The present work was submitted to the Faculty of Engineering

ASSESSMENT OF ULAANBAATAR AIR QUALITY BASED ON MONITORING STATIONS DATA

Bachelor Thesis

Anu-Ujin Sarantuya

Student ID: 14405783549698

Supervisor 1 / Examiner 1 **Dr. Lodoysamba Sereeter**

Supervisor 2 / Examiner 2 **MSc. Guyen Battuvshin**

Ulaanbatar/Nalaikh, 10th of August, 2018

STATUTORY DECLARATION

Sarantuya Anu-Ujin	14405793549698
Last Name, First Name	Student ID Number

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

ASSESSMENT OF ULAANBAATAR AIR QUALITY BASED ON MONITORING STATIONS DATA

Independently and without undue external help. 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.

Ulaanbaatar/Nalaikh, 3rd of August, 2018	
Place, Date	Signature

Table of Contents

Abstract

This thesis assesses the air pollution data from twelve monitoring stations in Ulaanbaatar (UB). The measurements cover major six pollutants including Particulate Matters (PM_{10}- all particles <10 µm and $PM_{2.5}$- all particles <2.5 µm), Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2), Carbon monoxide (CO) and Ozone (O_3). The data obtained from open-source database named OpenAQ. Briefly, there are overall 15 monitoring stations in Ulaanbaatar, but 12 of them are connected to the OpenAQ source and each station's data collected by 30-minutes range.

In the study, daily, monthly, seasonal and locational analysis of pollutants have been analyzed using time series analysis. The stove emission causes $PM_{2.5}$ pollution source in Ulaanbaatar during the winter time, and main source for PM_{10} is suspended dust from the soil. But pollution source apportionment work was not been done. From the result, the pollution in city has strictly seasonal character, and it is different in the central UB and residential (ger) districts. During the winter time, $PM_{2.5}$ concentration is much higher in the ger districts compared to the central area due to coal burning for heating and cooking, while the central area is mainly apartments and offices heated by central heating system. Last two years, average concentration of the $PM_{2.5}$ was 90 µg/m^3, exceeding WHO guideline 9 times. The average PM_{10} concentration was 142 µg/m^3, exceeding WHO guideline 6 times.

In the meantime, other pollutants such are CO, NO_2, O_3, and SO_2 were also estimated by this study. Annual average concentration of CO from incomplete combustion measured as 1244 µg/m^3 for 2016-2017. Comparing to the WHO guideline for annual concentration of CO, it is relatively low. For NO_2 and O_3, the annual concentrations were 46 µg/m^3 and 33 µg/m^3, which are both near or lower than WHO guidelines. Annual average concentrations of SO_2 from burning coal is 32 µg/m^3, exceeding 1.5 times MNS (Mongolian National Standard).

In addition, ratio of PM2.5/PM10 was calculated for data quality control and recommended to Air quality agency to check UB4 Monitoring station PM sensors.

Keywords: air pollution, air pollutants, monitoring station, data analysis, concentration, ger districts, coal combustion

List of Figures

List of Tables

List of Appendices

Acknowledgements

This thesis would not have been able to finish without enormous helps, supports and encouragements of many people.

First and foremost, I would like to express my particular grateful to my thesis supervisor, Professor Lodoysamba Sereeter for his invaluable help and guidance, suggestions and my thesis evaluator. I would also like to extend my special thanks to my co-supervisor Mr Guyen for his many good advices to improve my thesis, and his kind and valuable comments. My gratitude also goes to Mr. Soronzonbold for his interesting discussion, constructive comments and support.

I would like to express my gratitude to all those who encourage and support me to finish this thesis, especially for Engineering Faculty members of GMIT.

Additionally, I would like to thank Mrs Nyamdavaa and Mr Barkhas who work in NAMEM and CLEM for supporting me by additional data and materials related to my thesis work.

Last but not least, special thanks to my family for supporting me in every possible way for the last five years.

To all my colleagues at GMIT, wishing you all the best in your future career and life. It was a great experience and opportunity for me to study for 5 years in German-Mongolian Institute of Mining and Resources and learn the Environmental Engineering Program.

1 Introduction

1.1 Background

The city of Ulaanbaatar, Mongolia, is known as the coldest capital city in the world. Since 2000s, rapid urbanization has led to air quality worsening in the city, with emissions producing from growing number of industries and construction activities, increasing number of vehicles, higher electricity demand and domestic heating and cooking needs (1). In 2011, the World Health Organization listed Ulaanbaatar among the top 5 cities with the worst air quality in the world. At that time, coal combustion caused Particulate Matter concentrations in Ulaanbaatar were 10-25 times greater than Mongolian national air quality standards (2).

Until today, many research works, projects and studies have been done for reducing and monitoring air pollution of Ulaanbaatar. First serious study for establishment of baseline of Ulaanbaatar air pollution was conducted in June 2008- May 2009 and published in 2011 by World Bank (2). By the result of this study, the main measure to reduce air pollution of Ulaanbaatar was determined "Improved stove program", because main $PM_{2.5}$ source is emerged by household combustion in not properly designed stoves. More than 145 thousand stoves were changed by improved Top-Lit-Up-Draft stoves in 2010-2015. Since then, UB air pollution was decreasing year by year (3). But UB air pollution stopped to decrease from the time while stove program was stopped in 2015.

This study will identify and evaluate air pollution level in Ulaanbaatar since 2015 based on result of analyzing raw data from monitoring stations through OpenAQ database. In order to achieve the main purpose, this thesis is divided into six chapters and is structured as follows:

Chapter one provides an introduction of this report with general background and objectives of the thesis.

Chapter two describes the research area Ulaanbaatar. It will provide brief information about climate, population and geography.

Chapter three includes three sub-sections. First section contains general understanding of air pollution, its characterization, origin and effects. Second section describes current and previous situation of Ulaanbaatar's air quality based on literature. Last section includes information about legal and institutional frameworks, and projects and programs which have been done for reducing air pollution Ulaanbaatar.

Chapter four provides material and methods which are used for analysis.

Chapter five provides result and discussion from data analysis based on time series. This chapter will prove or deny my hypothesis which included in Chapter one

Chapter six and seven summarizes results and conclusion. Finally, it provides key recommendations.

1.2 Objectives of the study

The main objective is to evaluate current situation related air quality in Ulaanbaatar based on monitoring stations data. OpenAQ source is employed to obtain raw data, since there is a limited information available for students and researchers in Ulaanbaatar city Air Quality Agency (UBAQA).

The specific objectives of the study are:

- To estimate annual, monthly, and daily average concentration levels of air pollutants and compare it to the applicable regulatory standards,
- To analyze the patterns of spatial and temporal variability of pollutants, such are Particulate Matters, Sulfur dioxide, Nitrogen dioxide, Carbon monoxide and Ozone,
- To assess pollution sources based on the time series analysis,
- Analysis in this thesis will be compared with reports of UBAQA analysis, and quality control will be done based on determination of PM2.5/PM10 ratio.

Scope of the thesis:

Thesis is consist of analysis air quality data, obtained by Air quality monitoring stations. Therefore, the pollution source apportionments, modelling of air pollution, mitigation issues and health concerns are not considered by the thesis.

Data of the period, October 2015-March 2018 are used for analysis now that OpenAQ launched in November 2015.

Hypothesis of study:

- Ulaanbaatar PM air pollution is enormously exceeded the international and national air pollution standards,
- Air pollution is seasonal character, its level increased in cold season and decreased in warm season,
- The main source of air pollution is caused by the vehicle during the summer. The reason why is, that the usage of the coal is decreased in this period.

2 Study area

The study area, Ulaanbaatar, is in the central part of the country, at 46°0’N 105°0’E, belongs to a cold temperate zone with an extreme continental climate, with long-lasting cold and dry winters and short warm summers. The whole area is surrounded by four sacred mountains with the transition belt between the steppe, the boreal zone and the alpine tundra of the Khentii Mountains. Ulaanbaatar has a total area of 4.7 thousand km^2, which is consulted by 9 districts. Total population is about 1.5 million in 2017 (4), and with an average population density of 311 person/km^2.

Additionally, yearly average temperature of capital city Ulaanbaatar is -1.3°C and it is marked as the one of the coldest capital in Central Asian territory. Record high temperature reached +44°C, and the low temperature amounted -40°C. As shown in the Figure 2-1, the warmest month is July with an average of 17.1°C and the coldest month is January with an average temperature of -21.2°C, and an annual precipitation average is about 256 mm.

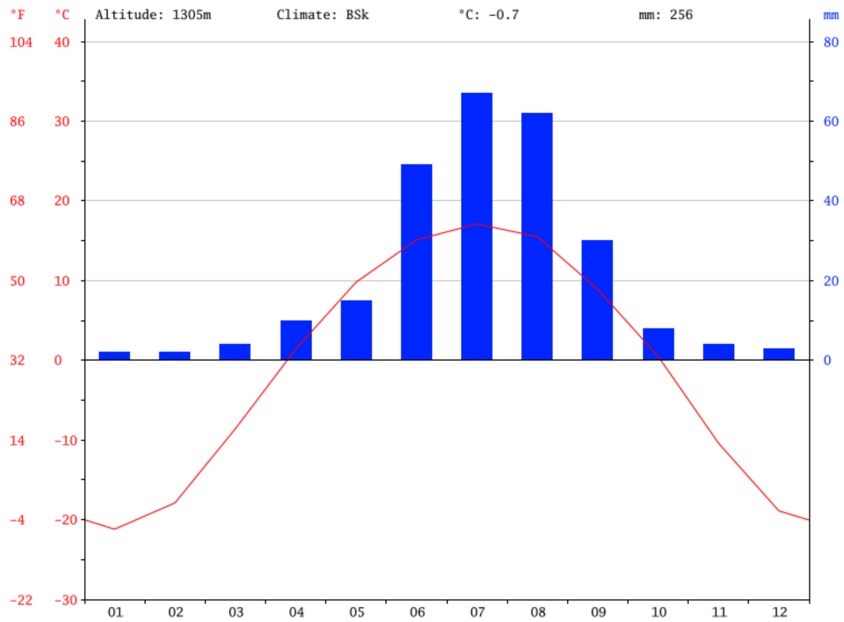


Figure 2.1. Climograph of Ulaanbaatar Source: https://en.climate-data.org/location/490/

3 State of the art

3.1 Fundamentals of Air Pollution

Breathing clean air is the most important thing for human health and well-being. The clean air contains non-harmful gaseous compositions as shown in the Table 3.1 (5). However, there are another chemical substances which are harmful for human health in the air. They are called as air pollutants. Air pollutants have known or suspected as adverse effects on human health and environment. When they emitted into the atmosphere, they create air pollution.

Compositions		**Volume content in % related to dry air**
Oxygen	(O_2)	20.93
Nitrogen	(N_2)	78.10
Argon	(Ar)	0.9325
Carbon dioxide	(CO_2)	0.03-0.04
Hydrogen	(H_2)	0.01
Neon	(Ne)	0.0018
Helium	(He)	0.0005
Krypton	(Kr)	0.0001
Xenon	(Xe)	0.000009

Table 3.1. Gaseous compositions in clean air by precent (5)

The origins of air pollution classified: natural and man-mad (anthropogenic). Commonly, natural air pollution released from volcano, forest fire, sand storms, oceans and plant pollen. Anthropogenic air pollution are created by human being e.g., industrial processing, coal burning, power plants and fuel combustion;

The most typical urban air pollutants in atmosphere include Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Sulfur Oxides (SO_x), Ozone (O_3), Lead (Pb), and Particulate Matters (PM). They also named “criteria air pollutants” because the US Environmental Protection Agency (EPA) regulates them by using two sets of criteria for pollutant standards. The first set of standard is aimed to protect public health and the second sets designed for prevent environmental damage. Of these six pollutants, the Particulate Matter (PM) is one of the most critical pollutant responsible for the largest health and economic damages (6). The concentrations of the pollutants typically measured in their mass per volume of air (µg/m^3).

Particulate Matter (PM) is a mixture of particles from different sources and of different sizes, compositions, and properties. Particulate matter categorized into different size fractions by its aerodynamic diameter: PM_{10} (all particles <10 µm (thoracic particle)), $PM_{2.5}$ (all particles <2.5 µm (fine particles)), particles between 2.5 and 10 µm (coarse particles $PM_{10-2.5}$) and $PM_{0.1}$ (ultrafine particles PM<0.1) (7). However, PM consists of very mixed particles, comprising particles from several different sources such are traffic, small and large-scale biomass combustion, waste incineration, industrial processes, long-range transported air pollution, road abrasion and suspension, car brake debris and dusts from soil erosion (8). The source of the coarse fraction is mainly crustal material, the fine and ultrafine fractions consists of carbonaceous combustion particles. For many years, PM has been considered as a serious health problem (8). Several studies mentioned that PM may affect the respiratory and cardiovascular system in humans and animals. The mechanisms of respiratory disease include direct interaction with the DNA of metabolized particle components and oxidative stress products, and the formation of adductions and mutations. In brief, high concentration of PM can be cause of acute health effects, chronic lung diseases, cardiovascular disease, heart disease, cancer and mortality (8).

Carbon Monoxide (CO) is one of the most important air pollutants which produced from incomplete oxidation of carbonaceous material. The major source of CO in the environment is motor vehicles which occupy 60% of the total CO emission per year in other countries. However, in UB, a main CO source is the coal combustion. Rest of the CO emission sources include industrial processes, solid waste disposal, hot water heaters, furnaces, space heaters, fireplaces and smoking. Moreover, CO can be emitted from the use of paint stripper, which contains methylene chloride (9).

Toxicity of CO results by interfering with the protein hemoglobin's ability to carry oxygen. Hemoglobin absorbs CO about 210 times faster than its absorption rate for oxygen (10). When CO-carrying protein sufficiently high, it can lead to acute and chronic effects in human body. In general, the Carbon monoxide rapidly absorbed through the lungs and can be cause of lung disease. Also high concentration of CO can lead to cardiovascular disease, anemia, and loss of consciousness. However, the small amount of CO in the blood considered neither beneficial nor harmful (10).

Nitrogen Oxides (NO_x) is released from combustion of Nitrogen contained fossil fuel. Both Nitric oxide (NO) and Nitrogen dioxide (NO_2) referred as NO_x. But Nitrogen dioxide is one of the most abundant air pollutants in many counties. In urban areas, major source of the NO_2 is automobile exhaust.

Nitrogen dioxide is considered to be a potential risk factor for asthma. Additionally, dangerous accumulation of nitric oxide and nitrogen dioxide can occur in agricultural silos, in enclosed mineshafts, and in industrial processes. A time interval of a few hours after acute exposure usually elapses before symptoms develop. After this interval, acute pulmonary edema, cyanosis, and bronchopneumonia characteristically develop. In fact, it can lead to death due to its toxic effect.

Sulfur Oxides (SO_x) are compounds of sulfur and oxygen molecules and there are many forms of sulfur oxides exist in atmosphere such are SO, SO_2, and SO_3 etc. The most dominant form is Sulfur dioxide (SO_2) which found in the Earth's lower atmosphere. Sulfur dioxide is a colorless gas but has a pungent odor at concentrations of 10,000 $\mu g/m^3$ (11).

During the burning fuels that contain sulfur, SO_2 produced and directly released into the air.

About 99% of Sulfur dioxide in the air produced from manmade activities (12). The major source of the Sulfur dioxide emissions worldwide include thermal power-plants burning high-sulfur coal or heating oil. Emissions from domestic coal burning and from vehicles can also contribute to high local ambient concentrations of SO_2. Sulfur dioxide is not only produced from manmade activities, it also can occur naturally by volcanoes (11).

Some published articles describe that sulfur dioxide is commonly used preservative in various beverages such as beer, wine, soda and cider as well as bottled fruit and vegetable juice. Also it used preservative in many dried products, especially in light-colored fruits to prevent browning (13).

Sulfur dioxide is highly toxic pollutant to both human and environment health. For human health, it can lead reduced lung function, increased incidence of respiratory symptoms and diseases, irritation of the eyes, nose and throat, and premature mortality after a long exposure. Usually SO_2 reacts with other substances in the atmosphere to create sulfate aerosols. Most sulfate aerosols are considered part of $PM_{2.5}$, so they might have a significant role in the health impacts related with fine particulates (11).

Environmentally, sulfur dioxide is harmful for vegetation including forests and agricultural crops. It may lose their greenery, turn into less productive, or die prematurely. Additionally, it can damage buildings, monuments and statues because of its acidic characterization. When sulfur dioxide react with moisture, it become sulfurous acid. Sulfuric trioxide, another type of sulfur oxide, can converted into sulfuric acid when it emitted into the atmosphere. This acids after can erode or corrode materials containing ferrous and nonferrous materials, also may damage paper and leather (11).

Ozone (O_3) – Ozone is a gas composed of three atoms of oxygen. There are 2 kinds of ozone exists in Earth's atmosphere. One is stratospheric ozone (good ozone) which is considered not harmful for human health and it occurs naturally in the Earth's upper atmosphere as a layer that protects us from sun's UV rays. The bad ozone, tropospheric ozone which also named as ground level ozone, formed in the Earth's lower atmosphere when pollutants emitted by motor vehicles, power plants, industrial boilers, refineries, and other sources react with presence of sunlight (14). The production of photochemical oxidants depends on sunlight intensity and temperature this occurs over several hours. This means that the highest concentration of ozone normally occurs in summer afternoons, downwind from major sources of ozone precursors. This smog is not emitted directly into air but is created when Volatile Organic Compounds (VOC) and Nitrogen oxides react in the presence of sunlight.

$$VOC + NO_X + heat + Sunlight \rightarrow O_3 \text{ (15)}$$

Breathing ozone can be the cause of variety of health problems including chest pain, coughing, throat irritation and congestion even at very low levels. It can worsen bronchitis, emphysema, asthma and lead to permanent lung damage after a long exposure. Additionally, ozone can damage ecosystem and vegetation if its level exceeded 50 µg/m^3 (15).

3.2 Air pollution in Ulaanbaatar

In the last few years, environmental quality has degraded due to human-related factors including rapid urbanization and industrialization; pollution levels have been rising adversely affecting the ecosystem. Further, the current situation has a harmful impact on the national economy, social development, health and living environment, potentially causing significant loss and harm (2).

Compared to other cities in the world, in 2009, the average concentration of PM_{10} in Ulaanbaatar ger area was the highest, approximately 5 times more than the next most polluted city of Cairo, Africa, but about 1.5 times higher in UB central. Pollution level in UB ger areas presented about 7 times greater value than most cities in China (2). (Figure 2.2.)

World Bank (2011), analyzed air quality of Ulaanbaatar based on data measured at monitoring stations between June 2008 and May 2009. This research work only considered $PM_{2.5}$ and PM_{10} pollution, due to their contribution to health effects on the population in Ulaanbaatar. As presented in their report, annual average $PM_{2.5}$ concentrations ranged from 98-625 µg/m^3. These $PM_{2.5}$ levels far exceeded the Mongolian AQ standard (hereafter MNS) (an annual mean of 25 µg/m^3). For PM_{10}, its annual average concentrations in the same year ranged from 67-560 µg/m^3, more than 10 times higher than the applicable regulatory standard (an annual mean of 50 µg/m^3) (2).

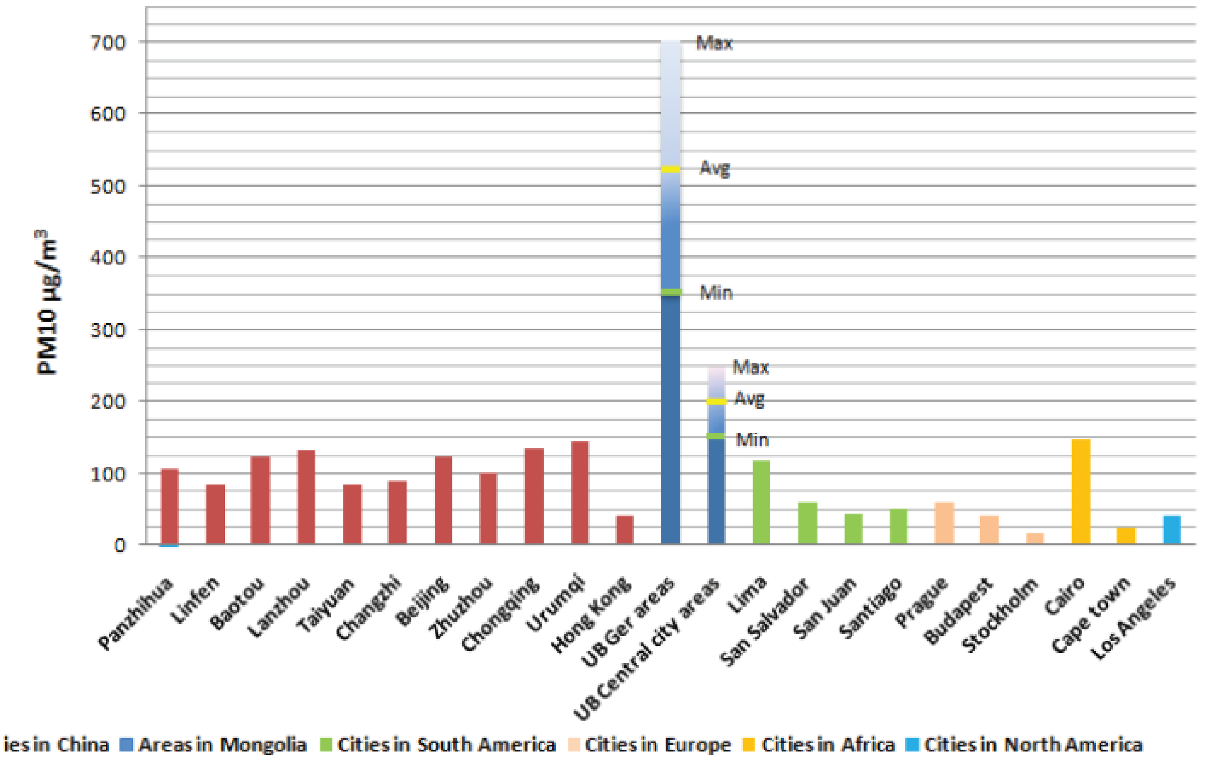


Figure 3.1. Comparison of UB PM_{10} concentrations (2008-09) with Chinese cities (2008) and other capitals in the world (2004) Source: Air Quality Analysis of Ulaanbaatar, World Bank (2011) (2).

According to Guttikunda (2013), there are three main contribution factors that lead to Ulaanbaatar's serious air pollution problem, such are population and economy, climate, and geography (16).

Mongolia covers an area of 1.5 million square km. Compared to the total area, population amount is relative low as 0.5 square km per person (4). However, due to rural to urban migration, people densely live in city of Ulaanbaatar. Within last 20 years, city's population has grown by 500 thousand (4). Most of the population growth has been in the city's ger districts where central heating system is not connected (6). In this district, households usually burn coal and wood due to its availability and cheap. Currently, about 200 thousand households burn over 660 thousand tons of coal in their traditional stoves per year (17). Because stoves are not properly designed for those coal, it produces high amount of pollution into the air.

