µg/m^3 in an average of hours. Consequently, it provided all categorized stations in the winter, spring, summer, and autumn, with the exception of traffic sites, which were exceeded in the winter (31.9 % greater than) and autumn (4.04 % higher than). Finally, carbon monoxide levels were found to be between 0.1 and 2 in remote, residential, and industrial areas, while traffic and ger levels were consistently over 100 µg/m^3 in all seasons.

Table 5.Seasonal averages for all pollutants in the Ger area from 2014 to 2020

Season	**Ger**					
	PM10	**PM2.5**	**SO2**	**NO2**	**O3**	**CO**
Spring	132.4 (195.7)	54.5 (73.7)	22.2 (58.5)	29.1 (46)	41.5 (86)	162.5 (946.5)
Summer	79.2 (148.4)	18.8 (36.6)	5.02 (9)	22.9 (34.2)	35.9 (78.2)	57.3 (241.9)
Autumn	149.6 (333.1)	58.6 (147.9)	34.6 (114.2)	34.9 (55.8)	27.6 (83.3)	220.7 (1693.1)
Winter	298.5 (565.8)	175.9 (316.9)	105.9(332.4)	56.9(77.8)	37.9(106.2)	664.5(2761.5)

Table 6.Seasonal averages for all pollutants in the remote area from 2014 to 2020

Season	**remote**					
	PM10	**PM2.5**	**SO2**	**NO2**	**O3**	**CO**
Spring	80.8 (253.8)	-	13.4 (50.3)	21.5 (31.4)	49.4 (64.9)	0.3(0.6)
Summer	59.9 (130)	-	6.9 (33.5)	12.5 (18.1)	46.9 (87.5)	0.4(1.9)
Autumn	109.9 (443.2)	-	17.1 (67)	22.8 (52.7)	30.3 (41.6)	0.5(1.1)
Winter	112.5 (146.69)	-	41.5 (95.6)	49.8 (80.6)	26.4 (44.2)	0.6(1.1)

Table 7.Seasonal averages for all pollutants in the residential area from 2014 to 2020

Season	Residential					
	PM10	**PM2.5**	**SO2**	**NO2**	**O3**	**CO**
Spring	93.9 (142.2)	18.8 (47.2)	19.2 (41.4)	57.5 (102.9)	31.3 (63.4)	0.6 (1.2)
Summer	65.6 (104.1)	12.9 (28.7)	4.2 (7.6)	44.9 (58.8)	34.8 (71.4)	0.4 (1.2)
Autumn	107.5 (175)	26.2 (58.6)	18.9 (51.2)	65.1 (96)	19 (56.7)	0.9 (2.4)
Winter	153.4 (193.8)	60.6 (128.1)	59.8 (126.5)	79.7 (132.5)	21.2 (73.7)	1.5 (2.3)

Table 8.Seasonal averages for all pollutants in the industrial area from 2014 to 2020

Season	Industrial					
	PM10	**PM2.5**	**SO2**	**NO2**	**O3**	**CO**
Spring	97.6 (134.1)	-	18.5 (47.6)	30 (42)	33.9 (69)	0.6 (1.3)
Summe r	74 (105.8)		4.9 (8.8)	23.6 (36.1)	30.1 (48.9)	0.5 (0.99)
Autumn	112 (169.9)		14.4 (35.4)	35.4 (55.2)	22.1 (76.3)	0.7 (1.2)
Winter	133 (181.6)	-	38.1 (114.9)	49.3 (68.6)	20.5 (65)	1.4 (1.98)

Table 9.Seasonal averages for all pollutants in the traffic area from 2014 to 2020

Season	**Traffic**					
	PM10	**PM2.5**	**SO2**	**NO2**	**O3**	**CO**
Spring	62.1 (111.1)	37.3 (57.1)	20 (36.7)	72.3 (144.2)	95.2 (159.7)	136.1 (920.6)
Summer	38.7 (70.3)	19.2 (28.2)	9.6 (23.7)	59 (125.4)	73.9 (112.5)	56.5 (316.8)
Autumn	77.8 (132.1)	40.8 (93.7)	21.5 (57.6)	66 (106.3)	104.2 (219.3)	90.9 (890.5)
Winter	131.9 (165.7)	103.8 (140.5)	55.5 (139.8)	88.1 (142.9)	146.8 (221.1)	363 (2160.4)

Color coding is used in the following figures illustrating the averaged seasonal distribution of the six contaminants. The Table.. shows what it means and it's divided in 5 colors.