In winter time, air pollution level is extremely increased due to coal consumption. The Ulaanbaatar's winter temperature is in range of -20°C to -30°C, but it can be as low as -40°C at night (17). Therefore in order to survive the harsh winter condition, all ger district households extensively use coal and wood, contributing to the effects of air pollution.

Geographically, Ulaanbaatar is surrounded by four mountains that creates "black hole" to the air pollution. Because of having calm wind speeds of 1-2 meter per second in winter, the polluted air could not easily blown by wind. (18).

For as 2013, main sources for air pollution in UB are stoves (184 thousand ger household), transportation vehicles (306 thousand), small and medium size low pressure boilers (1,4 thousand), Coal Heated Power plants (3), and other sources. As illustrated in ther Figure 3.2, almost half of the total air pollution originated in households stove (19).

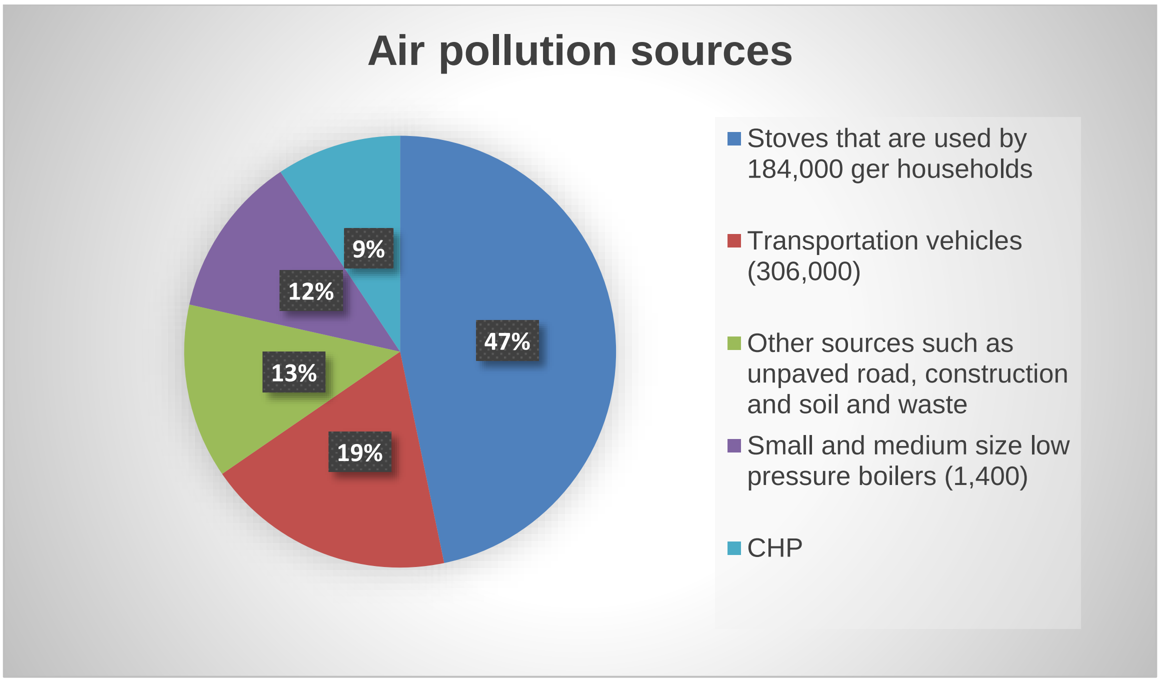


Figure 3.2 Ulaanbaatar Air pollution souces and shares in percentage

Source: „The Results of Air Pollution Reduction Measures and Impacts on Human Health" report, 2013

3.2.1 Air Pollution Standards

The ambient air quality standards (AQS) for Mongolia MNS4585:2016 are presented in Table3.2 together with WHO guideline standard. Analysis in this thesis will be compared with those standards.

Pollutants		Unit	WHO guidelines	MNS4585:2016
PM2.5	Annual mean	µg/m3	10	25
	24-hour mean		25	50
PM10	Annual mean	µg/m3	20	50
	24-hour mean		50	100
O3	8-hour mean	µg/m3	100	100
NO2	Annual mean	µg/m3	40	40
	24-hour mean		-	50
	1-hour mean		200	-
SO2	Annual mean	µg/m3	-	20
	24-hour mean		20	50
	10-minute mean		500	450
CO	8-hour mean	µg/m3	-	10,000
	1-hour mean		-	30,000
	20-minute mean		-	60,000

Table 3.2. Concentration limits for major ambient air pollutants in WHO and MNS.

3.3 Measures to Reduce Air pollution in UB

Legal and policy framework

There are several laws related to air quality in Mongolia such as “Law on Air” (2012), “Law on Air Pollution Reduction of the Capital City” (2011), “Law on Pollution Payment” (2010) and Law on Special Government Funds, governing foundation of Clean Air Fund (CAF). Each law aimed to reduce air pollution and its impact to the citizens’ health. (20)

The purpose of the “Law on Air Pollution Reduction of the Capital City” (2011) was to reduce Ulaanbaatar’s air pollution level. Based on the law, Mongolian Ikh Khural (Parliament) implemented following measures such are (21):

- to reduce electricity tariff, in the ger districts of Ulaanbaatar
- to support any uses, services, and industries which are oriented to reduce air pollution, heat loss, and greenhouse gas emissions and save energy
- to educate citizens about sources and negative impacts of air pollution
- to support use of low emission sources, such as electricity, coking coal and gas for heating
- to improve existing standards of on energy efficiency
- to prohibit use of raw coal etc.

The “Law on Air” (17 May 2012) was approved to regulate actions related to protection of ambient air, prevention from pollution, and reduction and monitoring of emissions of air pollution (21).

In addition, the Government approved plenty of regulations included “Regulation to provide incentives to ger district households in the air quality improvement zone”, “Regulation to provide incentives to individuals, companies and institutions that are engaged in air pollution reduction, energy efficiency and electricity saving activities”, “Regulations for individuals, companies and institutions located in the air quality zone”, “Regulation to store and supply processed coal for distribution in ger districts”, “Regulation to provide front financing to establish a processed fuel store in the air quality zone”, “Regulation of conduct of inspectors to work in the air quality zone” and “Regulation on receiving air pollution payment rates from individuals, companies, and institutions, who are using air polluting substances”.

Institutional Framework

In 2009, the National Committee on Reducing Air Pollution (NCRAP) was established under the Office of the President of Mongolia that is responsible for coordinating the policy to enforce air pollution reduction and for ensuring and overseeing interrelations of operations. The National Committee is re-shifted to the Cabinet of the Government Recently. The Law on Air governs establishment of regional and district committees. As part of the initiative, District Committees were established in 6 districts of Ulaanbaatar and chaired by the District Governors (16).

Under the Environment Minister, the Clean Air Fund was established and specific action plans started to be incorporated in the state budget. The Law on the Government Special Funds was responsible for operation and budget of the CAF.

The Air Pollution Reduction Department was first established as “Air Quality Service” in the Ulaanbaatar city Municipality October 2006.

The Municipality Air Quality Office (MAQO) is key municipality office, which is responsible for air quality, air pollution monitoring and research, sources of pollution, environmental and public health threats. The MAQO has been introducing new technologies to reduce the negative impacts of air pollution and implementation of government policy and decisions from Ulaanbaatar City Mayor.

Projects and programs

In order to reduce air pollution, a number of short-term projects and programs have been implemented in Ulaanbaatar. For instance, the Clean Air Project (CAP) was implemented by the Millennium Challenge Account during 2010-2013. The aim of the project was to reduce air pollution in UB by increasing the adoption of energy efficient products and homes in the ger districts, and to support the development of renewable energy. During the course of the project, the program provided nearly 100,000 improved stoves, 20,000 ger insulations, 5,000 entrances and 100 energy efficient buildings with 90% of subsidy(19).

As a follow up of the CAP, the World Bank launched the Ulaanbaatar Clean Air Project (UBCAP) to continue the ger stove subsidies program in 2012. The project was continued to supply 4 types of energy efficient stoves, such are Olzii, Dul, Talst and Bekas, for the remaining households in ger districts. The energy efficient stoves use 30% less fuel, and emit 70%-90% less pollution than traditional stoves. The original closing date of the UBCAP was in 2017, which was later revised to 2019 to complete remaining activities(22). According to Clean Air Fund report, totally 140,000 stoves have been distributed to citizens by these two project(19).

In 2006, the Air Quality Division was established by the Ulaanbaatar city government under Nature Environmental Protection Department of the Capital City. After 3 years, it was upgraded to “Air Quality Department of the Capital City (AQDCC)” (now re-organized as Air Pollution Reduction Department (APRD))(23). In 2007, the Government of Mongolia requested Government of Japan to provide technical assistance for air pollution problems in Ulaanbaatar city due to lack of skilled technician by this field in APRD(23). Based on the request, the Government of Japan provided technical assistance through Japan International Cooperation Agency (JICA) “Capacity Development Project for Air Pollution Control in UB” during 2010-2016. The project process divided into two phases, such as Phase 1 (2010-2013) and Phase 2 (2013-2016). Phase 1 based on the activities include technical transfer for credible emission inventory elaboration, air pollution simulation, on-site emission measurements of boilers including dust, boiler registration system, proposal of a control measures of power plants and heat only boilers, and elaboration of emission control measures. For Phase 2, it was more concentrated on data management and accuracy improvement of ambient air monitoring (23).

In 2017, National Program on Reduction of Air and Environmental Pollution is aimed to decreasing air pollutants by 80 percent, prohibiting use of unprocessed coal in Ulaanbaatar except thermal power plants, and reducing air and environmental pollution by at least 50 percent by 2025 (24).

4 Materials and Methods

4.1 Data source

In the thesis, data source is based on two individual sources OpenAQ and National Agency Meteorology and the Environmental Monitoring (NAMEM).

First, for the analysis, OpenAQ data, newly established in USA global AQ database, is used. In brief, the OpenAQ (https://openaq.org) is a global database of open, aggregated real-time air quality data, publicly provided by governments and research entities. To date, the platform holds more than 200 million data points from 65 countries. The platform itself is open-source at https://github.com/openaq.org (25).

Benefits of OpenAQ are:

- better evaluation of the air quality situation, planning of air pollution mitigation,
- initiatives and enhance the study of air pollution,
- researchers in related fields can use real-time data of air pollution and apply to their studies in health, economic and social impacts,
- researchers from other countries can help evaluate the situation in Ulaanbaatar city, learn from other cities air quality situation and work together to improve Air Quality,
- to observe and monitor Air quality in other cities and countries and learn from them,(25)

Second, National Agency Meteorology and the Environmental monitoring agency established on 1924 in Ulaanbaatar, the main activity is weather forecasting. Additionally, NAMEM is responsible for collecting and analyzing raw data from all monitoring stations. The analyzed data are distributed through its platform for giving air quality information to the residents.
For next chapters, 30 months data from OpenAQ and NAMEM will be used for analysis.

4.2 Monitoring stations and instruments

In 1976, the first air quality monitoring system was established in Ulaanbaatar. This system was including 4 passive stations which were equipped by gas sampling pumps and measured sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) until 2006 (6).

In 2009, GTZ had donated 4 used automatic air quality monitoring stations. Afterwards, they had renewed in 2013 (26). The first on-line air quality monitoring system consisted 6 stations was established in UB comprising of 4 GTZ stations and 2 stations by loan from France government in 2010. In 2015, one new automatic air quality monitoring station was established by JICA project (26). Currently, about 40 air quality monitoring stations are under operation and are used to observe an air pollution within Mongolia (24).

In fact, there are 15 continuous air monitoring stations operated by both NAMEM/CLEM and APRD. However, 12 stations' data are used in this study. Figure 4.1 shows the locations of monitoring stations in Ulaanbaatar. Monitoring data from UB3, UB9 and UB11 were not considered in this study because period of record for UB3 station was insufficient (i.e., new station started in January, 2018), and UB9 and UB11 are passive stations. The main air pollutants analyzed in the thesis include NO_2, SO_2, $PM_{2.5}$, PM_{10}, and CO. However, not all of these air pollutants are measured at every monitoring station.

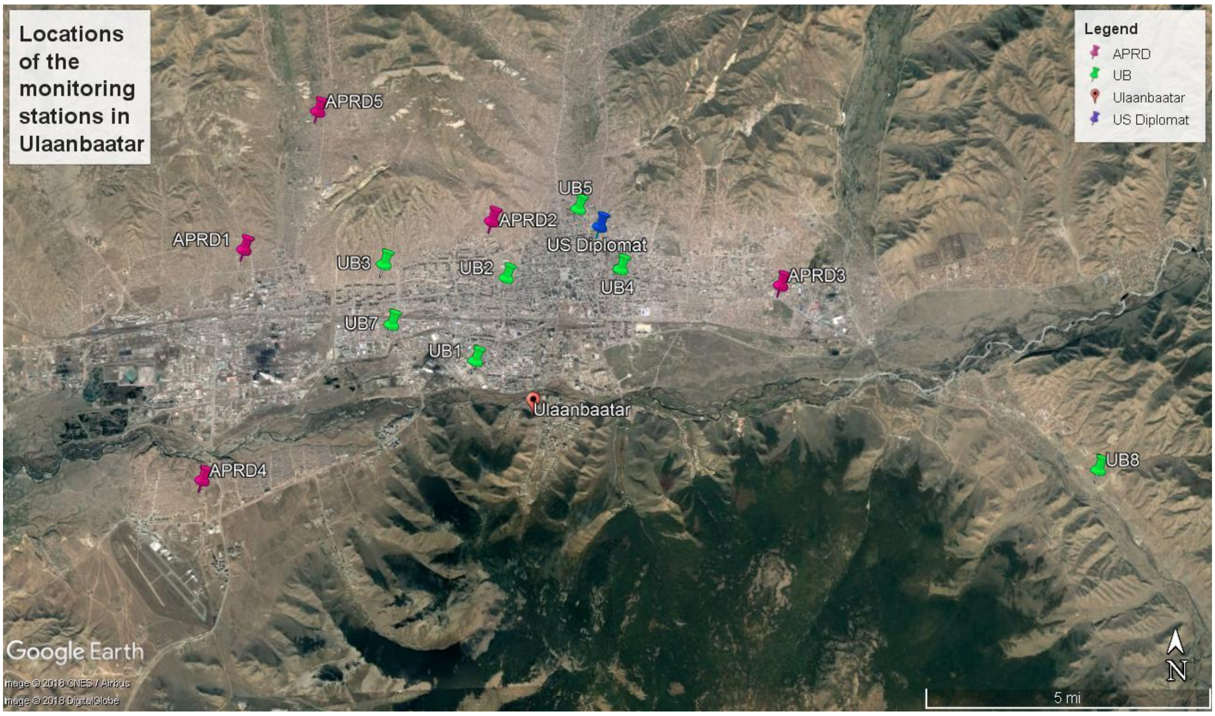


Figure 4.1. Map of real-time air pollution monitoring stations. Map shows the locations of air quality monitoring sites in Ulaanbaatar. UB: Stations operated by NAMEM (National Agency Meteorology and the Environmental Monitoring). APRD: Stations operated by UBAQA (Ulaanbaatar Air Quality Analysis)

This study used data collected from monitoring stations and assessment was carried out. The assessment includes data from monitoring stations between 2016 and 2018.

The specific information are described in Table 4.1 and Table 4.2.

Table 4.1 shows location descriptions and its starting date. In the Table 4.2, name of stations, place names and measuring pollutants are shown. APRD(1-4) and UB4 stations are measuring all 6 pollutants, UB2 measure 5 pollutants, excluding O_3, UB5 and UB8 measure pollutants not including $PM_{2.5}$, APRD5 measures PM_{10}, $PM_{2.5}$ and SO_2, UB1 measures PM_{10}, SO_2 and O_3.

US diplomacy residence is measuring $PM_{2.5}$ and introducing data to UB AQA and to OpenAQ.

It is noted that it is important to measure $PM_{2.5}$ in all stations for assessment of air quality, as most challenging problem, smoke is consists of $PM_{2.5}$.

Name	Location	Latitude	Longitude	Started date	Description of location
UB1	Misheel Expo	47,8943389	106,8824722	2010	Located at the CLEM, isolated from ger district influence and surrounded by grass covered surfaces
UB2	Baruun 4 zam	47,9153,833	106,8941944	2010	There were working GTZ station 2009 until 2015 (2 stations were working at same place)
UB3	Tahilt	47.55'07"	106.50'52"	2018-1	• (ger district)
UB4	Bukhiin urguu	47,9176056	106,9373611	2010	Located in cetral part of the city, near to cross road
UB5	100 ail	47,9329056	106,9213833	2010	Located between ger district and central part of the city
UB7	Mongol gazar	47,9035389	106,8507083	2010	Located near to the power plant and main road
UB8	Urgakh Naran	47,8664611	107,1180194	2010	Remote area in Ulaanbaatar. Surrounding area is grass and located near to the main road.
APR D1	Tolgoit	47,922495	106,794805	2015-9	Ger district
APR D2	MNB	47,929732	106,888629	2009	Located near to the ger district and main road
APR D3	Amgalan	47,913429	106,997907	2015-9	Near to main road and ger district
APR D4	Nisekh	47,863943	106,779094	2009	Located in remoted area of Ulaanbaatar, near to airpot. Surrounded by gers and
APR D5	Bayan-khoshuu	4,795756	106,822752	2016-1	Surrounded by gers, open soil and road surface. Located 100m east from main road, and near to the large brick factory (does not work during winter)
US. Dip		47,928387	106,92947	2015	Located between ger and central area
UB9	Mining institude				Passive
UB11	Hailaast				Passive

Table 4.1 Locations of monitoring stations in Ulaanbaatar

Locations/ pollutants	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
UB1		x	x			x
UB2	x	x	x	x	x	
UB4	x	x	x	x	x	x
UB5		x	x	x	x	x
UB7		x	x	x	x	
UB8		x	x	x	x	x
APRD1	x	x	x	x	x	x
APRD2	x	x	x	x	x	x
APRD3	x	x	x	x	x	x
APRD4	x	x	x	x	x	x
APRD5	x	x	x			
US. Diplomat	x					

Table 4.2. Symbol x shows that stations are measuring the corresponding pollutants.

4.3 Data analysis method

Given data availability, this study conducts for the years 2015 through 2018. One of the main types of analysis of the data is to look at time series in concentrations over time. Basically, daily average concentration of pollutants are the main parameter for time series analysis. Therefore, daily average concentrations of each pollutants were calculated using raw data from OpenAQ by 30-minutes range. Based on daily average concentration, monthly, seasonal, and locational time series analysis were performed to assess air quality.

According to NAMEM information, methods of measurement of pollutants have not been changed at any of the stations during the 2015-2018 period. Thus, there should be no disruptions in time series due to changed measurement methodology/instruments.

Changes in the near surroundings of a station often affect the PM concentrations and thus the time series. The following changes has occurred, that needs to be considered when interpreting time series variations:

- UB5: During the period since 2010, gers have been gradually removed from this area, apartment buildings have been constructed, and the main road passing through has been paved. However, the station is still significantly influenced by emissions from gers in the valley leading north from the station, which is still full of gers, starting from just north of the station. The ger emissions in the valley are transported south towards the area of the UB5 station through low winds down the valley that occur much of the time.
- UB2: Some roads nearby, north of the station, have been paved.
- UB4: The cross-road was reconstructed, creating dust during the construction, and possibly changing the traffic pattern near the station.
- UB7: Some roads built north of the station, in ger area, not very nearby.

5 Results and Discussions

5.1 Daily time series analysis

1. Particulate matter <2.5 μm ($PM_{2.5}$)

For the year 2015-2018, daily averages of $PM_{2.5}$ pollution concentration are shown in Figure 5.1-5.4. Time series of 4 monitoring stations, out of 12 monitoring station, are shown as an example. Time series graphs of other 8 monitoring stations are presented in the Appendix 7. Two of them are (APRD1, APRD5) located in ger area, another one is (UB2) located in central area, representing ger and central area, and the last one is at the airport area as remote area of Ulaanbaatar.

As shown in the Figure 5.1-5.4, $PM_{2.5}$ pollution is strong seasonal character. The most polluted period of all stations is in the cold season (October to March), and the lowest pollution period is in the warm season (April to September). It can be concluded that $PM_{2.5}$ pollution is closely linked to coal-burning ger area. Due to increase of the coal consumption in December and January, $PM_{2.5}$ pollution is at its highest level.

Time series of APRD5 is starting from June 2016 because the monitoring station was newly established in that period at Bayankhoshuu.

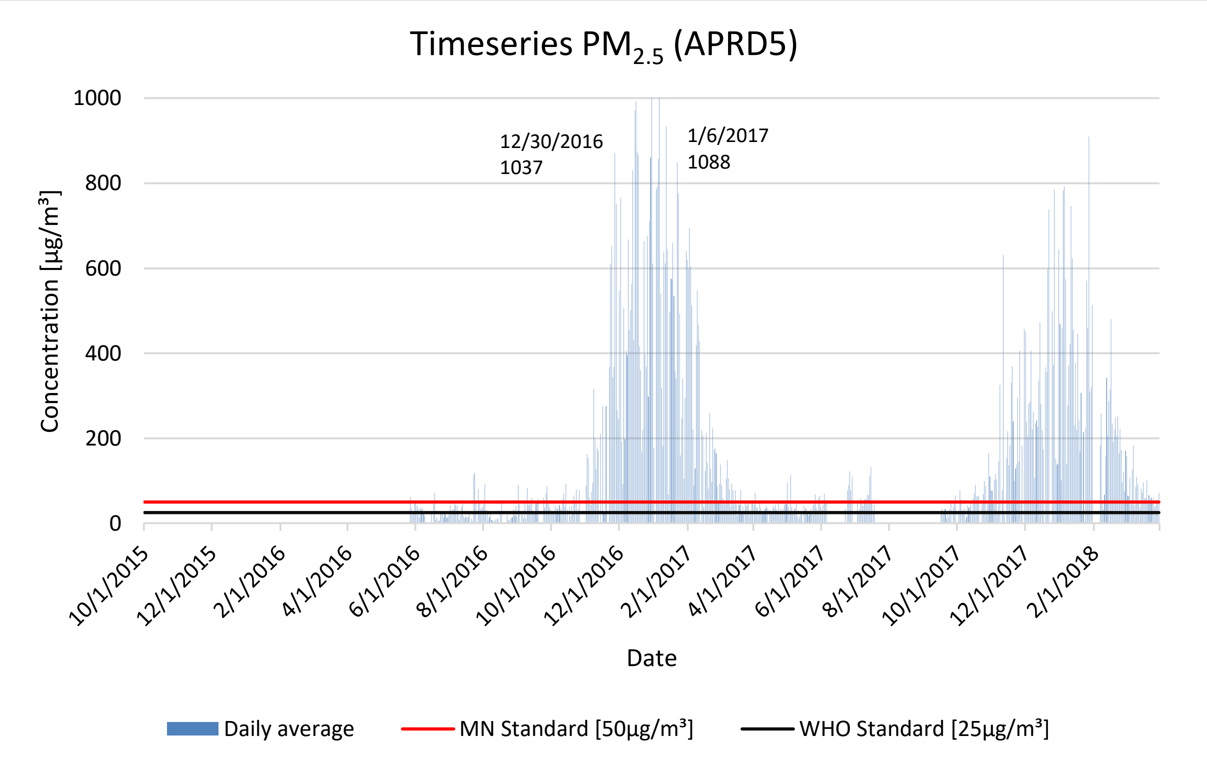


Figure 5.1. Daily average $PM_{2.5}$ concentrations at station APRD5 , October 2015-March 2018

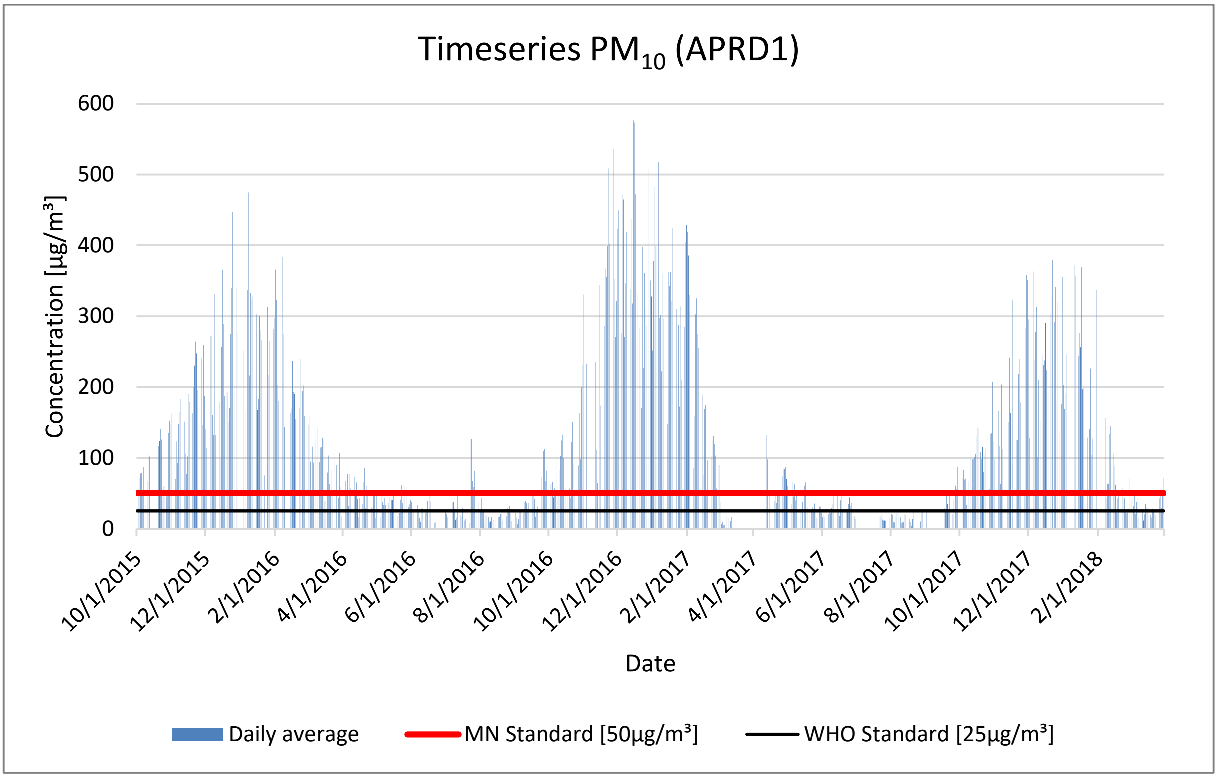


Figure 5.2. Daily average $PM_{2.5}$ concentrations at station APRD1, October 2015-March 2018

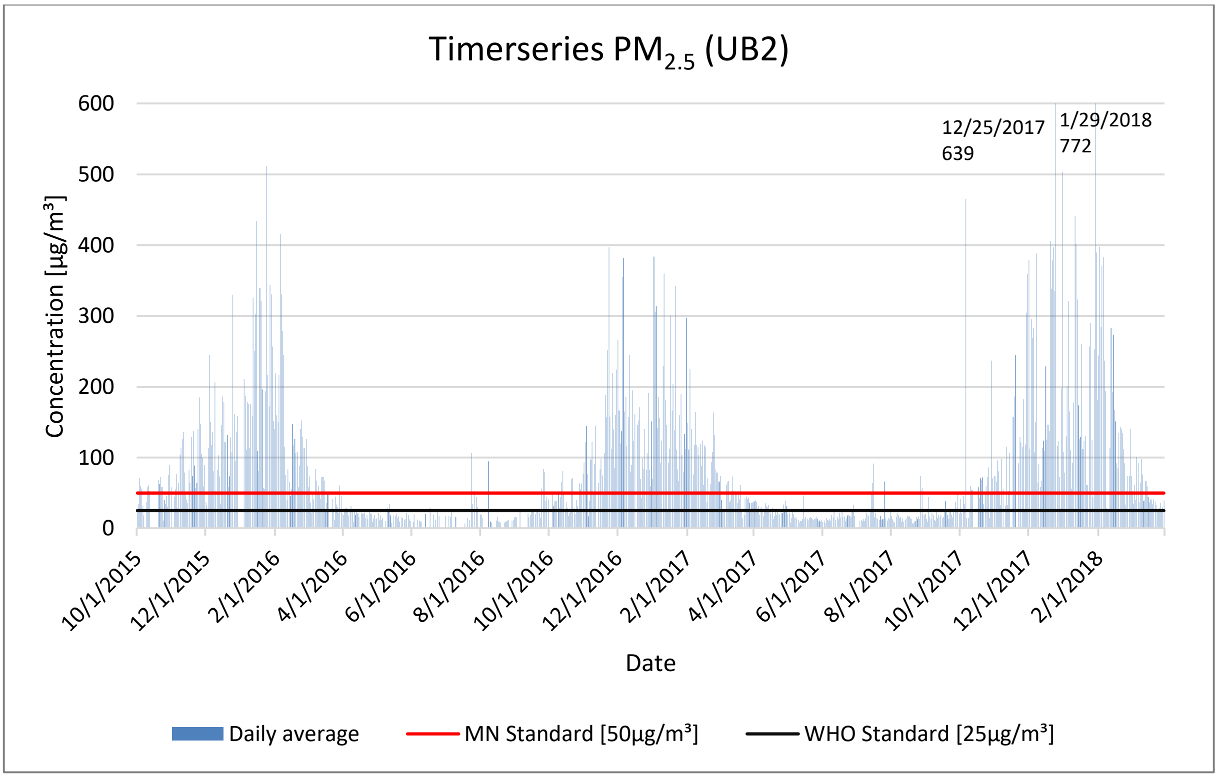


Figure 5.3. Daily average $PM_{2.5}$ concentrations at station UB2, October 2015-March 2018

In winter 2017, $PM_{2.5}$ concentration peaked at 1088 µg/m^3, which appeared at APRD5 station which located in the most polluted area. From here, the average daily concentration is about 45 times higher than the WHO guideline and 20 times more than Mongolian AQ standard. From the beginning of warm season, the pollution is clearly declining. It has reached a same level at all stations during that period. One can see that PM2.5 pollution is strongly seasonal character. The level of PM2.5 during the winter is enormously exceeded daily standard level while air pollution concentration in the summer is not exceeding MNS and even WHO's guideline.

Compared to the average concentrations of other stations, APRD1 and APRD5 are relatively polluted, depending on their location. The pollution level of UB2 station, which located in the central area, is much lower than ger area despite the relatively higher than the APRD4. As a result, it shows that PM2.5 is directly related to the location and environment. Although APRD4 is low in pollution levels compare to other stations, it is generally 3-4 times higher in the winter time than standard MNS.

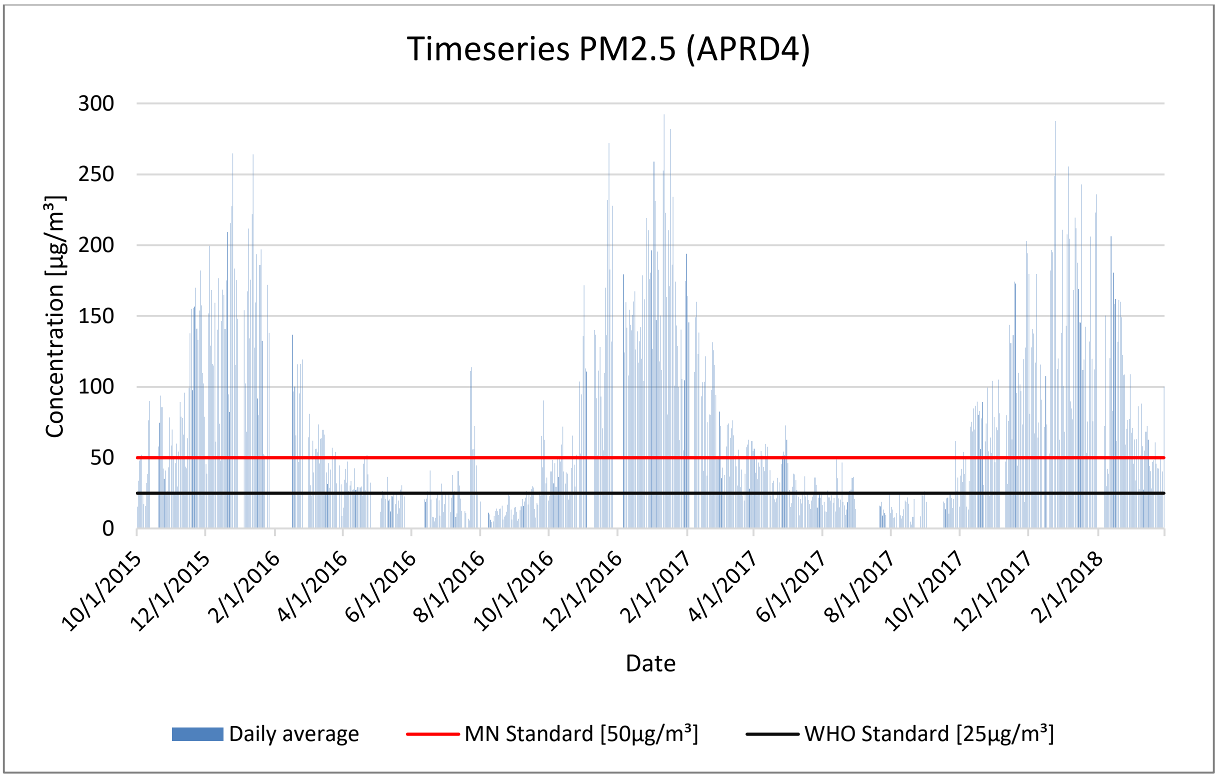


Figure 5.4. Daily average PM2.5 concentrations at station APRD4, October 2015-March 2018

2. Particulate matter <10 μm (PM_{10})

Patterns of daily time series of PM_{10} in ger area stations are displayed in Figure 5.5 and 5.6. Figures show the average concentration of PM_{10} in the APRD5 station is the highest. From here, the surrounding area of APRD5 station can be described as the most polluted area in Ulaanbaatar during winter.

PM_{10} pollution levels are increasing in winter season, but it is not decreasing in warm seasons namely, in the spring, different than $PM_{2.5}$. This indicates that PM_{10} pollution depends on the soil suspension dust. PM_{10} levels are increasing due to thaw of soil during warm seasons. Particularly, the pollution in the ger area is associated with unpaved surface of soil due to low maintenance. The PM_{10} pollution in the central part of the city is relatively low because most areas are paved.

Although the pollution of PM_{10} is higher than summer concentration in the spring due to the soil, the pollution level is the highest in the winter related to coal-burning in the ger area.

Measurement in UB8 is in remote area, concentration in winter is relatively low, but it should be noted that measurements have some error and failure.

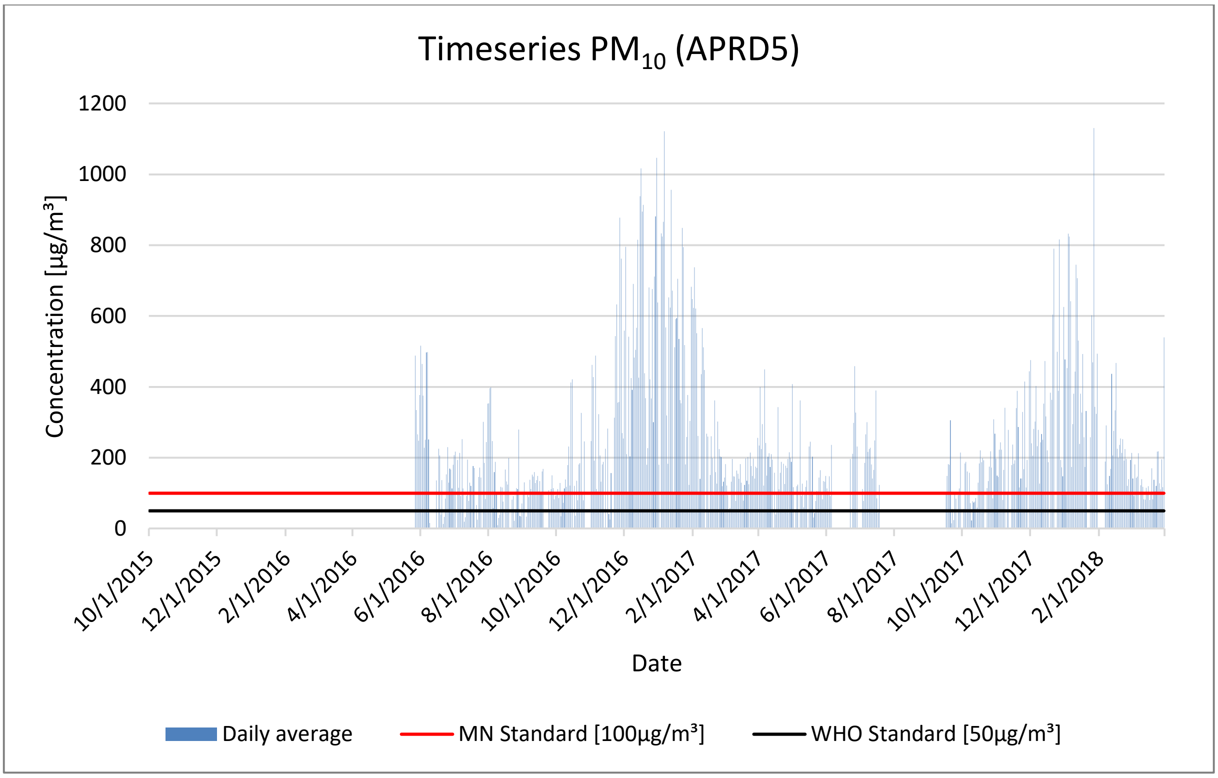


Figure 5.5. Daily average PM_{10} concentrations at station APRD5, October 2015-March 2018

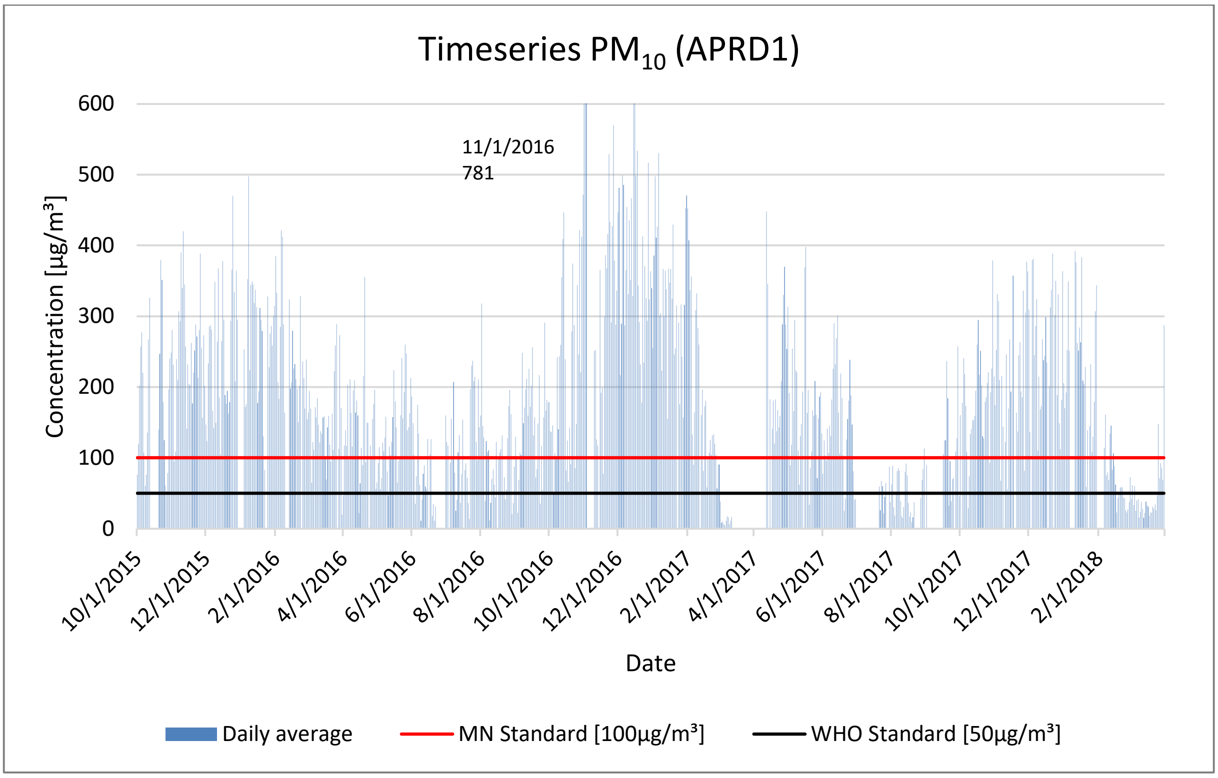


Figure 5.6. Daily average PM_{10} concentrations at station APRD1, October 2015-March 2018

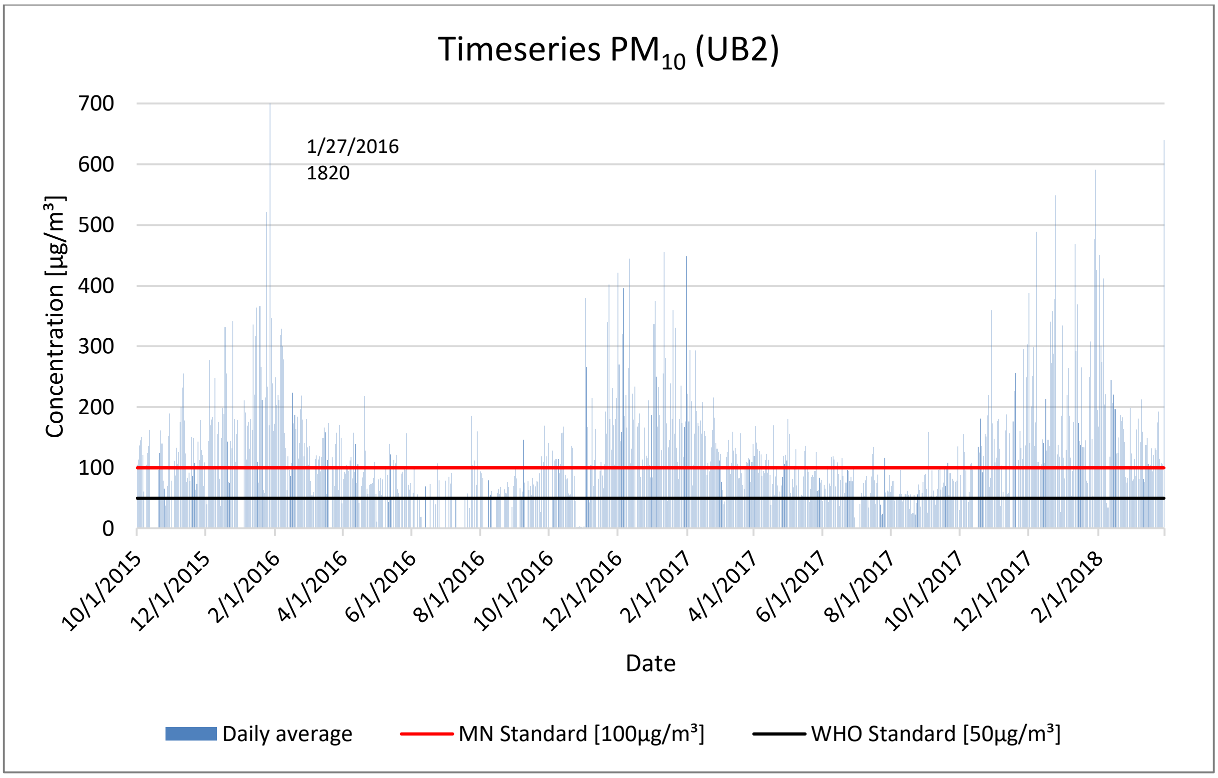


Figure 5.7. Daily average PM_{10} concentrations at station UB2, October 2015-March 2018

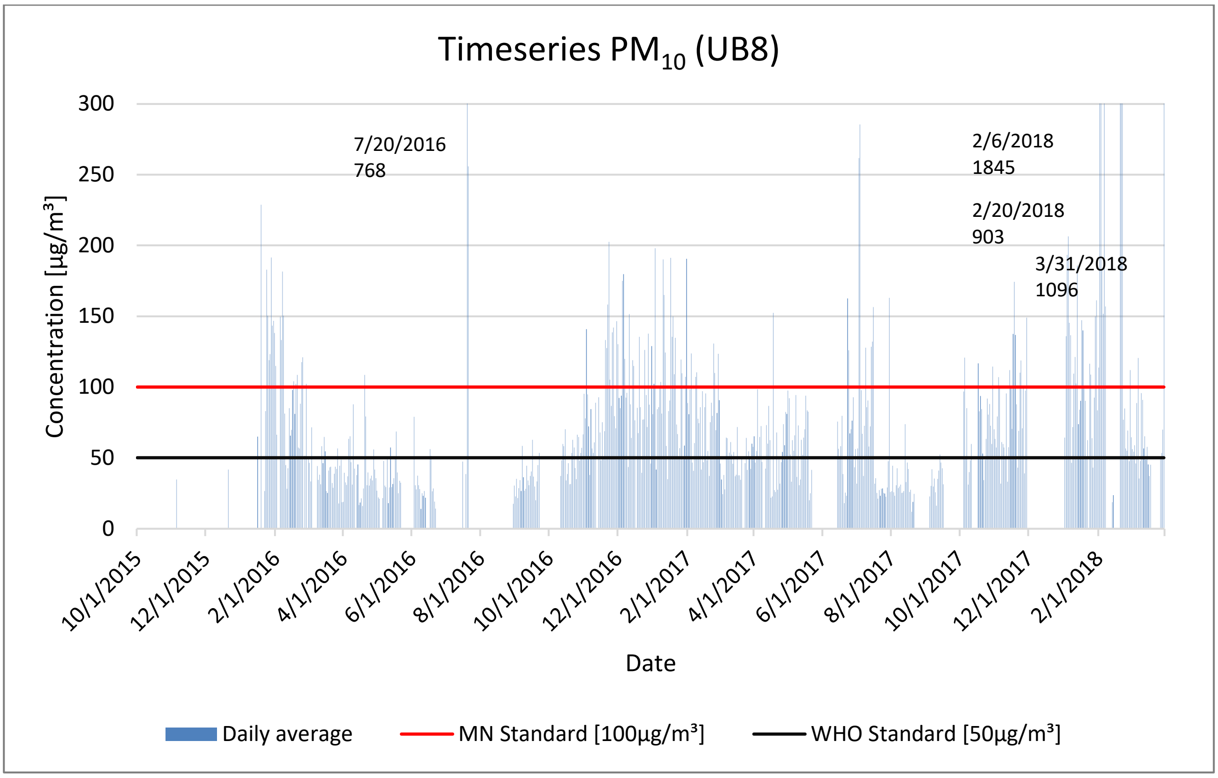


Figure 5.8. Daily average PM_{10} concentrations at station UB8, October 2015-March 2018

3. Sulfur Dioxide (SO_2)

Daily average concentration of SO_2 at different stations for October 2015-March 2018 are shown in Figure 5.9-5.12. As presented, the pollution levels of SO_2 also have seasonal character, same as $PM_{2.5}$. It can be concluded that SO_2 emission highly related to coal combustion.