Table 10.Color coding description

Color	Description
Deep green	Air quality is satisfactory and acceptable.
Light green	Air pollution poses little or no risk and is acceptable.
Yellow	The air quality is satisfactory. However, some people, particularly those who are unusually sensitive to air pollution, may be at risk.
Orange	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Some members of the general public may experience health effects. Members of sensitive groups may experience more serious health effects.

Figure 27 depicts the averaged seasonal distribution of sulfur dioxide concentrations in 12 monitoring stations from 2014 to 2020 (not including the U.S embassy station). The label is divided into five sections: 0-10, 10-20, 20-40, 40-100, and 100-200 $\mu g/m^3$. In Mongolian National Standard, the available average maximum SO2 concentration is 20 $\mu g/m^3$. Thus, deep green and light green indicate acceptable concentration between 0-20 $\mu g/m^3$. In the winter, the acceptable levels did not occur, revealing three distinct colors: yellow, orange, and red. The largest values were found in ger areas in UB3, APRD1 and APRD2, whereas the minimum and yellow colored value was only imaged in U7 (industrial area). The remaining stations were painted yellow. The colors transition to light green, yellow, and orange in the spring, indicating that SO2 concentrations have not surpassed 100 $\mu g/m^3$. The only station in U3 (ger area) is noted as being between 40 and 100 $\mu g/m^3$. The yellow zone included U1 (industrial), APRD1 (ger), APRD2 (ger), and APRD6 (ger), whereas the light green zone included others. During the summer, all stations were tinted green, indicating that they were all within allowed limits. Then, in the autumn, the hue of SO concentrations altered, particularly in the APRD1 monitoring station, which went from deep green to hazardous red. The green and smallest characteristics occurred in Niseh (ger), Buhiin Urguu (residential), Baruun 4 zam (roadside), Urgakh Naran (remote) and Mongol gazar (industrial).

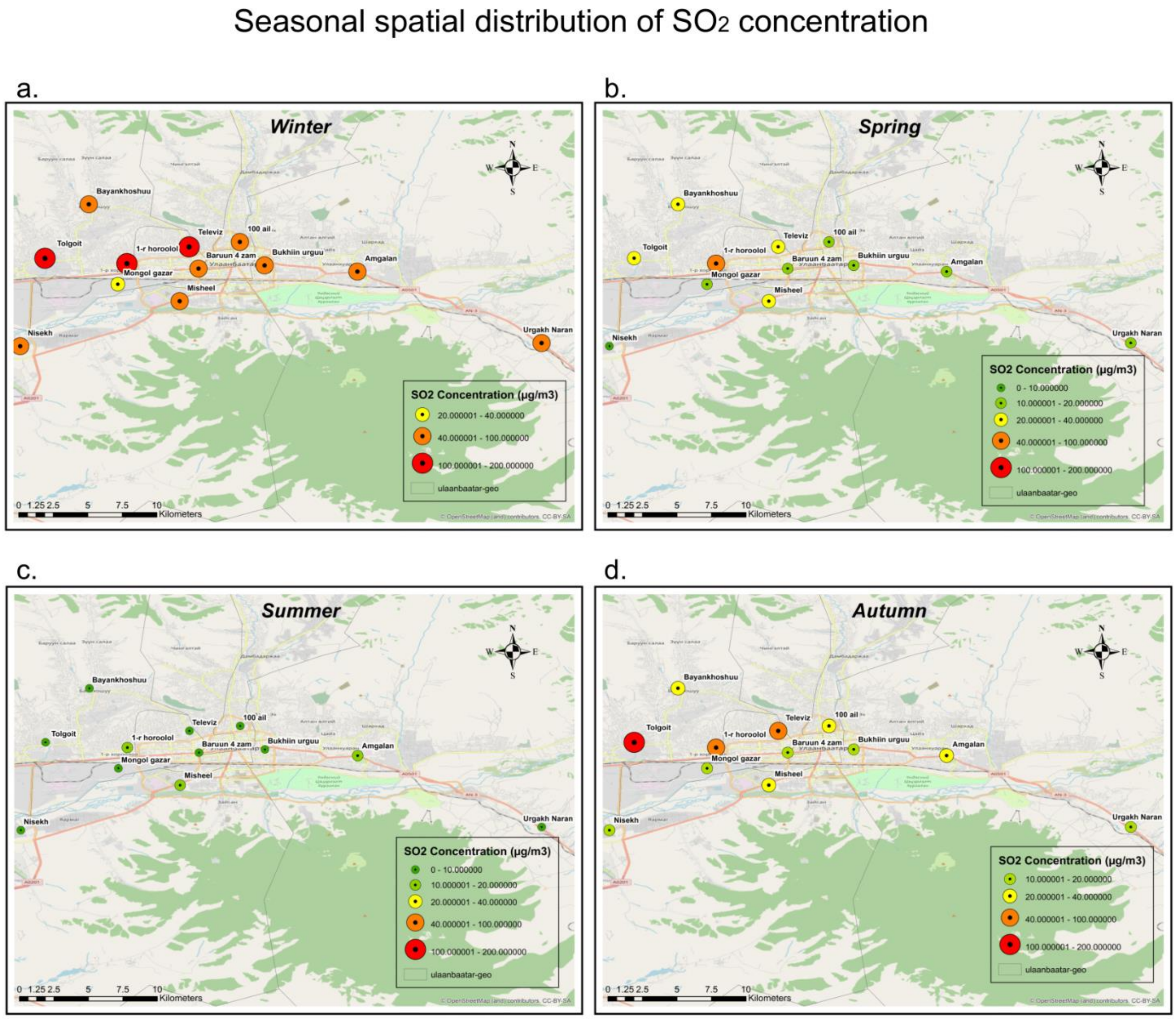


Figure 27.The averaged seasonal distribution of SO2 concentration from 2014 to 2020

As you can investigate Figure 28, Spatial variation of the mean ozone concentration from 2014 to 2020.Throughout all seasons, the U2 and U3, which correspond to traffic and ger areas, respectively, have the largest shape in comparison to other stations, except from during the summer. In this study, ozone concentrations between 0 and 50 µg/m^3 are considered insufficient to hurt and affect human health and the environment. In summer and autumn, O3 values did not exceed the available concentration without including U2 and U3 monitoring areas. However, ozone concentrations in APRD1 and APRD2, which both belong to the ger region, were found to be higher than the allowed limit in spring and summer. Interestingly, the highest values of APRD2 were found in summer when others were decreased. Summer ozone levels were greater than winter and autumn without the U2 and U3 stations.