Daily average of SO_2 in cold season has been declining since 2015, which is observed at all stations. However, seasonal growth is also associated with ger area. During the warm months between April and October, the amount of SO_2 pollution is lower than the WHO guideline and the MNS standard.

Table 5.1 shows that the 3 year average SO_2 pollution of the stations in the ger areas is 2-3 times higher than the MNS standard, and it grows 5-6 times than Mongolian AQ standard between October and March.

For the stations located in remote areas, the pollution level in any season is lower than MNS standard.

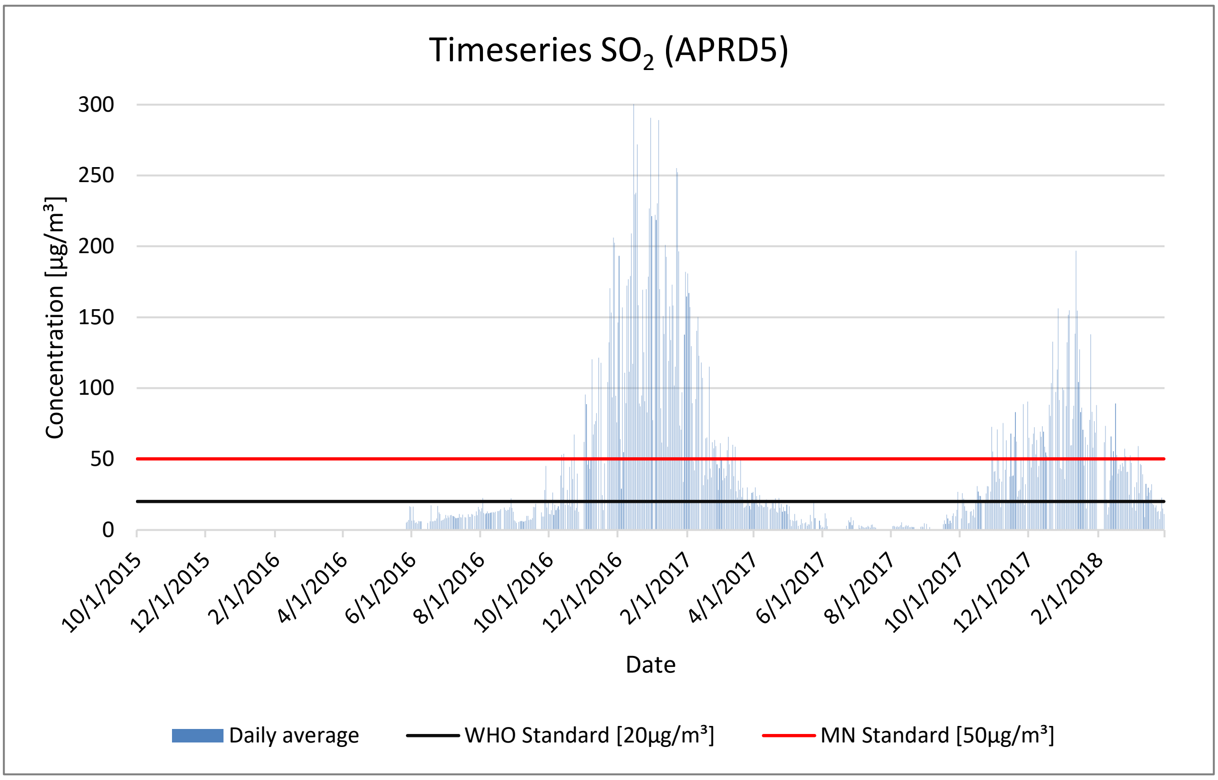


Figure 5.9. Daily average SO_2 concentrations at station APRD5, October 2015-March 2018

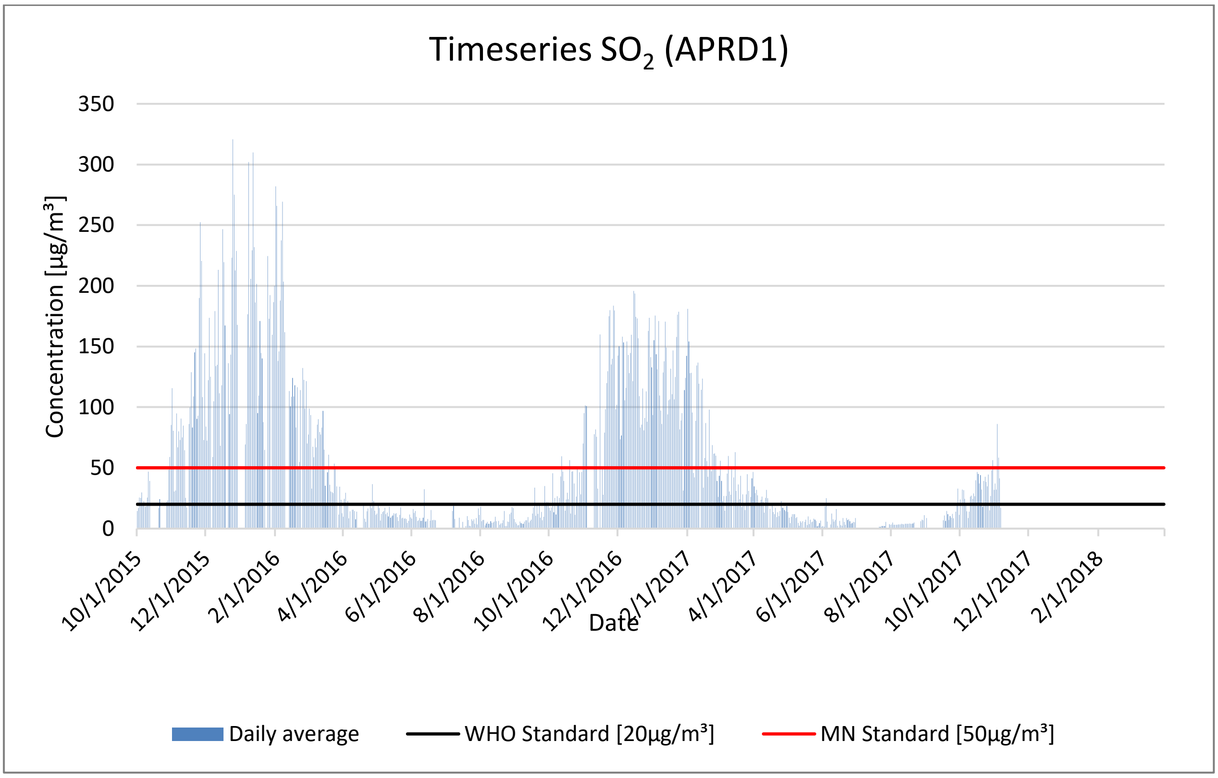


Figure 5.10. Daily average SO_2 concentrations at station APRD1, October 2015-March 2018

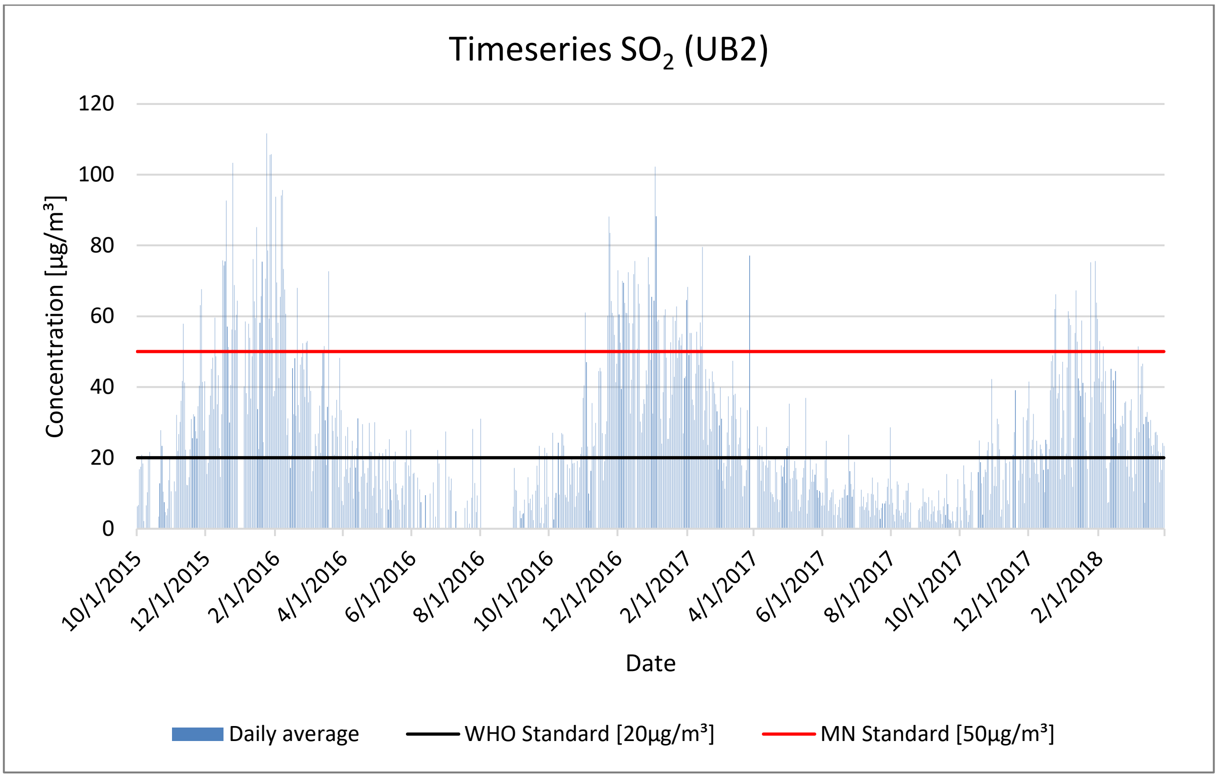


Figure 5.11. Daily average SO_2 concentrations at station UB2, October 2015-March 2018

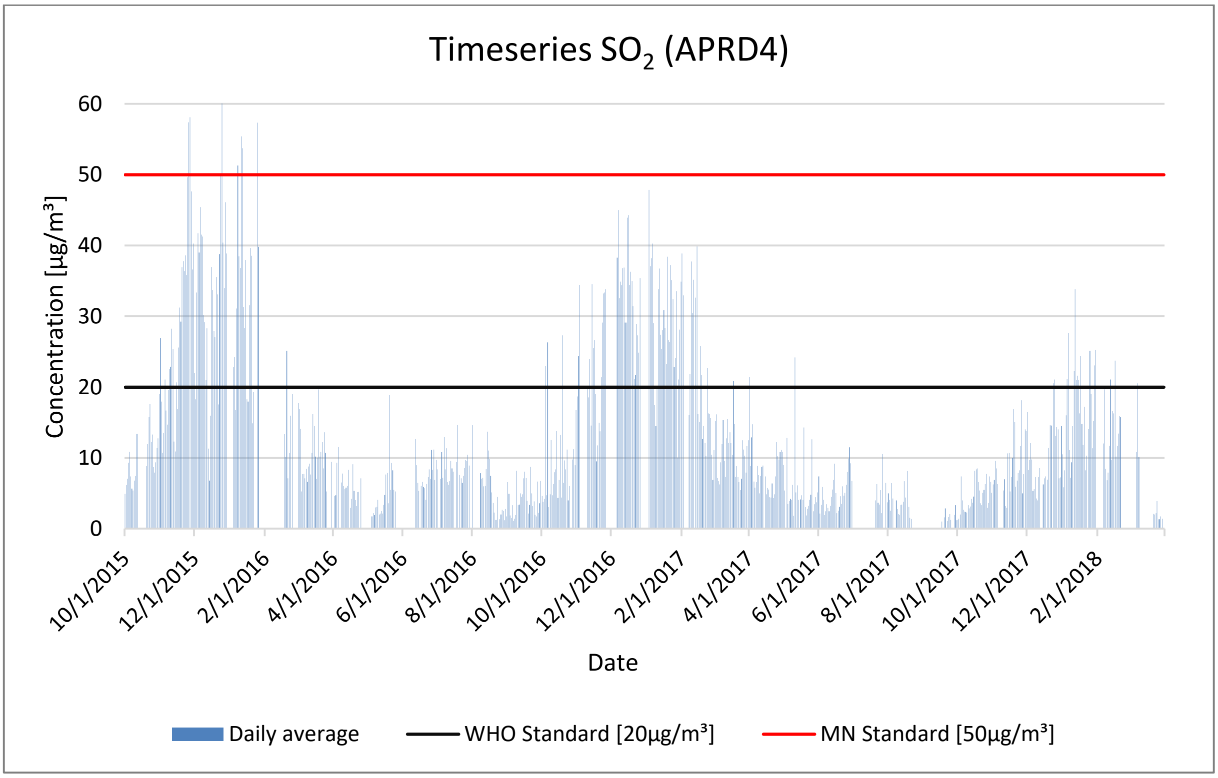


Figure 5.12. Daily average SO_2 concentrations at station APRD4, October 2015-March 2018

4. Nitrogen Dioxide (NO_2)

For NO_2 pollution, there is no considerable changes caused by locations (ger, central and remote areas), but seasonal character has been observed as well. However, the NO_2 pollution in the winter season is much lower than other pollutants, which is twice more than the standard, whereas $PM_{2.5}$ level is 4-5 times exceeding the standard.

The pollution level of UB2 and UB4 stations located near the main road, are higher than the standard both in summer and winter time. It is related to NO_2 pollution from the vehicles.

Concentration of NO_2, increasing in the winter time, shows that this pollutant is also related to combustion. However, the summer to winter ratio is either much lower or no big difference (e.g. this ratio is less than 0.5 in UB2 which is located near the western cross road, higher intensity of traffic). It shows that this pollutant source is the reason of vehicles.

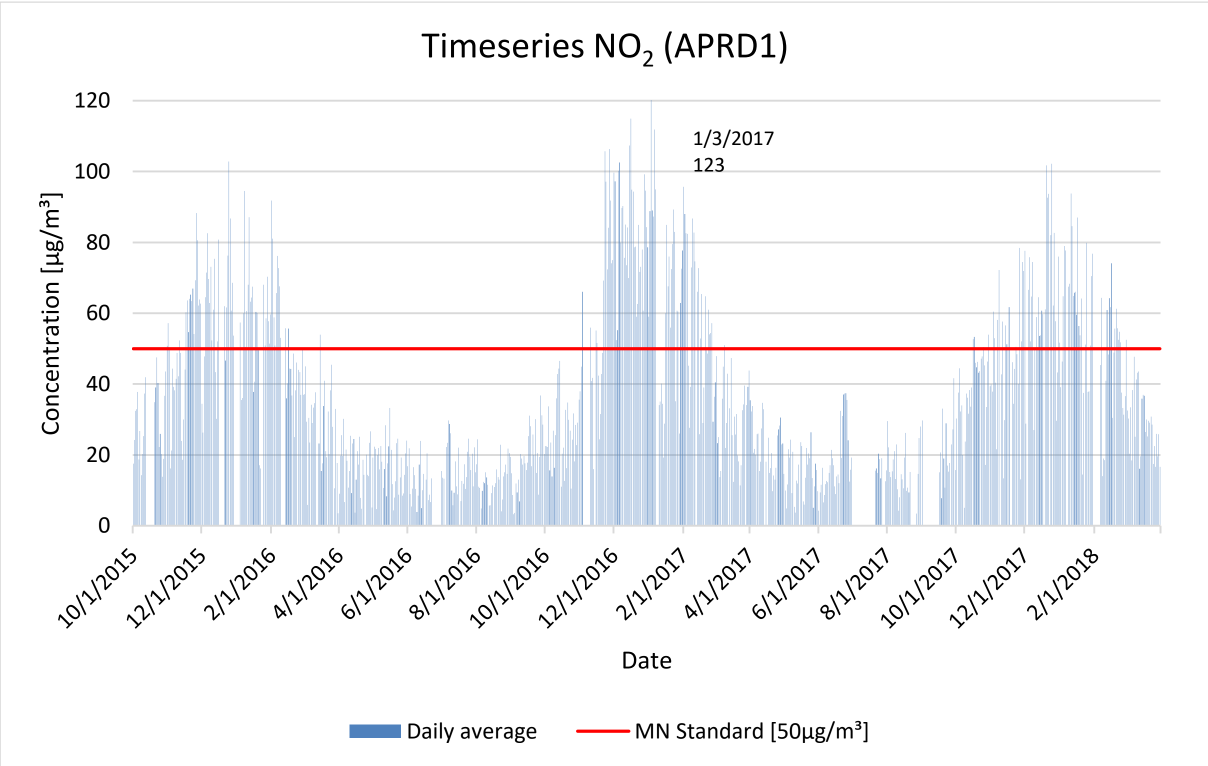


Figure 5.13. Daily average NO_2 concentrations at station APRD1, October 2015-March 2018

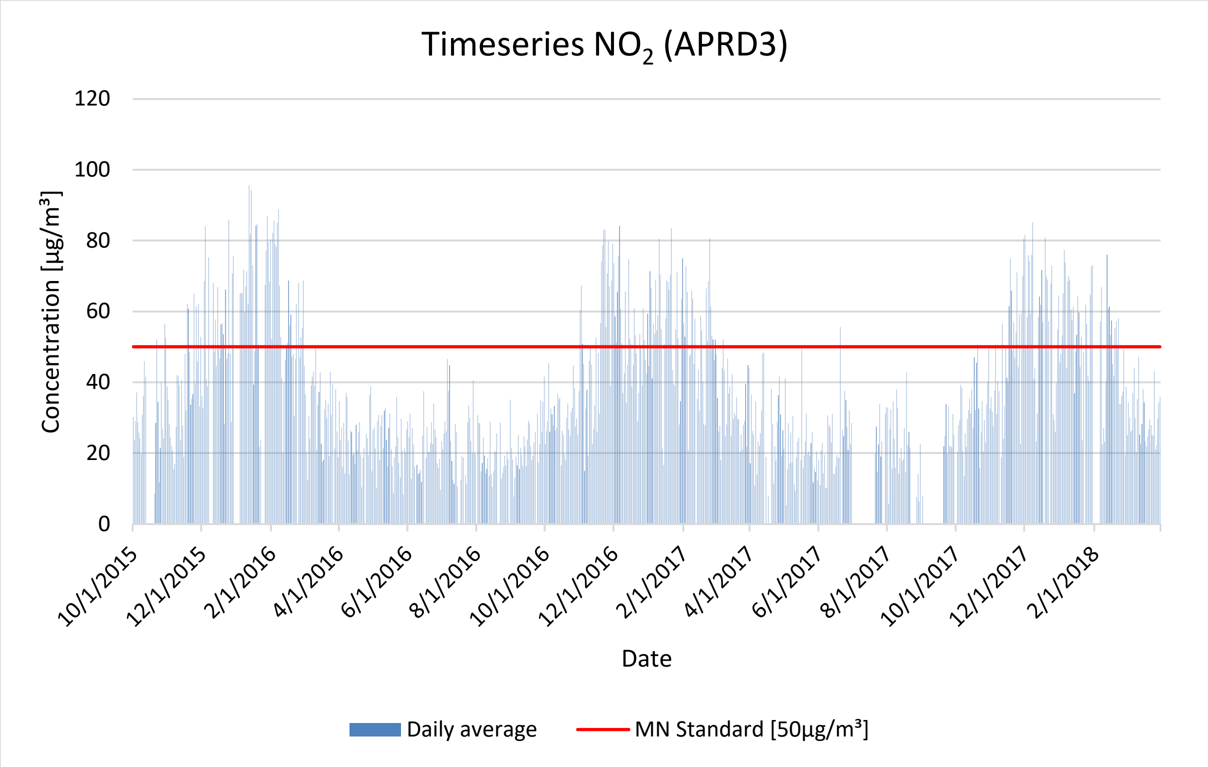


Figure 5.14. Daily average NO_2 concentrations at station APRD3, October 2015-March 2018

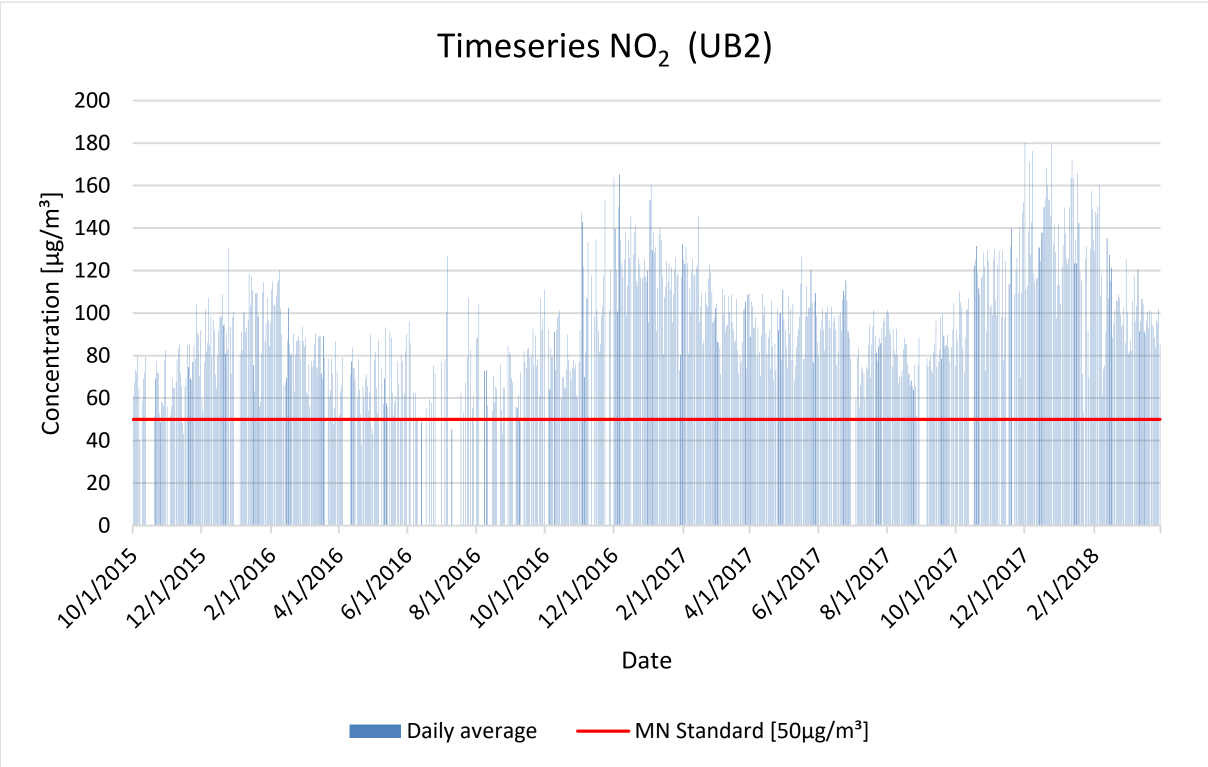


Figure 5.15. Daily average NO_2 concentrations at station UB2, October 2015-March 2018