Seasonal spatial distribution of O_3 concentration

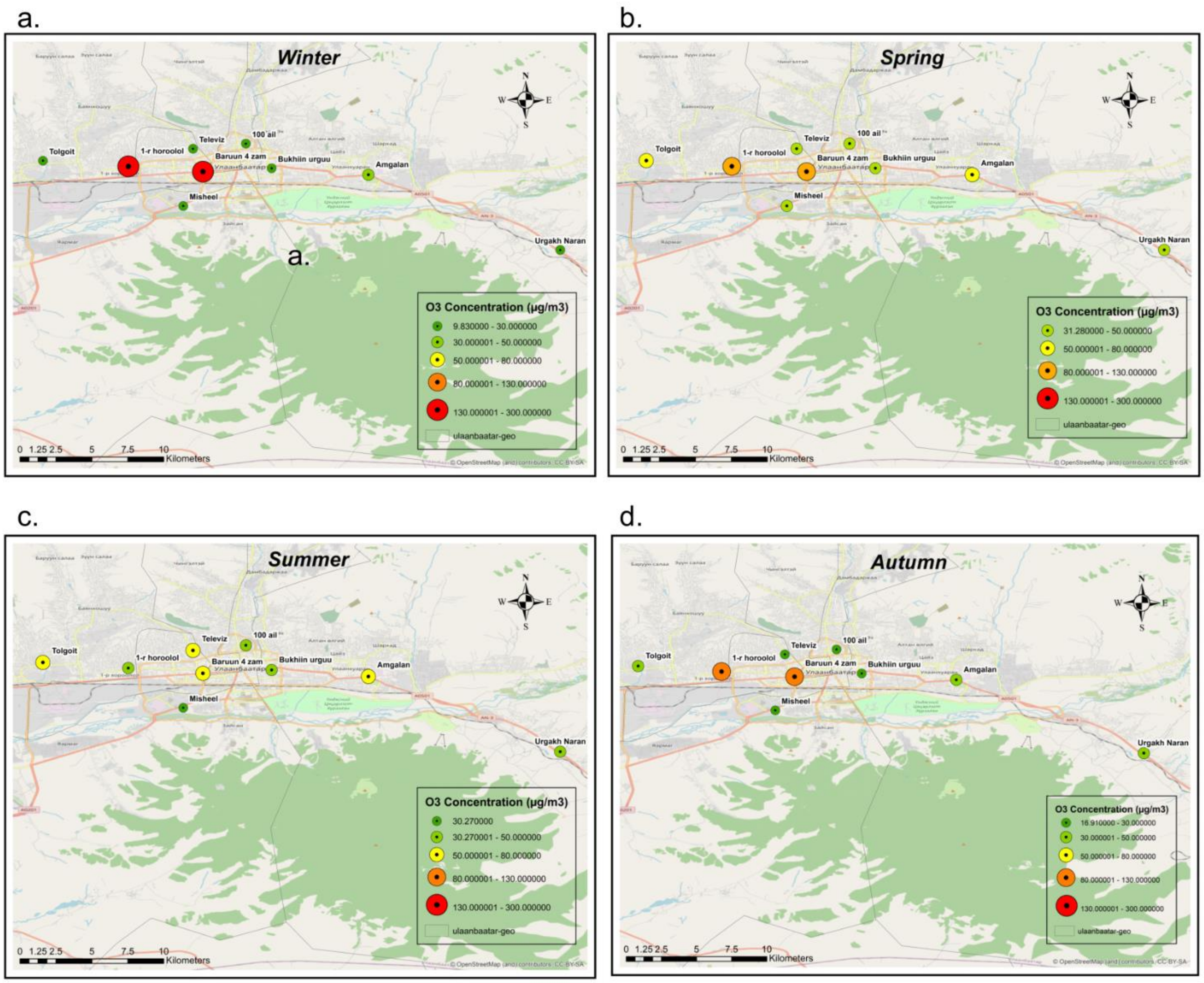


Figure 28.The averaged seasonal distribution of O3 concentration from 2014 to 2020

The regional distribution of the mean CO concentration from 2014 to 2020, as shown in Figure 29. There are some specific regions, ger areas (APRD1, APRD2, APRD3, and APRD4), that are not green and do not meet the permitted threshold of 100 $\mu g/m^3$. Especially in winter and autumn, carbon monoxide concentrations ranged from 1000 to 4000 $\mu g/m^3$. Fortunately, the rest of areas which are residential, remote, industrial and roadside were considered a green zone throughout the season.