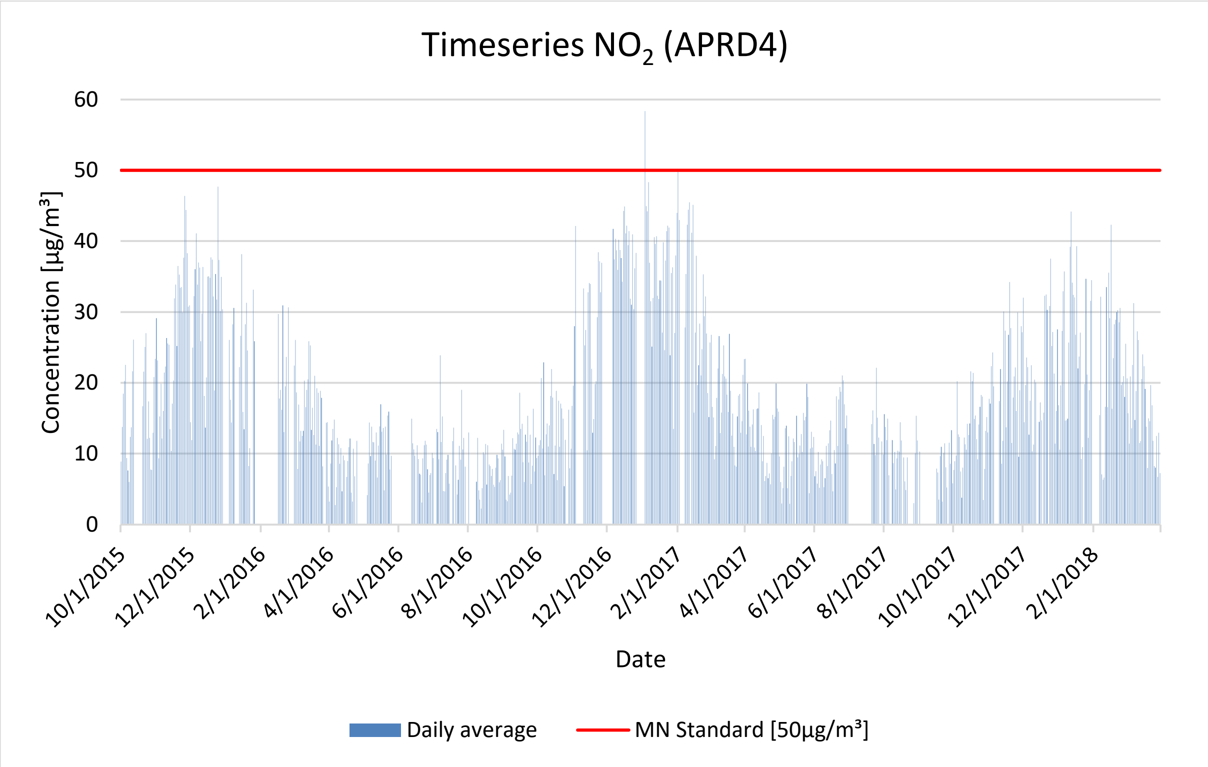


Figure 5.16. Daily average NO_2 concentrations at APRD4, October2015-March 2018

5. Carbon Monoxide (CO) and Ozone (O_3)

Both CO and O_3 have seasonal character. But O_3 emission increases during the summer while CO emission increases during the winter. It indicates that CO emission is also related to the combustion.

The increasing level of O_3 during the summer shows that this pollutant has not anthropogenic origin.

For O_3 and CO pollutants, there is no daily average standard in the MNS and WHO guideline. Therefore, the graphs for the 2015-2018 daily average content shows the 8 hour average standard level. For all stations, the pollution levels of these 2 pollutants were less than the average of 8 hour standard.

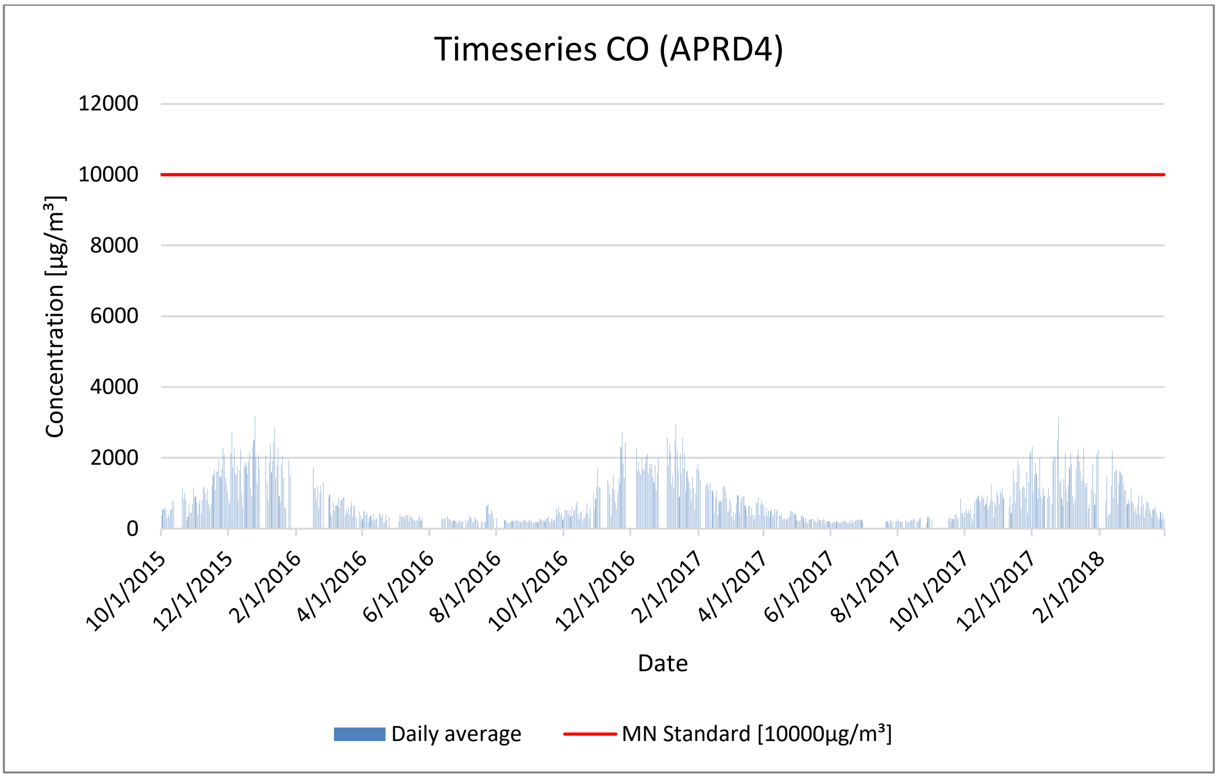


Figure 5.17. Daily average CO concentrations at station APRD4, October 2015-March 2018

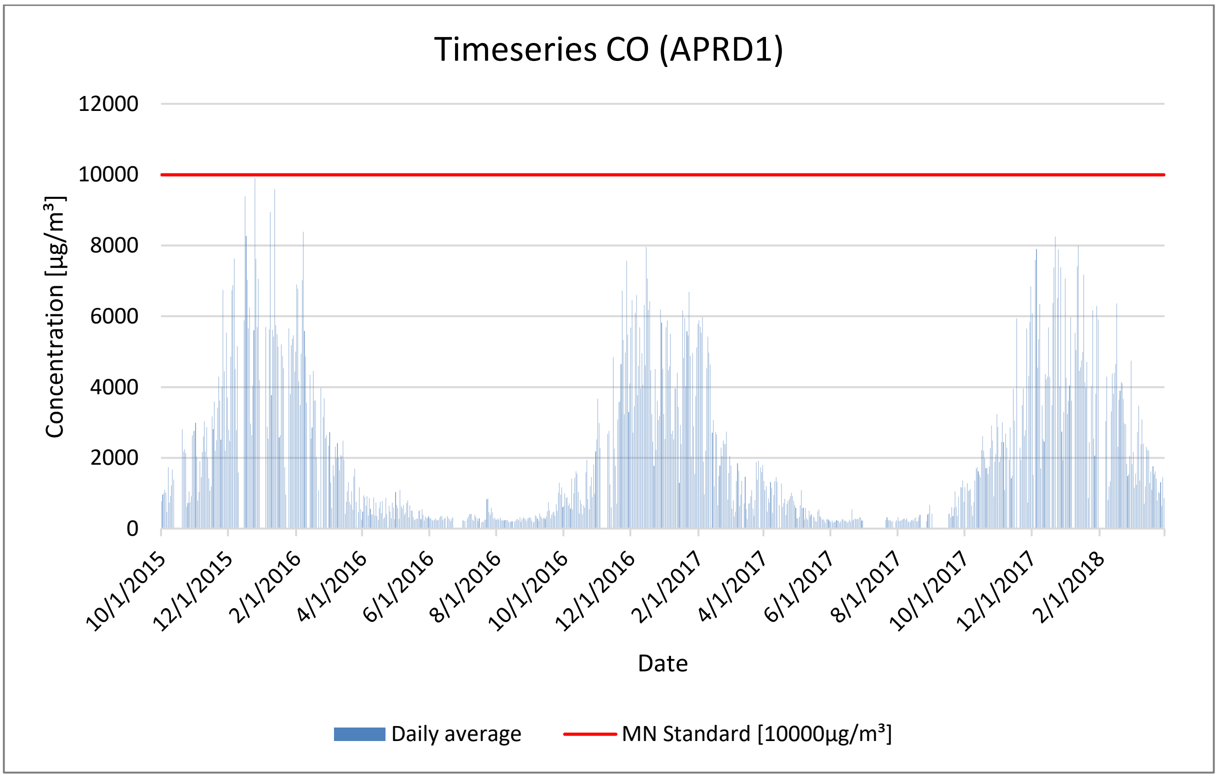


Figure 5.18. Daily average CO concentrations at station APRD1, October 2015-March 2018

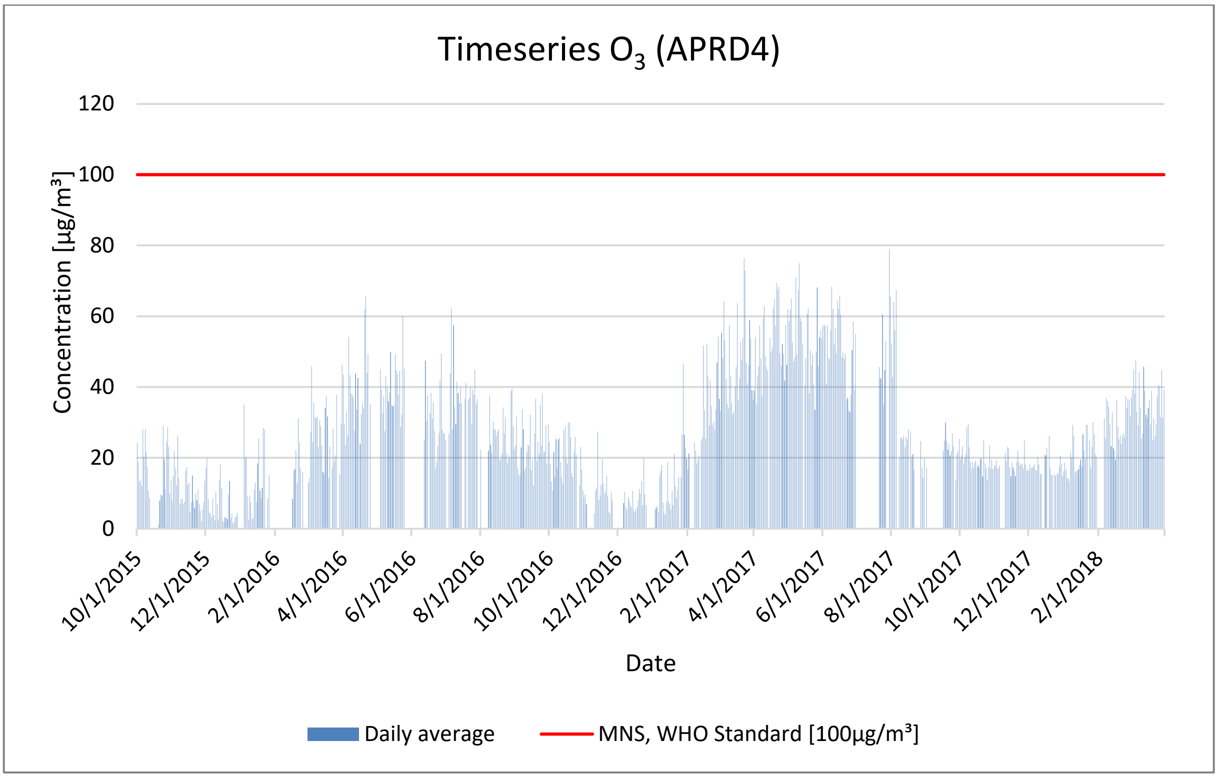


Figure 5.19. Daily average O_3 concentrations at station APRD4, October 2015-March 2018

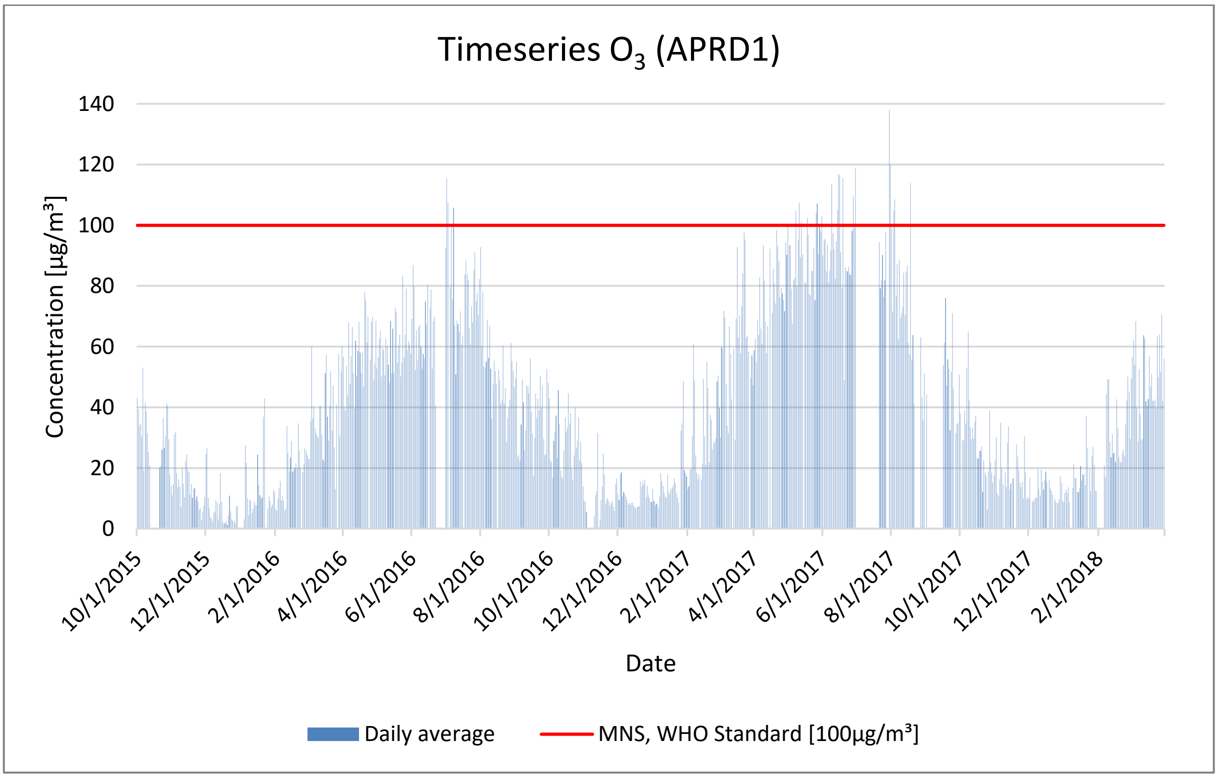


Figure 5.20. Daily average O_3 concentrations at station APRD1, October 2015-March 2018

5.2 Winter Pollution analysis

In this analysis, last three years cold seasonal average concentrations are compared. From Figure 5.21-5.26, it is difficult to conclude change of air pollution concentration level. For example, the average winter concentration level of $PM_{2.5}$ is increased for three years at the station APRD3 while its concentration is decreased in APRD5, UB4, and US Dip. In other stations such as UB2, APRD2, APRD4, and APRD1 it is difficult to identify dependence of concentrations and locations.

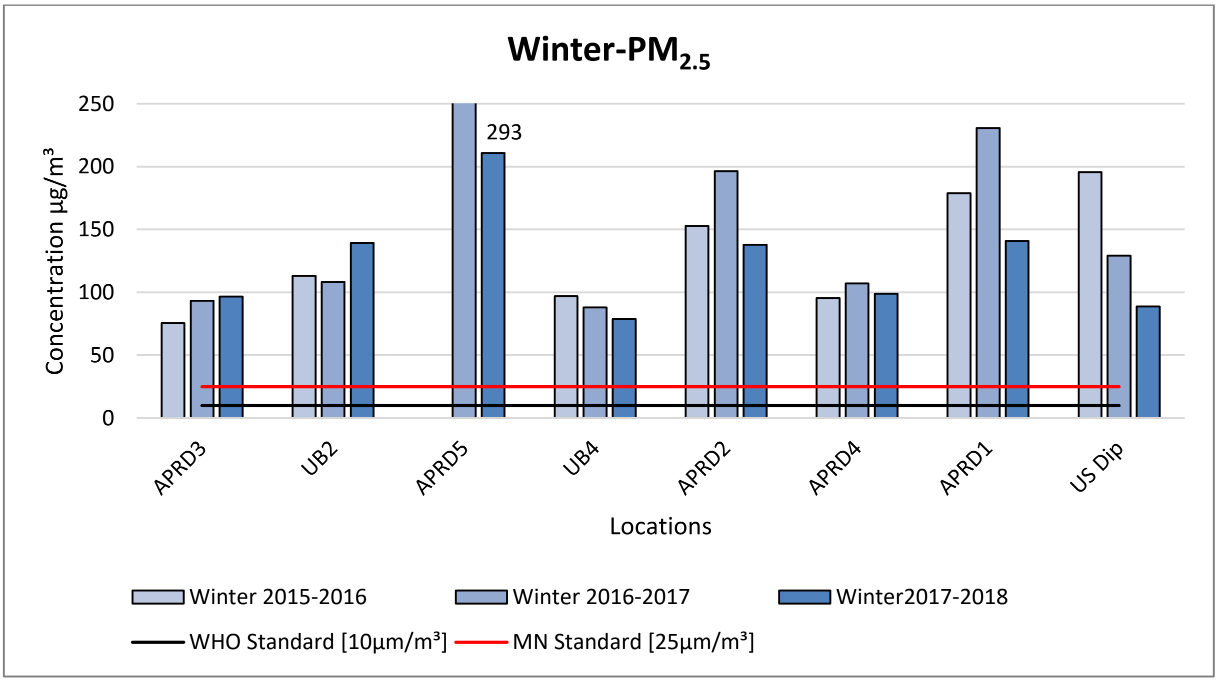


Figure 5.21. Average winter concentrations of $PM_{2.5}$ for last 3 years at all stations

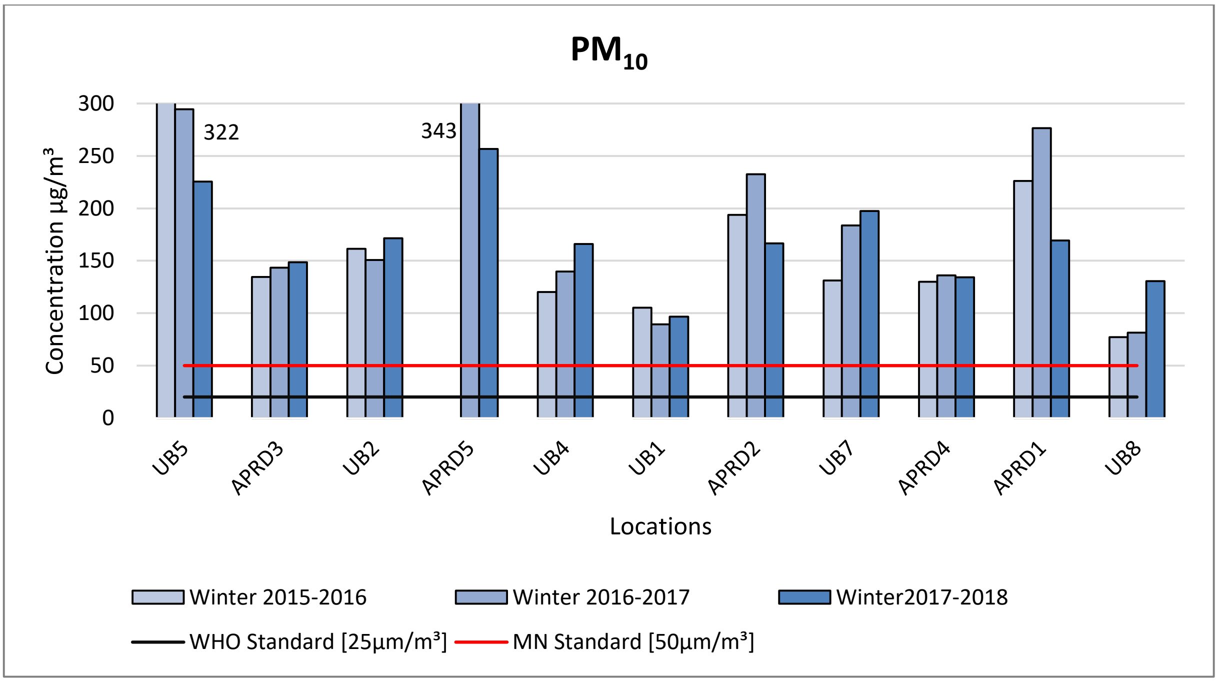


Figure 5.22. Average winter concentrations of PM_{10} for last 3 years at all stations