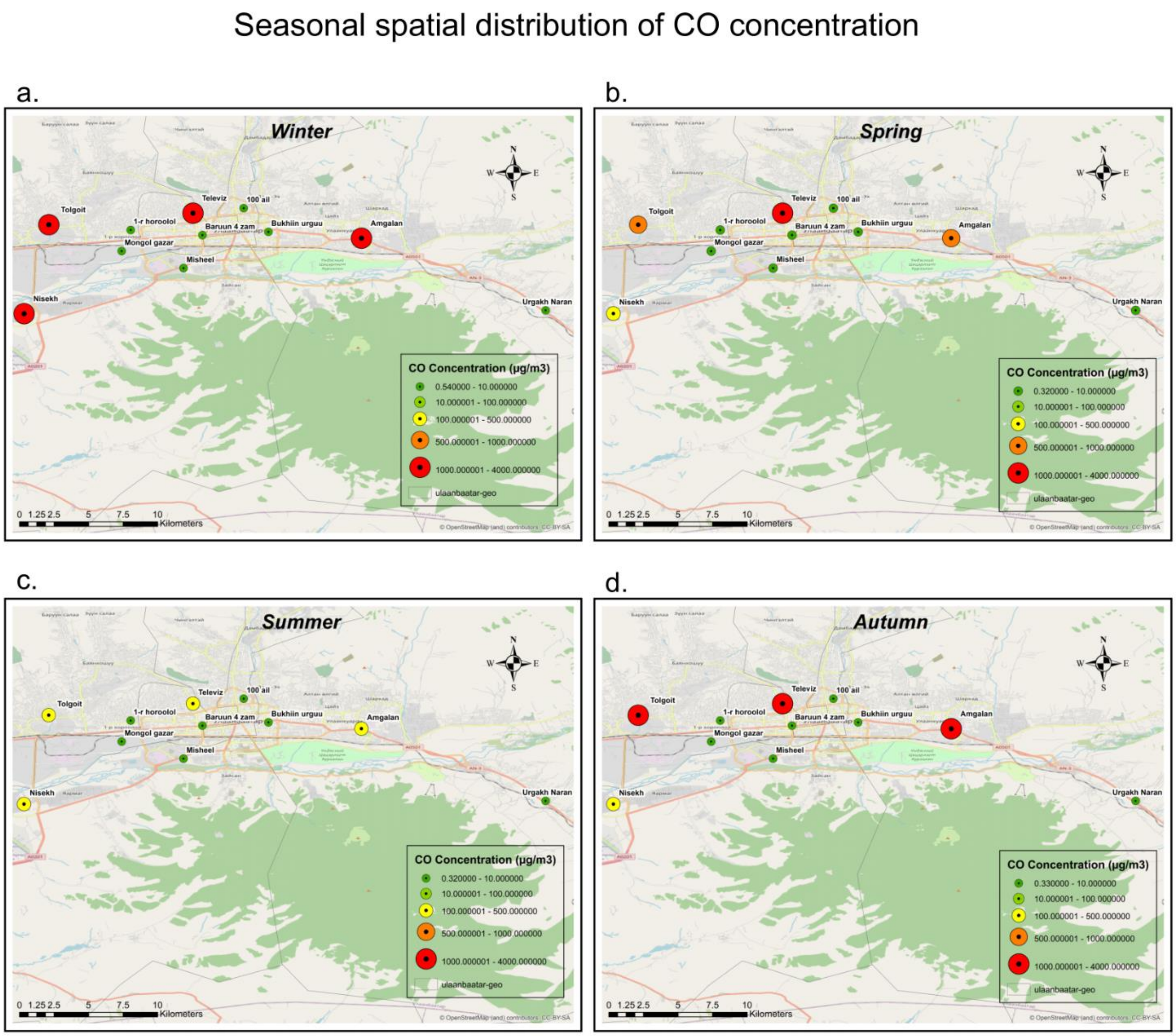


Figure 29.The averaged seasonal distribution of CO concentration from 2014 to 2020

The averaged seasonal spatial distribution of nitrogen dioxide content in the last seven years through 2020 can be shown in Figure 30. The largest amount (shape) was detected in the traffic area. Thus, the NO2 distribution was easily exposed in the traffic area (Baruun 4 zam) as compared to other stations. Its concentration ranged 80 to 110 µg/m^3 in winter, spring and autumn and ranged 60 to 80 µg/m^3 in summer. Almost all stations, excluding Nisekh (ger) and Misheel (industrial), did not meet the criterion of a mean annual NO2 concentration of 40 µg/m^3 during the winter season. Except for Baruun 4 zam and adjoining Buhiin urguu (residential), the green and tiniest shape predominated in spring, summer, and fall.