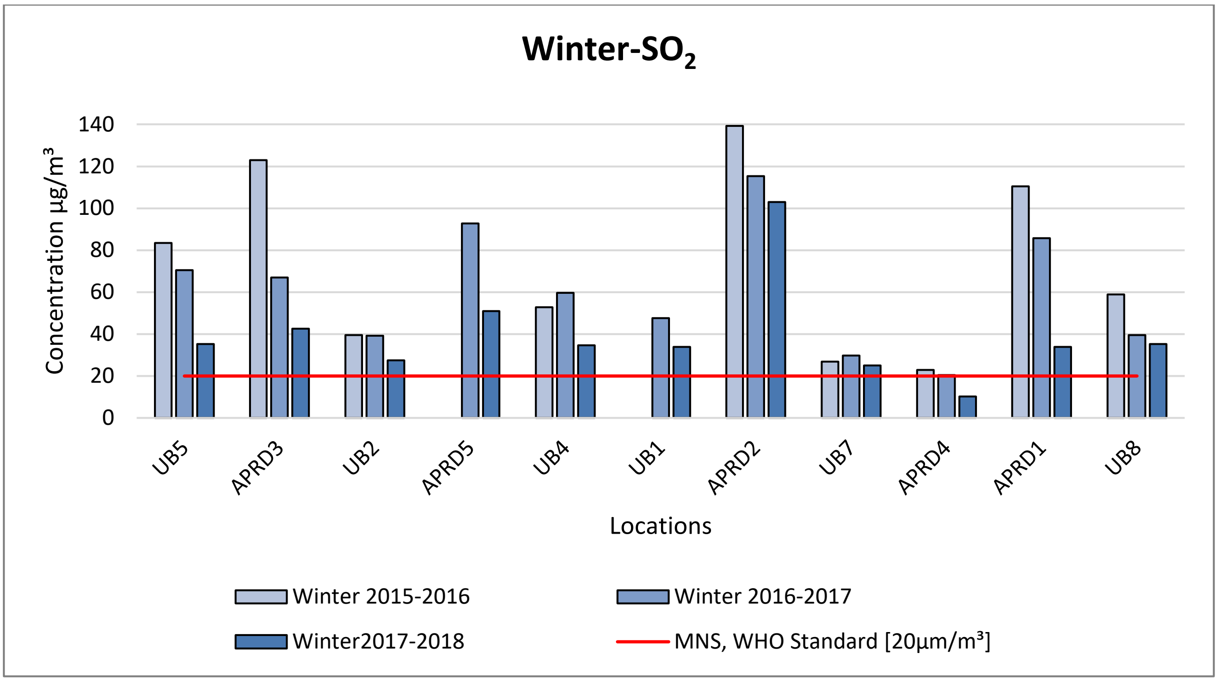


Figure 5.23. Average winter concentrations of SO_2 for last 3 years at all stations

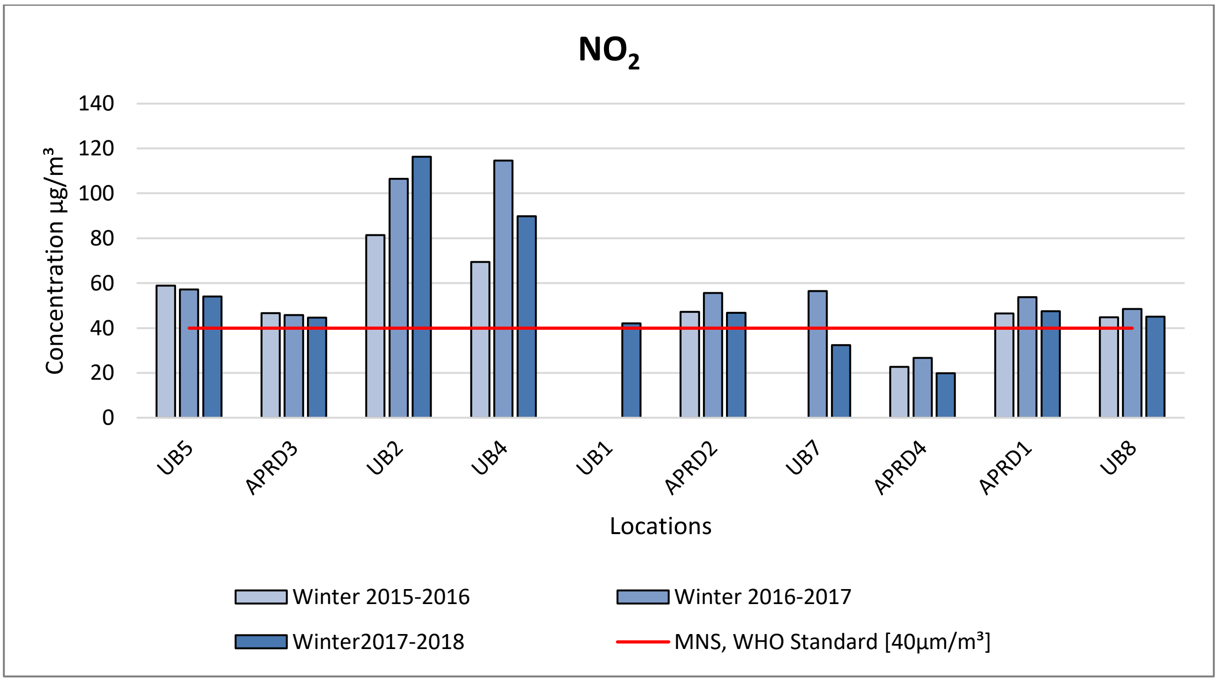


Figure 5.24. Average winter concentrations of NO_2 for last 3 years at all stations

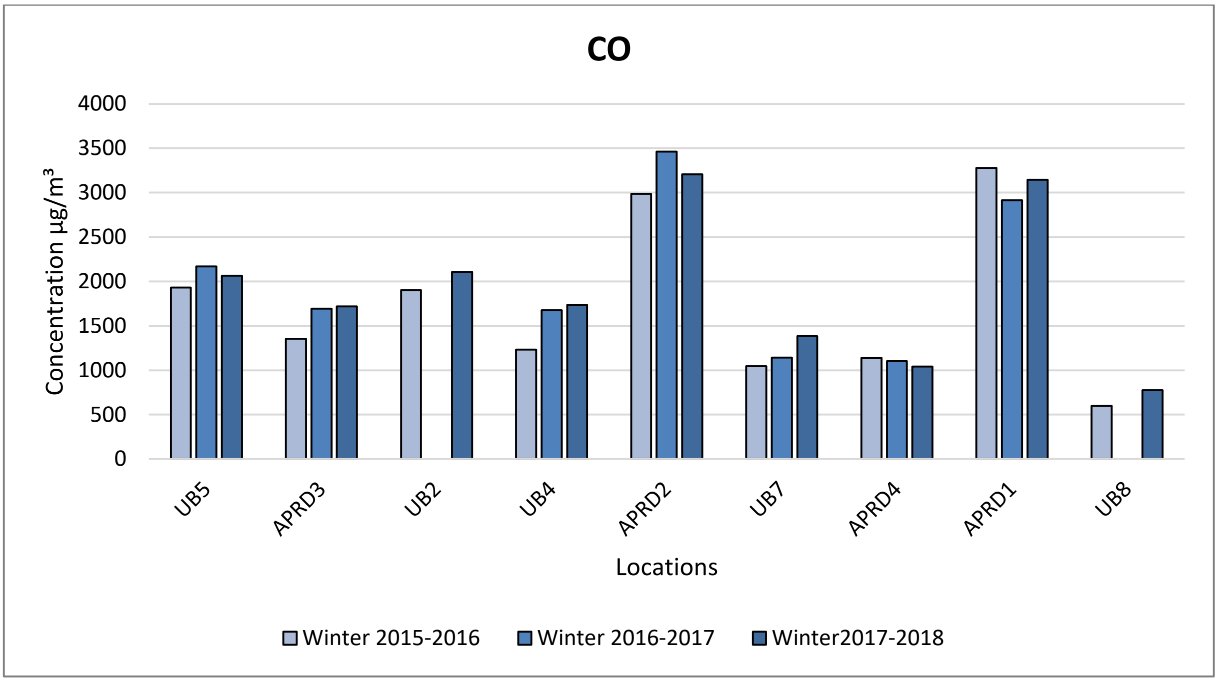


Figure 5.25. Average winter concentrations of CO for last 3 years at all stations

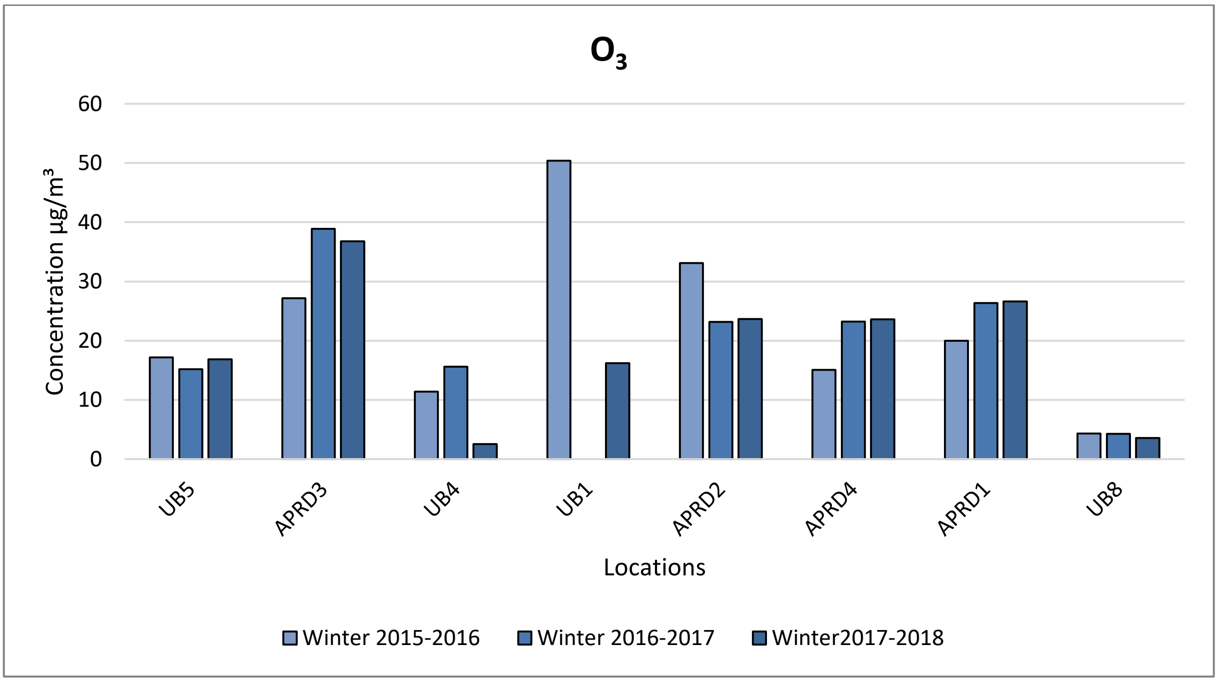


Figure 5.26. Average winter concentrations of O_3 for last 3 years at all stations

5.3 Monthly time series analysis

Monthly time series analysis were done for each stations and each pollutants, because reports of air quality of the cities usually have monthly time series, even though it is presented in the seasonal analysis of air quality of Ulaanbaatar city.

Seasonal character and other analysis have been calculated in the daily time series analysis chapter 4.1.

Here monthly time series analysis is employed to compare locations, and to compare warm and cold seasons. Analysis graphics is presented in Annex2.

Here presented comparison of different locations for four seasons:

PM_{10}:

Comparison of January PM_{10} concentration is shown in the Figure 5.27. The most polluted area is APRD5 (Bayankhoshuu), which is the highest populated area of Ulaanbaatar, the lowest polluted place is UB8 (Urgakhnaran) or less remote area of Ulaanbaatar. Pollution is depended on the population density. The central area is less polluted, due to mainly apartments and offices there.

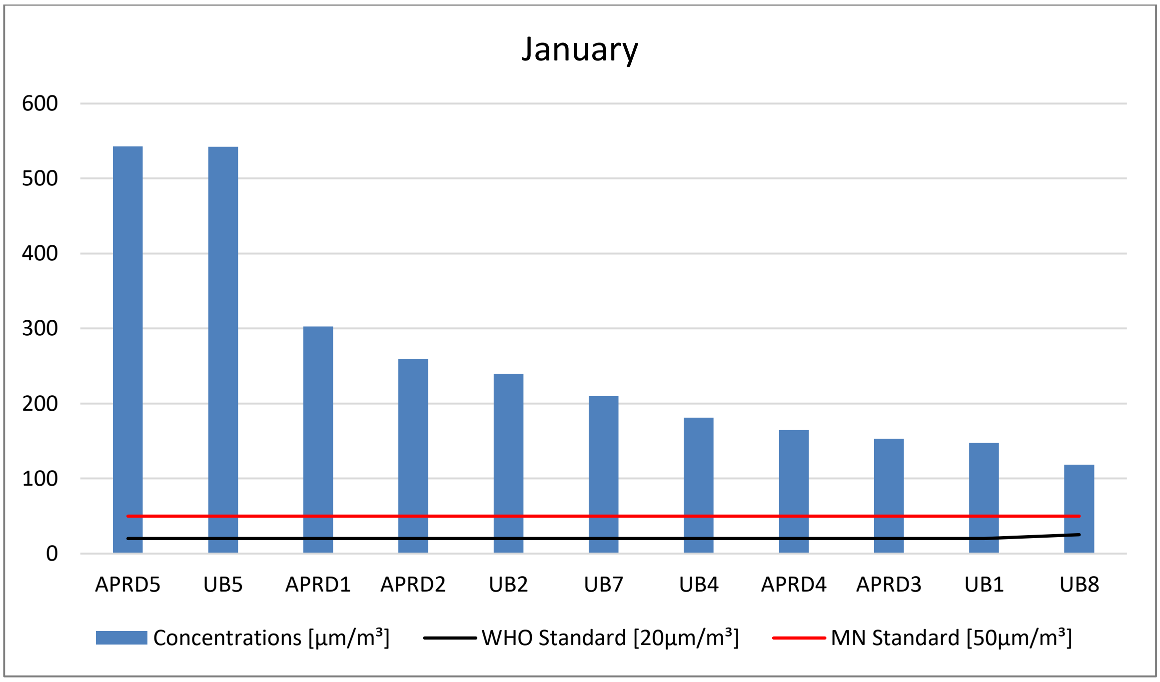


Figure 5.27. Comparison of PM_{10} concentrations at different locations in January

In Figure 5.28, PM_{10} comparison graph of July in different stations. As of July, stations UB7, UB8 and APRD5 have higher concentration. This shows, main component of PM_{10} concentration is soil suspension dust and dust from the unpaved road in the remote areas. The low concentration in July in central areas due to less open soil and unpaved road.

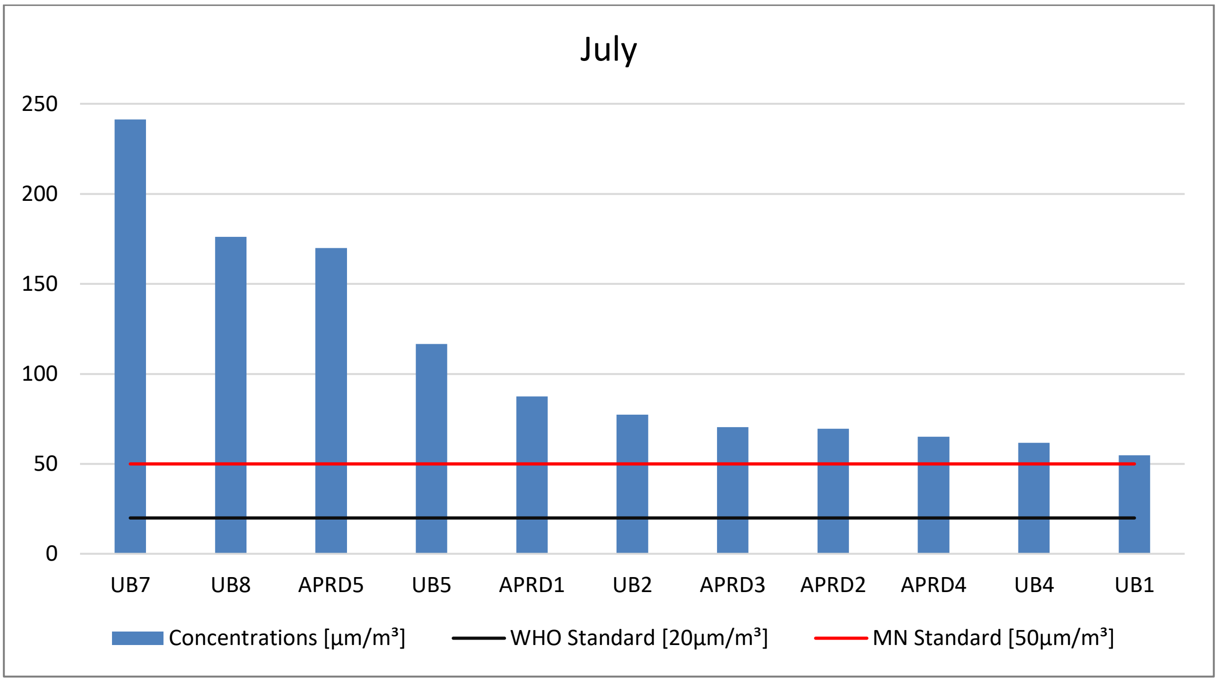


Figure 5.28. Comparison of PM_{10} concentrations at different locations in July

$PM_{2.5}$:

Comparison of January $PM_{2.5}$ and July $PM_{2.5}$ concentrations are shown in the Figure 5.29 and Figure 5.30. Most polluted area is APRD5 (Bayankhoshuu) as PM_{10}, which is the highest populated area of Ulaanbaatar, and the lowest polluted place is APRD3 (Amgalan). It should be noted that $PM_{2.5}$ comparison could not cover all stations, because some stations does not have $PM_{2.5}$ measurements. Figure 5.30 presents the comparison of $PM_{2.5}$ concentrations in July. There are no considerable differences between locations, especially in central and ger area. Also it proves that main source of $PM_{2.5}$ in winter is the combustion. They are mainly in same level as no combustion in summer.

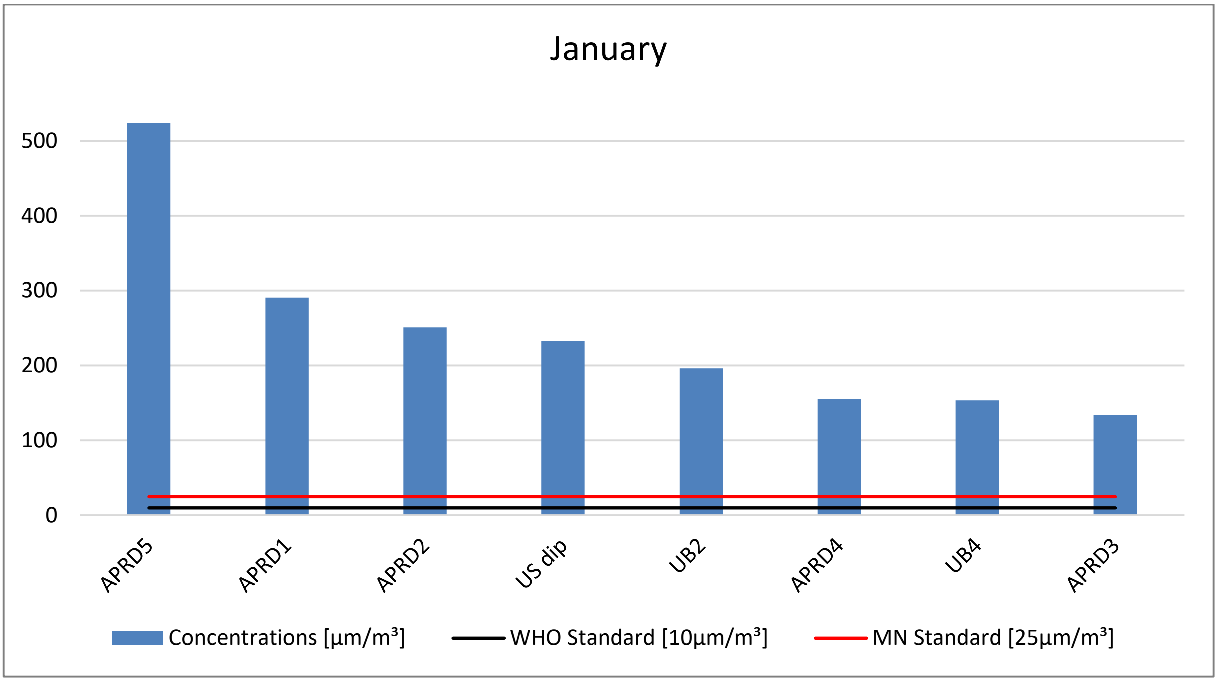


Figure 5.29. Comparison of $PM_{2.5}$ concentrations at different locations in January

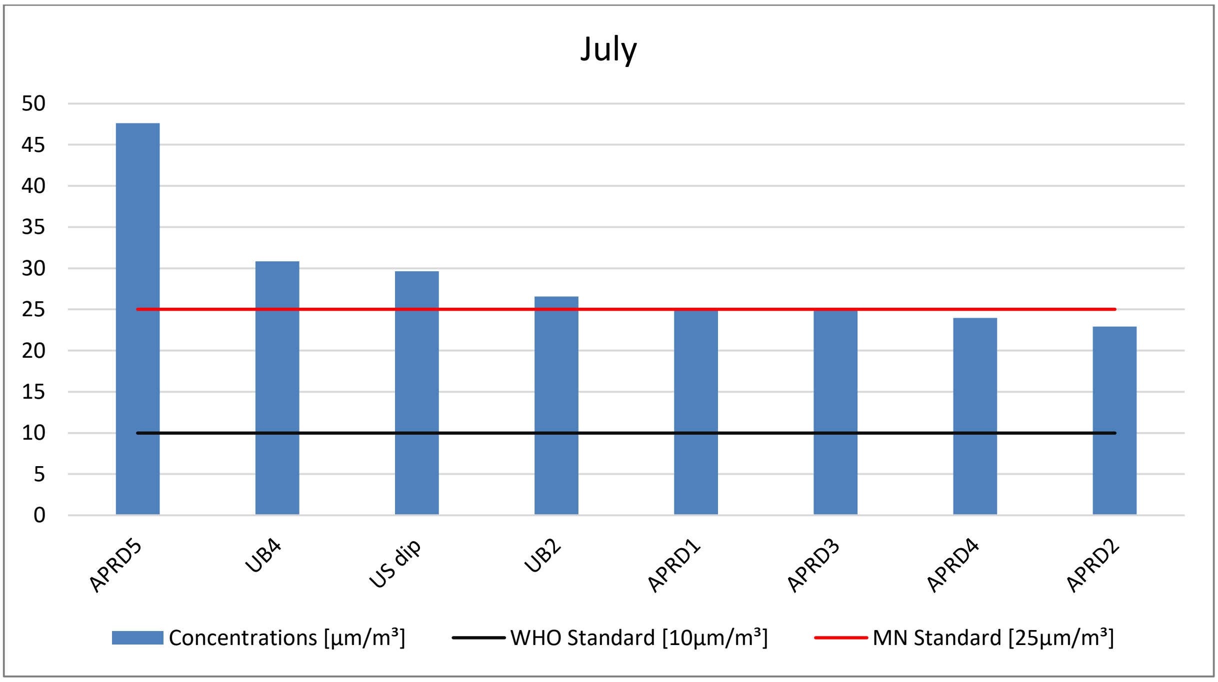


Figure 5.30. Comparison of $PM_{2.5}$ concentrations at different locations in January

SO_2:

As presented in the Figure 5.31 and Figure 5.32, the monthly comparisons of SO_2 concentration in January and July are most similar to $PM_{2.5}$ comparison. This shows that the combustion causes the SO_2 pollution. The below Figure 5.31 indicates the distinct differences of concentration at the central and ger area in January.