Chapter 5: Discussion

The spatial distribution of the urban air pollutants PM10, PM2.5, SO2, NO2, CO, and O3 in Ulaanbaatar has been studied using 13 monitoring sites from 2014 to 2020. According to Chapter 4, the highest concentrations of PM10, PM2.5, SO2, and CO were mostly researched in Ger areas which are 163.63, 82, 42.23 and 305.47 µg/m^3, respectively, due to coal combustion, while 54.4 percent of Ulaanbaatar's population resides in ger districts [32]. The roadside region was analyzed for the highest dispersion of O3 and NO2 concentrations, owing to the fact that vehicles, lorries, and buses (burning of fuels) are the primary emitters of NO2 emissions (according to research from the air quality index project, 55% of NO2 released from mobile) [33]. As a result of the chemical interactions between nitrogen oxides (NOx) and volatile organic compounds (VOC), ozone is produced . For overall mean analysis of PM10, PM2.5, NO2 and SO2, they exceeded the yearly average Mongolian National Standard which are 2.3, 1.9, 1.1, 1.4 times greater than the annual permissible level, respectively, while CO and O3 were provided MNS 4585:2016 of average of 8 hours. However, if the annual average is taken into the standard, the investigation of CO and O3 concentrations may alter. During the overall analysis, the greatest occurrences in PM2.5 (2016), PM10 (2014), SO2 (2020), NO2 (2020), O3 (2014), and CO (2017) were 94.7 percent, 95.6%, 50.6%, 42.4%, 90.5%, and 34.75% higher than the daily average MNAQS, respectively. This shows that the air quality in Ulaanbaatar has been hazardous to human health, particularly during the winter. Fortunately, in comparison to 2017 and 2020, the concentrations of PM10 and PM2.6 reduced by 45.8%, because of a ban imposed on the raw coal consumption in Ulaanbaatar city as an effort to tackle air pollution. The remaining pollutants were increased from 2014 to 2020, especially SO2 which constantly increased from 2019. For the overall averaged analysis and the monthly mean CO in ger and traffic sites, Dramatical increases were observed between 2017 to 2019. Maybe some errors happened in monitoring stations.

From chapter 4.2, observation of characteristics of pollutants at different sites were evaluated. The CO pollutant was hard to compare MNS 4585:2016 due to having an average of 20 minutes, 1 hour and 8 hours. Furthermore, CO concentrations in ger and traffic regions grew by 99.8% and 99.8%, respectively, in 2016 and 2017. As a result, certain errors were made during monitoring. Whereas, industrial, remote and residential regions provided the MNAQS (The maximum values were between 2 and 3 µg/m^3). For SO2 concentration, ger area was dominated by 200 µg/m^3 (the maximum peak value in 2020) while the minimum peak value was 115 µg/m^3 in industrial area. The general overview of monthly mean SO2 characteristics, the peak values of industrial, traffic, remote and residential areas were in the approved air quality level from 2018 to 2019, not including ger area. But, it was dramatically increased in 2020, with values about twice as high as in 2019 especially in ger and traffic locations. The NO2 concentrations, notably all areas, did not satisfy the average daily mean level in MNS 4595:2016, which is 40 $\mu g/m^3$. Nitrogen dioxide concentrations in roadside areas were about two times greater in 2020 than they were in 2019. The features of PM10 and PM2.5 were the opposite of SO2 and NO2, implying that concentrations declined steadily from 2018 to 2020, with the exception of PM10 readings in distant areas (2019). For example, the lowest levels of PM10 and PM2.5 are found in Dominated Site, a ger region, with decreasing rates of 57.1 percent and 64.1 percent, respectively, between 2017 and 2020. Despite the fact that PM10 and PM2.5 concentrations decreased, they remained under the MNAQS. Beginning in 2019, the PM2.5 concentration in residential areas met the permitted air quality annual mean threshold. This analysis raises the question of why SO2 and NO2 concentrations increased between 2019 and 2020, when the government implemented the raw coal prohibition project. There are two assumptions here: the number of mobiles is increasing, and briquet coal produces more sulfur dioxide. According to the Meteorological and Environmental Research Agency [34], the sulfur content in Ulaanbaatar's air increased from 67 µg/m3 in 2018 to 211 $\mu g/m^3$ in 2020. When the Specialized Inspection Agency conducted laboratory analysis of Tavan Tolgoi briquettes, the sulfur content was one or less according to the standard, but almost twice the sulfur content of Baganuur and Nalaikh coal. Also, they mentioned that in order to eliminate the use of raw coal, two improved fuel plants have been established in the western and eastern regions of Ulaanbaatar. Unfortunately, the results were poor, but the toxicity increased and Ulaanbaatar became a sulfur valley.

From the result section, The pollutants distribution arrangement was explored using time variations of all pollutant concentrations at all classed locations Figures 27-32. It was provided so that the prioritizing could be easily visualized and observed. From the Table 11, the limits range from 1 to 5 have shown that increasing the number from 1 to 5 reduces the amount of pollutants. For example, ger region is home to four of the six contaminants listed in number one, indicating that ger area is the primary source of Ulaanbaatar's worsening air pollution. The table…, the roadside area is the second most considered place for air pollution. Then, residential, industrial, and remote areas are numbered 3, 4 and 5, respectively.

Table 11.The distribution arrangement from time variations analysis

Order by polluted degree	**PM10**	**PM2.5**	**SO2**	**CO**	**NO2**	**O3**
1	Ger	Ger	Ger	Ger	Traffic	Traffic
2	Industrial	Traffic	Traffic	Traffic	Residential	Remote
3	Residential	Residential	Residential	Residential	Ger	Ger
4	Remote	-	Remote	Industrial	Industrial	Industrial
5	Traffic	-	Industrial	Remote	Remote	Residential

The intent of this section is the evaluations of which area has dominated in selected pollutants are provided in the following tables (tables from 12 to 17). Figures of seasonal spatial distribution of each pollutant were utilized to find particular values. For example, color indicators ranging from deep green (lowest pollutant level) to red (highest pollutant level) were employed (highest pollutant level). The colors are numbered 1 (lowest pollution level) to 5 (highest pollutant level) in this assessment (highest pollutant level). Afterwards, it was counted for categorized area and considered average value such as for SO2 in ger area were measured in 6 stations. So, the assessment in all seasons was noted with averaged values in 6 stations.

As you can see these bellowing tables, the highest SO2, O3, CO NO2, PM10 and PM2.5 evaluations are 11.8 in ger area, 12.5 in traffic area, 11.4 in ger area, 13.5 in traffic area, 14.5 in ger area, 14.2 in ger area. All grouped areas have a large amount from calculation in the table of SO2 analysis, the evaluation between 11.8 and 9, which demonstrates that SO2 pollutants have been a dangerous situation in Ulaanbaatar. The traffic rating is over 2 times higher than residential, industrial, and remote sites, according to the Table 13. It demonstrates that roadside areas are the main source of ozone. For the CO concentration, the estimation of ger and traffic areas are similar to each other which are 11.4 and 10.5, respectively, from Table 14. But, they are almost 2 times higher than other stations, which means CO level is the approved level in industrial, remote, and residential areas. The highest calculations in Table 15 are 14 and 13.5 for residential and traffic sites, respectively. It appears that NO2 levels emitted by mobiles have impacted in nearly residential locations. From Table 16, generally all categorized groups have a high amount of PM10 concentrations. Even if the government banned the use of raw coal, they have to pay attention to PM10 and PM2.5.