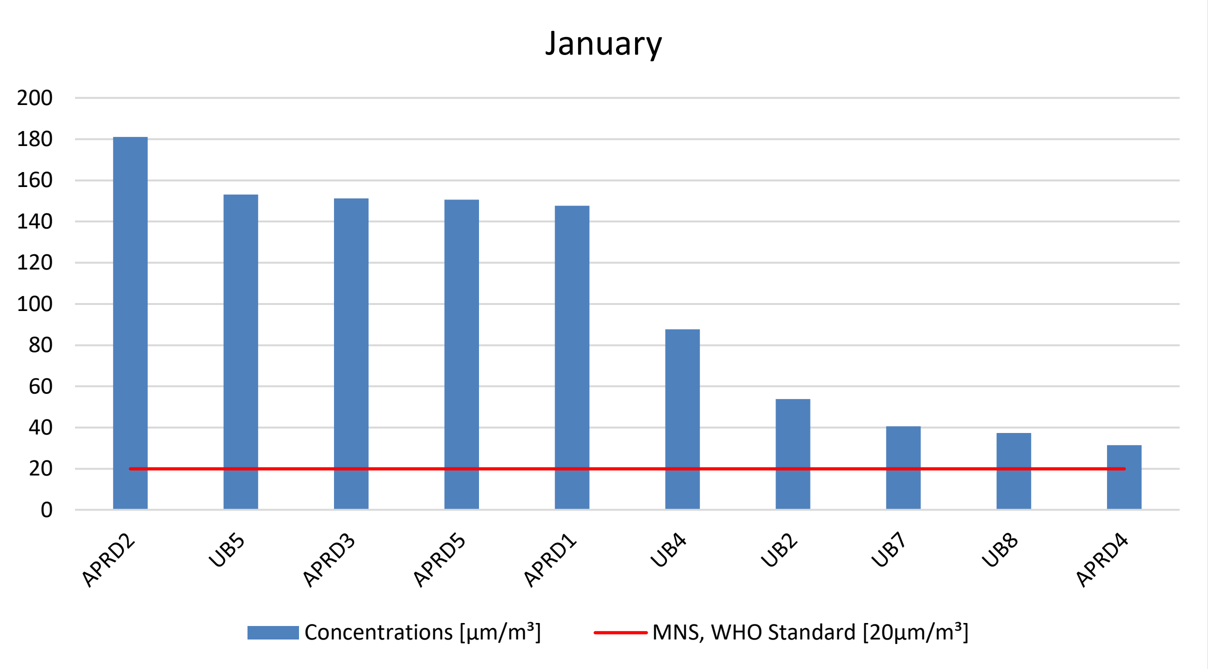


Figure 5.31. Comparison of SO_2 concentrations at different locations in January

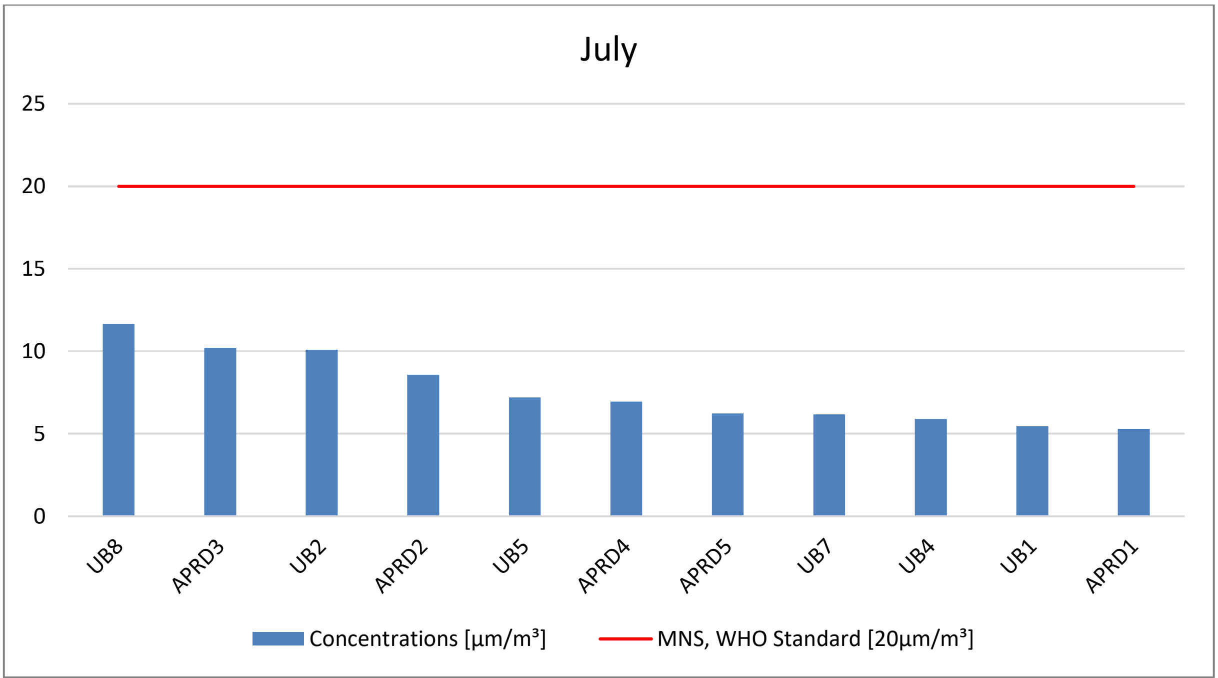


Figure 5.32. Comparison of SO_2 concentrations at different locations in July

NO_2:

As presented in the Figure 5.33 and Figure 5.34, the highest concentration level occurs at UB2 in both January and July. This shows less dependences of season for NO_2 or more vehicle origin of this pollutant.

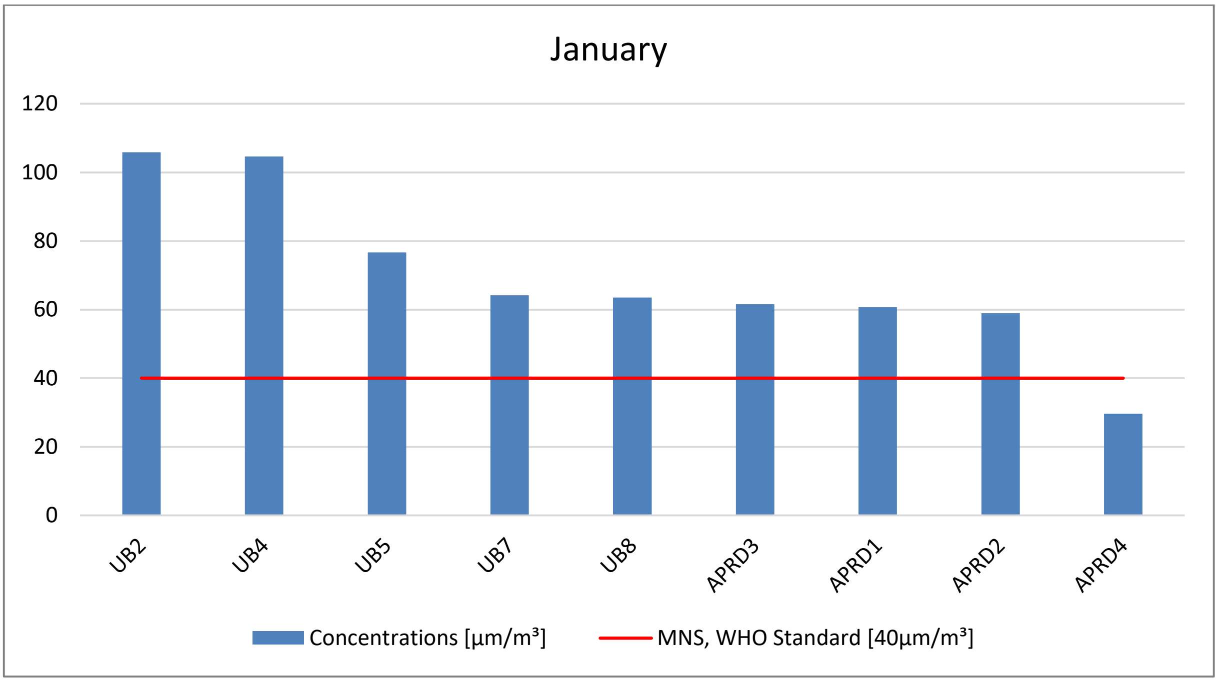


Figure 5.33 Comparison of NO_2 concentrations at different locations in January

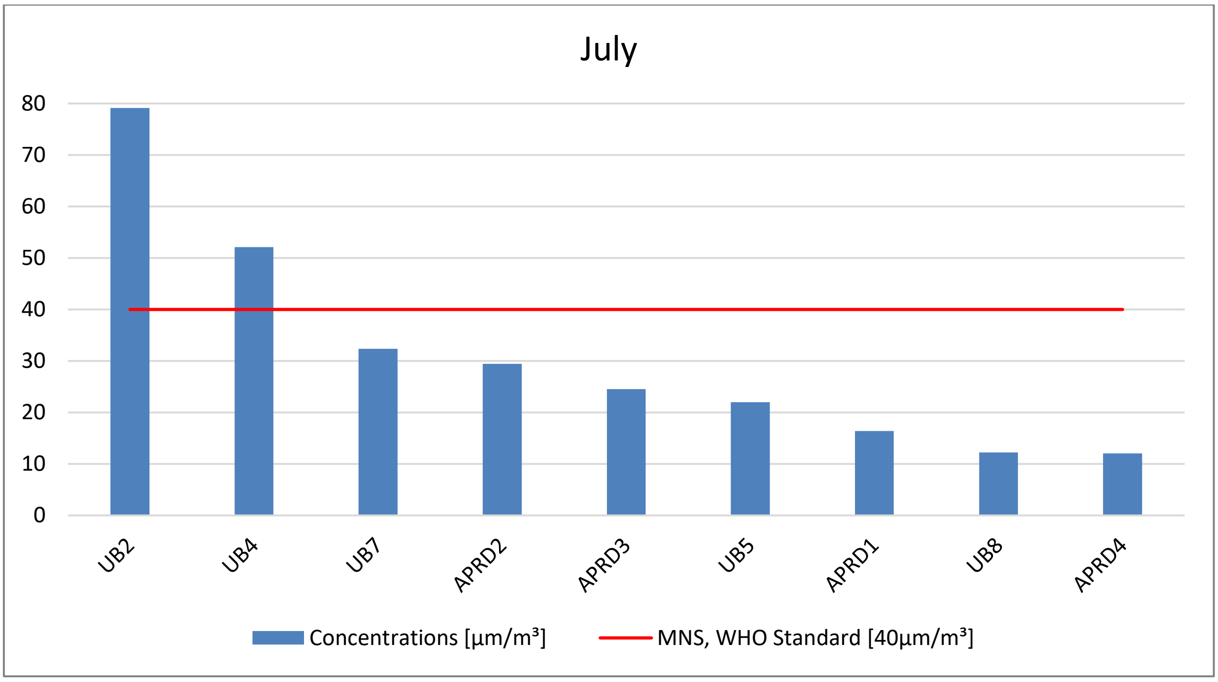


Figure 5.34. Comparison of NO_2 concentrations at different locations in July

5.3.1 Locational analysis

In Figure 5.35, the average monthly PM_{10} concentrations for 2016-2017 in both ger and central area are significantly increased from August to January. Then it sharply decreased until March. Between March and April, the concentration of PM_{10} in ger area is started to increase, while PM_{10} in central area is becoming constant. It indicates that soil suspension dust raises by increasing windy days. It is also shown in the Figure 5.37, as increasing concentration of coarse PM pollution. In conclude, coarse particles in Ulaanbaatar city is mainly suspended dust from the soil. As shown in the Figure 5.36, $PM_{2.5}$ pollution level is high in ger district during the cold season, and $PM_{2.5}$ is carried by wind direction from north to south. Therefore, one can observe that $PM_{2.5}$ is increased in the central area in the winter as well.

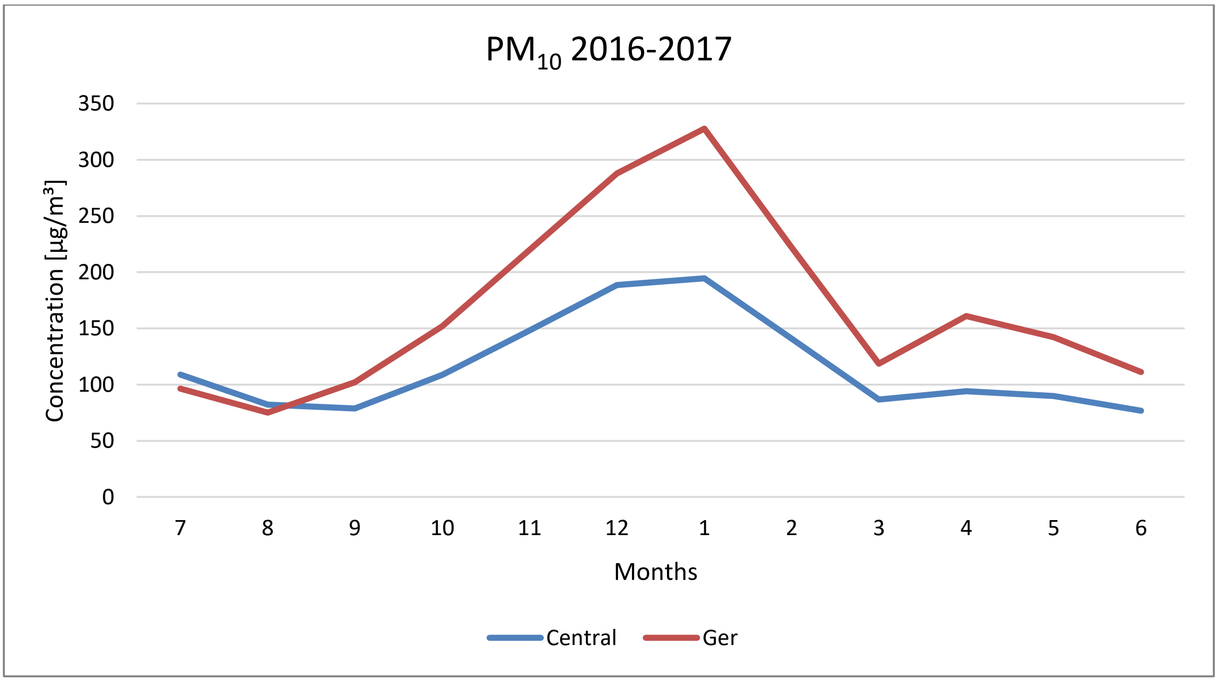


Figure 5.35. Average monthly PM_{10} analysis for 2016-2017 at central and ger area

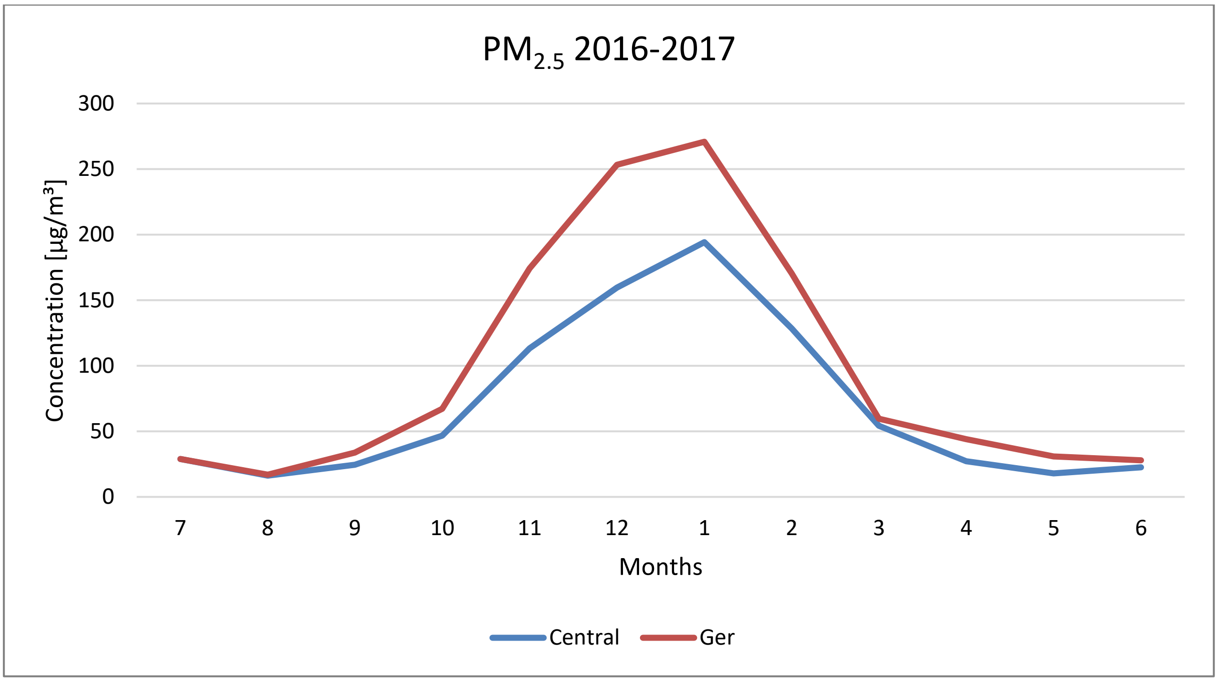


Figure 5.36. Average monthly $PM_{2.5}$ analysis for 2016-2017 at central and ger area

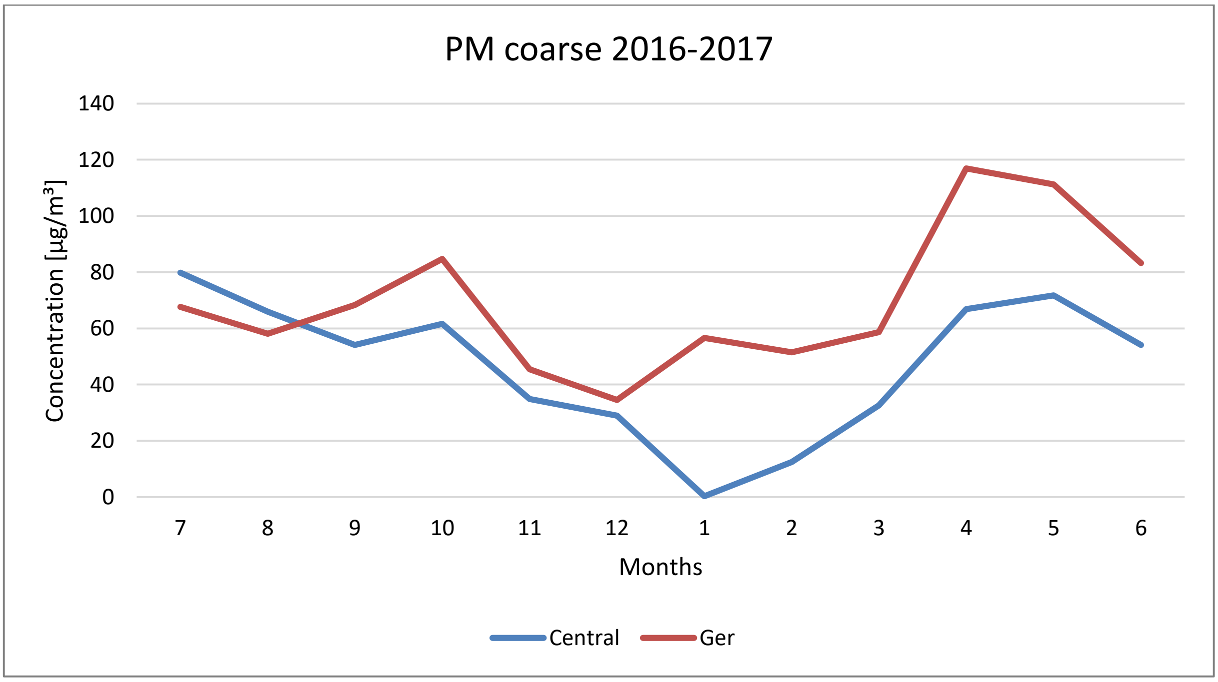


Figure 5.37. Average monthly PM coarse analysis for 2016-2017 at central and ger area

5.4 Quality control for monitoring stations

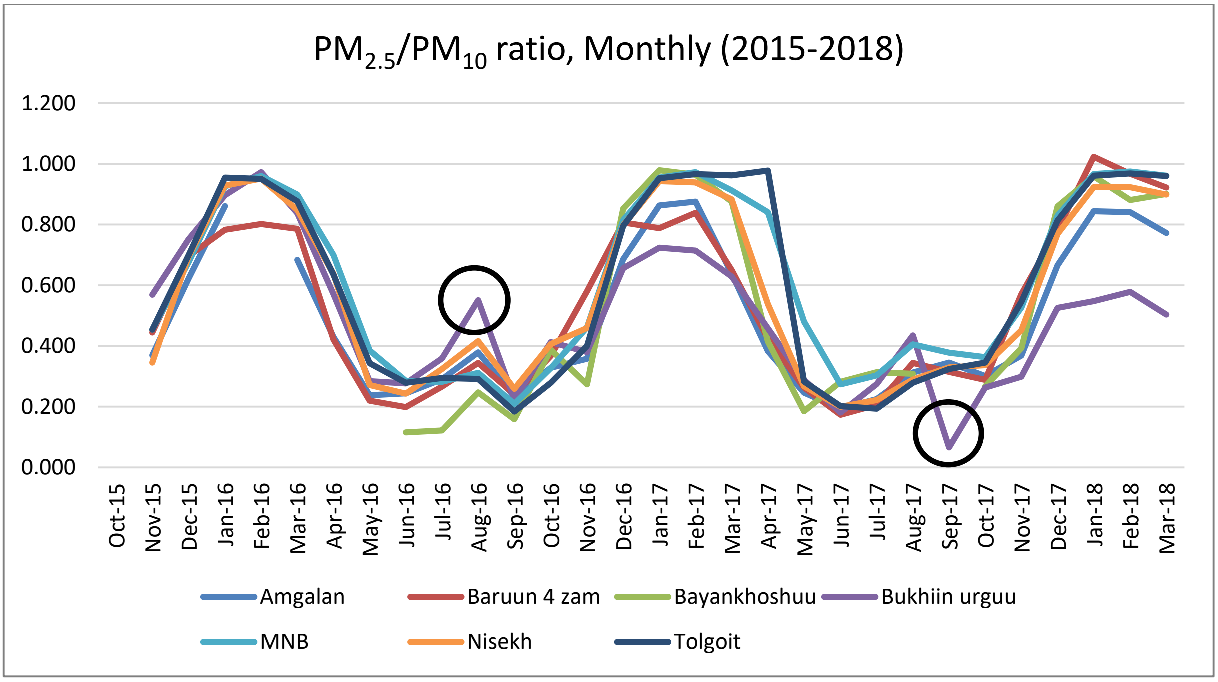


Figure 5.38. $PM_{2.5}/PM_{10}$ ratio at every stations for October 2015-March 2018

There are 8 stations, out of 12 stations, measure both $PM_{2.5}$ and PM_{10}. In this analysis, ratio of $PM_{2.5}$ and PM_{10} is used for quality control of measurements. It was checked that radio of $PM_{2.5}/PM_{10}$ should be less than one and this ratio should keep certain range depending on location and seasons. Ratio of $PM_{2.5}$ and PM_{10} is shown in the Figure 5.38. From the Figure Bukhiin urguu station has not stable (as circled) $PM_{2.5}/PM_{10}$ ratio and it is concluded that sensors should be checked. Baruun 4zam station the ratio had once more than one. Other stations are considered to be satisfactory in quality checking.