Table 12.The assessment of SO2 pollutant in all over stations

Pollutant	Season	Ger	Traffic	Residential	Industrial	Remote
SO2	Winter	4.5	4	4	3.5	4
	Spring	2.6	2	2	2.5	2
	Summer	1.2	1.5	1	1.5	1
	Autumn	3.5	2.5	2	2.5	2
Sum		**11.8**	10	9	10	9

Table 13.The assessment of O3 pollutant in all over stations

Pollutant	Season	Ger	Traffic	Residential	Industrial	Remote
O3	Winter	2	3.5	1	1	1
	Spring	2.7	3	2	2	2
	Summer	2.5	3	2	1	2
	Autumn	2	3	1	1	2
Sum		9.2	**12.5**	6	5	7

Table 14.The assessment of CO pollutant in all over stations

Pollutant	Season	Ger	Traffic	Residential	Industrial	Remote
CO	Winter	3.4	3	1	1	1
	Spring	2.8	2.5	1	1	1
	Summer	2.2	2	1	1	1
	Autumn	3	3	1	1	1
Sum		**11.4**	10.5	4	4	4

Table 15.The assessment of NO2 pollutant in all over stations

Pollutant	Season	Ger	Traffic	Residential	Industrial	Remote
NO2	Winter	3.4	4	4	2.5	3
	Spring	1.8	3.5	3	2	2
	Summer	1.4	3	3	1.5	1
	Autumn	1.8	3	4	1.5	2
Sum		8.4	13.5	**14**	7.5	8

Table 16.The assessment of PM10 pollutant in all over stations

Pollutant	Season	Ger	Traffic	Residential	Industrial	Remote
PM10	Winter	4.5	4	4	4	4
	Spring	3.7	3	3	3.5	3
	Summer	2.5	2.5	3	3.5	3
	Autumn	3.8	3.5	4	3.5	4
Sum		**14.5**	13	14	**14.5**	14

Table 17.The assessment of PM2.5 pollutant in all over stations

Pollutant	Season	Ger	Traffic	Residential	Industrial	Remote
PM2.5	Winter	5	5	2.5	-	-
	Spring	3.5	3	2	-	-
	Summer	2	2	1.5	-	-
	Autumn	3.7	3	2	-	-
Sum		**14.2**	13	8	-	-

Chapter 6: Conclusion

This study analysis the spatial variation of 6 criteria pollutants, PM2.5, PM10, SO2, NO2, CO and O3, in Ulaanbaatar from 2014 to 2020. The research area consisted of 13 monitoring stations grouped into five categories: ger, traffic, residential, industrial, and remote places. From all investigation, ger areas are the largest source of air pollution in Ulaanbaatar, PM2.5, PM10, SO2, and CO were prioritized first, and NO2 and O3 were placed second. That means that nearly 66 percent of air pollution is discharged from ger areas, with the remaining percent coming from traffic areas. Although industrial and residential, remote locations are affected small amount, I believe they have not influenced air quality. Because there are several industrial regions where pollutants are produced, and pollutants in residential areas are linked to roadside area.

For the seasonal analysis, the human health has risked in winter time because of ger areas. Almost all pollutants were seen in high concentration in that region. Despite the fact that pollutant concentrations were lower in the summer, some contaminants in classified groups remained high and have not met the approved level, particularly in PM10 in summer. Seasonal variations in six pollutants were altered in all sites, with the exception of ozone, which is not affected by the season.

According to the findings, SO2 levels raised nearly two times between 2019 and 2020, but PM levels steadily fell due to Mongolia's raw coal prohibition. I believe that it is caused by briquette coal which is not provide and not properly industrialized. Thus, the government and individuals have to consider air quality management. In addition, the observation builds a comprehensive understanding between nitrogen dioxide and ozone. The increasing number of cars and mobiles are influenced rise of NO2. This cause touches the growth of the ozone concentration because of photochemical process. Therefore, roadside areas are dominated NO2 and O3.

At last, the assessment of distribution analysis has proved that 66% of air pollutants from ger area. But, the evaluation of maximum number in the assessment of NO2 pollutant in all over stations has observed in residential area. Even though the greatest pollutant of PM10 and SO2 have investigated in ger areas, the pollutants' distribution study was similar in all locations.

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