6 Result summary

- Average pollution concentrations for 2016-2017 in each stations were calculated in Table 6.1

	$PM_{2.5}$ [µg/m3]	PM_{10} [µg/m3]	SO_2 [µg/m3]	NO_2 [µg/m3]	CO [µg/m3]	O_3 [µg/m3]
UB1	-	78	31	-	-	32
UB2	76	125	26	94	1526	-
UB4	61	114	32	81	1125	24
UB5	-	202	41	40	1450	30
UB7	-	158	19	42	920	-
UB8	-	68	25	34	500	5
APRD1	123	191	49	34	1815	45
APRD2	103	150	70	39	2070	47
APRD3	61	124	51	36	1098	51
APRD4	64	111	12	17	694	30
APRD5	161	246	45	-	-	-
US Dip	79	-	-	-	-	-
Overall average	90	142	36	46	1244	33

Table 6.1. Mean value of pollutant concentrations of each stations for 2016-2017

The two years average concentration of $PM_{2.5}$ was 90 µg/m^3 for 2016-2017. It was exceeding WHO guideline 9 times. The average concentration of the PM_{10} were 142 µg/m^3, exceeding WHO guidelines 6 times. carbon monoxide measured as 1244 µg/m^3 . For NO_2 and O_3, the annual concentrations were 46 µg/m^3 and 33 µg/m^3 in both near or lower to WHO guidelines. Annual average concentrations of sulfur dioxide (SO_2) is 32 µg/m^3 1.5 times exceeding Mongolian standard. As presented in the Table 6.1, the mean value of $PM_{2.5}$ and PM_{10} concentrations at APRD5 is the highest.

- Daily and monthly time series analysis of pollutants have been analyzed,
- Seasonal variations of pollution concentration are calculated,
- Difference of pollution concentrations in central Ulaanbaatar and Ger area was evaluated,
- Quality assessment of pollution sources were evaluated,
- Quality control for PM_{10} and $PM_{2.5}$ measurement was assessed using ratio of $PM_{2.5}/PM_{10}$ concentrations and recommendation to check some sensors were made,
- It is the first time that Open AQ platform was used for calculation and assessment of air quality in Ulaanbaatar city.
- 97 Graphics and 2 Tables were introduced in the Appendices for future studies.

7 Conclutions and Recommendations

To conclude:

1. Air pollution of Ulaanbaatar city has strong seasonal character, high in winter peaking in January and low in summer, except O_3 which is high in the summer and low in the winter. The 2016-2017 two years average concentration of $PM_{2.5}$ was 90 µg/m^3, exceeding WHO guideline 9 times. The concentration of the PM_{10} average concentrations were 142 µg/m^3, exceeding WHO guideline 6 times. Annual average concentration of carbon monoxide measured as 1244 µg/m^3 . For NO_2 and O_3, the annual concentrations were 46 µg/m^3 and 33 µg/m^3 in both near or lower to WHO guidelines. Annual average concentrations of sulfur dioxide (SO_2) is 32 µg/m^3 1.5 times exceeding Mongolian standard.
2. $PM_{2.5}$ pollution source is combustion, as it is increasing in winter, peaking in January and decreasing in warm season getting minimum in July and August. The highest concentration in winter is Bayankoshuu, located most densly populated ger area, which shows that main source of $PM_{2.5}$ is most populated ger area or combustion for heating and cooking using coal and wood in ger area. $PM_{2.5}$-PM_{10} or coarse particles concentration increases in the spring and automn peaking in April. This consides with increasing wind speed and its frequensy, shows main sourse of coarse particles pollution is soil dust.
3. SO_2 and CO pollution concentration is icreasing in winter and has it minimum in summer, main pollution source is combustion, similar as $PM_{2.5}$.
4. NO_2 pollution is also increasing in winter, but ratio winter and summer pollution concentration is near to 2 lower than PM concentration. Highst concentration of NO_2 is not ger district but Western Cross road, where most intence trafic. It concluded that main NO_2 source is vehicles rather than combustion. Increasing NO_2 concentration in winter explains also second main source of NO_2 is combustion, probably higher temperature combustion or power plants and bigger Heat Only Boilers.
5. O_3 ozon has non antropogenic origen as it is increasing in summer and getting minimum in winter.
6. Ulaanbaatar air pollution is different in central area and ger district. PM, CO, and SO_2 pollutants are high in Ger district and low in the central UB. NO_2 concentration is higher in central streets of UB and lower in the ger area.
7. It is difficult to conclude tendency of air pollution of Ulaanbaatar city, but can be concluded that no considerable change of pollution last 3 years.
8. Quality control calculation for PM2.5 and PM10 of monitoring stations shows that the UB4 PM sensors have some error.

9. Open AQ platform is useful source of data, that can be used for air pollution assessment of the world cities

Recommendations:

- $PM_{2.5}$ and PM_{10} sensors of monitoring station UB4 should be properly checked.
- In the NAMEM monitoring stations UB1, UB5, UB7and UB8 should be installed $PM_{2.5}$ sensors, as $PM_{2.5}$ pollution should be controlled properly, which is main pollutant of UB air. At least it should be done in the UB5, as this is basic monitoring site to measure main Northern Valley pollution.

8 References

1. Guttikunda SK, Lodoysamba S, Bulgansaikhan B, Dashdondog B. Particulate pollution in Ulaanbaatar, Mongolia. Air Qual Atmosphere Health. 2013 Sep;6(3):589–601.

2. World Bank. Air Quality Analysis of Ulaanbaatar: Improving Air Quality to Reduce Health Impacts [Internet]. World Bank; 2011 [cited 2018 Jul 4]. Available from: http://elibrary.worldbank.org/doi/book/10.1596/26802

3. EMW2015_XacBank_N.Elbot_.pdf.

4. National Statistical Office of Mongolia [Internet]. [cited 2018 Jul 28]. Available from: http://www.en.nso.mn/index.php

5. Baumbach G. Air Quality Control: Formation and Sources, Dispersion, Characteristics and Impact of Air Pollutants — Measuring Methods, Techniques for Reduction of Emissions and Regulations for Air Quality Control [Internet]. Berlin Heidelberg: Springer-Verlag; 1996 [cited 2018 Aug 10]. (Environmental Engineering). Available from: //www.springer.com/la/book/9783642790034

6. Amarsaikhan D, Battsengel V, Nergui B, Ganzorig M, Bolor G. A Study on Air Pollution in Ulaanbaatar City, Mongolia. J Geosci Environ Prot. 2014;02(02):123–8.

7. Vallero DA. Fundamentals of air pollution. 4th ed. Amsterdam ; Boston: Elsevier; 2008. 942 p.

8. Schwarze PE, Øvrevik J, Låg M, Refsnes M, Nafstad P, Hetland RB, et al. Particulate matter properties and health effects: consistency of epidemiological and toxicological studies. Hum Exp Toxicol. 2006 Oct;25(10):559–79.

9. Stewart RD. The Effect of Carbon Monoxide on Humans. Annu Rev Pharmacol. 1975;15(1):409–23.

10. Blumenthal I. Carbon monoxide poisoning. J R Soc Med. 2001 Jun;94(6):270–2.

11. World Bank. Pollution prevention and abatement handbook, 1998: Toward cleaner production [Internet]. The World Bank; 1999 [cited 2018 Jul 15]. Available from: http://elibrary.worldbank.org/doi/book/10.1596/0-8213-3638-X

12. Sulfur dioxide (SO2) - Air quality fact sheet [Internet]. [cited 2018 Jul 23]. Available from: http://www.environment.gov.au/protection/publications/factsheet-sulfur-dioxide-so2

13. Sulfur Dioxide – toxicity, side effects, diseases and environmental impacts [Internet]. Chemicals News. [cited 2018 Jul 23]. Available from: https://www.chemicals.news/2017-11-08-sulfur-dioxide-toxicity-side-effects-diseases-and-environmental-impacts.html

14. [cited 2018 Jul 22]. Available from: http://www.geo.sunysb.edu/bad-ozone/files/Download/lesson_plans_pacholik-2.htm

15. Robert G. Dal Sasso. Ambient Air Monitoring Using Ecotech Analyser Technology.

16. 12.pdf [Internet]. [cited 2018 Jul 29]. Available from: https://www.tsukuba.ac.jp/education/g-courses/pdf/tokouhishien/2014/12.pdf

17. Lodoyasamba S, Pemberton-Pigott C. MITIGATION OF ULAANBAATAR CITY'S AIR POLLUTION – FROM SOURCE APORTIONMENT TO ULTRA-LOW EMISSION LIGNITE BURNING STOVES. :7.

18. Allen RW, Gombojav E, Barkhasragchaa B, Byambaa T, Lkhasuren O, Amram O, et al. An assessment of air pollution and its attributable mortality in Ulaanbaatar, Mongolia. Air Qual Atmosphere Health. 2013 Mar;6(1):137–50.

19. Tsevegjav B. ASSESSMENT OF URBAN AIR POLLUTION ABATEMENT POLICY IMPLEMENTATION VIS-Á-VIS THE ROLE OF HOUSEHOLD ENERGY USE IN GER AREAS OF MONGOLIA [Internet]. [The Netherlands]: The University of Twente; 2012. Available from: https://essay.utwente.nl/65055/1/Final_version_-_BulganmurunTsevegjav-Thesis.pdf

20. Gheorghe A, Ankhbayar B, Nieuwenhuyzen H van, Sa R de. MONGOLIA'S AIR POLLUTION CRISIS: A call to action to protect children's health [Internet]. National Center for Public Health; 2018. Available from: www.unicef.mn

21. . .:: www.Legalinfo.mn - Хуулийн нэгдсэн портал сайт ::.. [Internet]. [cited 2018 Aug 5]. Available from: http://www.legalinfo.mn/law/details/8669?lawid=8669&sword=%D0%B0%D0%B3%D0%B0%D0%B0%D1%80

22. Projects : Ulaanbaatar Clean Air Project | The World Bank [Internet]. [cited 2018 Aug 4]. Available from: http://projects.worldbank.org/P122320/ulaanbaatar-clean-air-project?lang=en

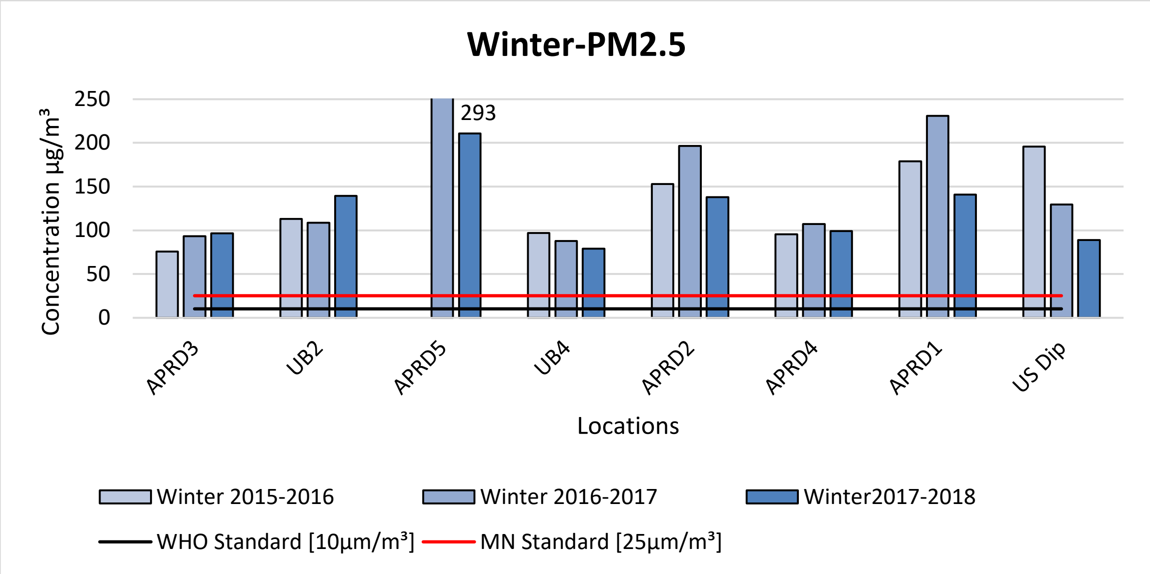
23. Japan International Agency. Capacity Development Project for Air Pollution Control in Ulaanbaatar City Phase 2 in Mongolia [Internet]. 2017 Jun. Available from: http://open_jicareport.jica.go.jp/pdf/12289195.pdf

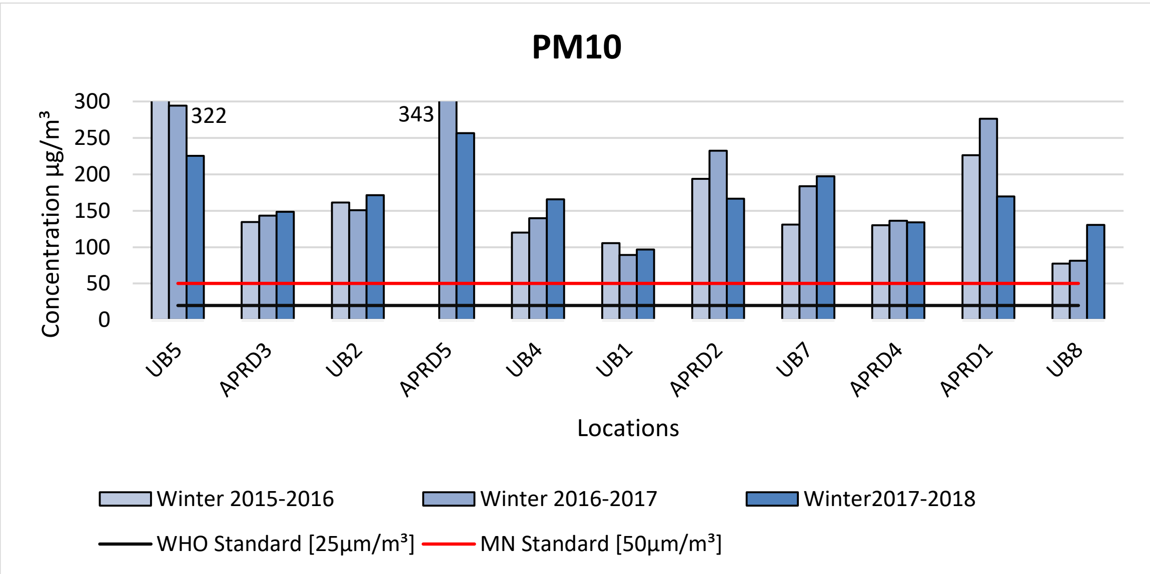
24. 20180228_policy_brief_on_air_pollution.pdf [Internet]. [cited 2018 Jul 29]. Available from: http://www.wpro.who.int/mongolia/publications/20180228_policy_brief_on_air_pollution.pdf

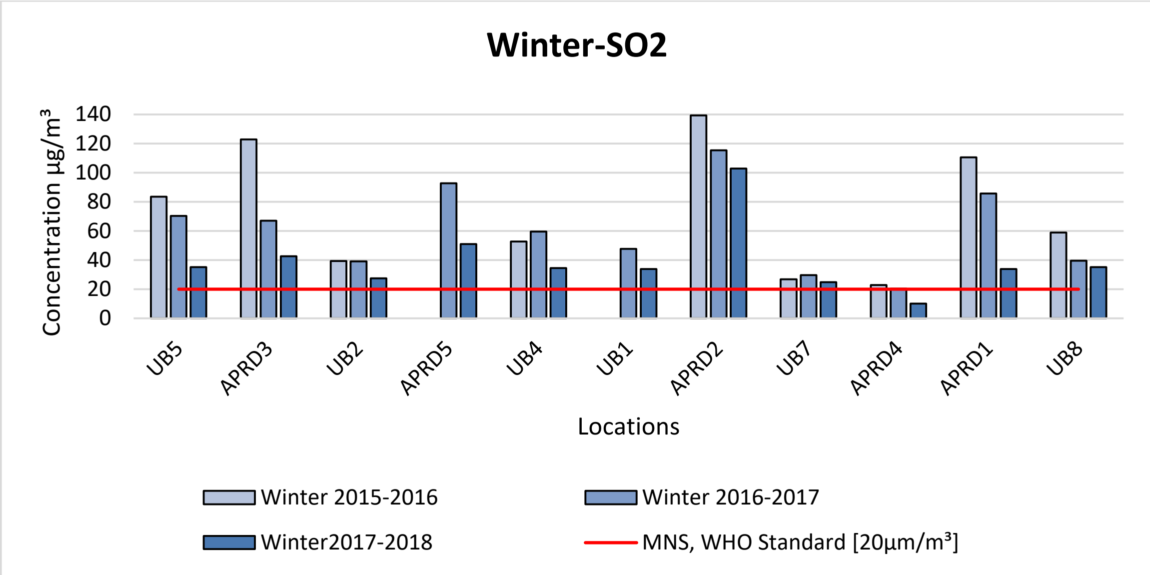
25. OpenAQ [Internet]. OpenAQ. [cited 2018 Aug 10]. Available from: https://openaq.org/

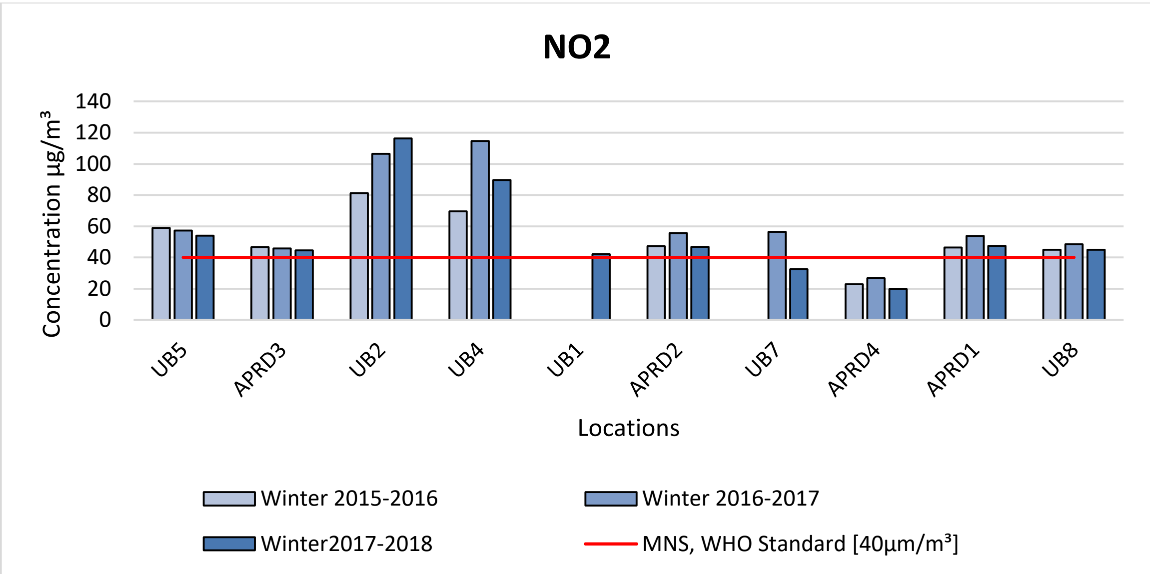
26. BALDORJ B. Air quality monitoring in Mongolia. :17.

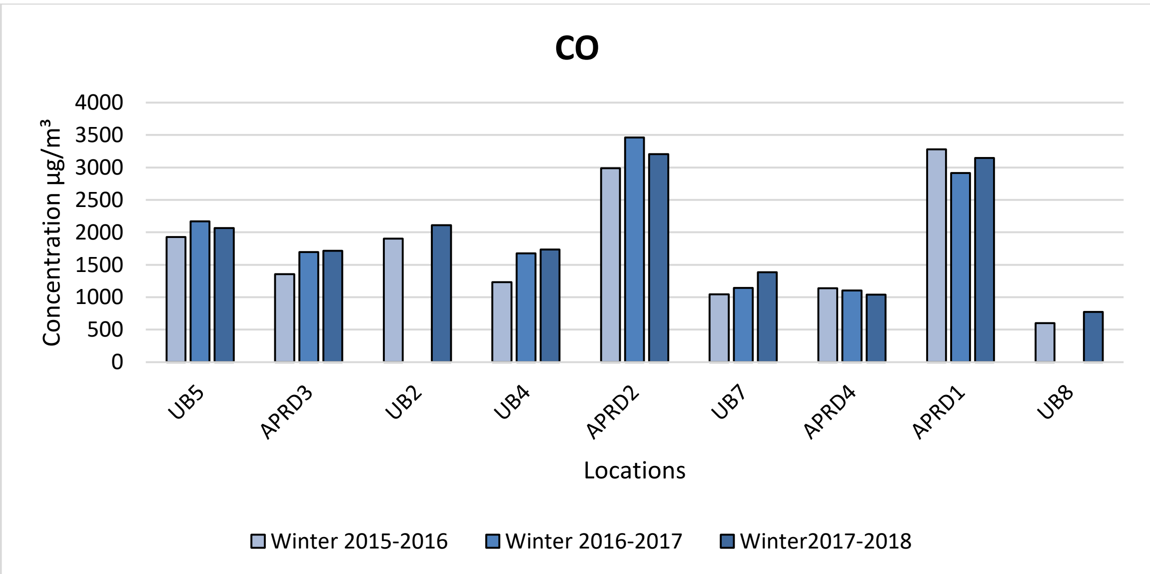
Appendix 1. Average pollution level differences in winters for 2015-2018

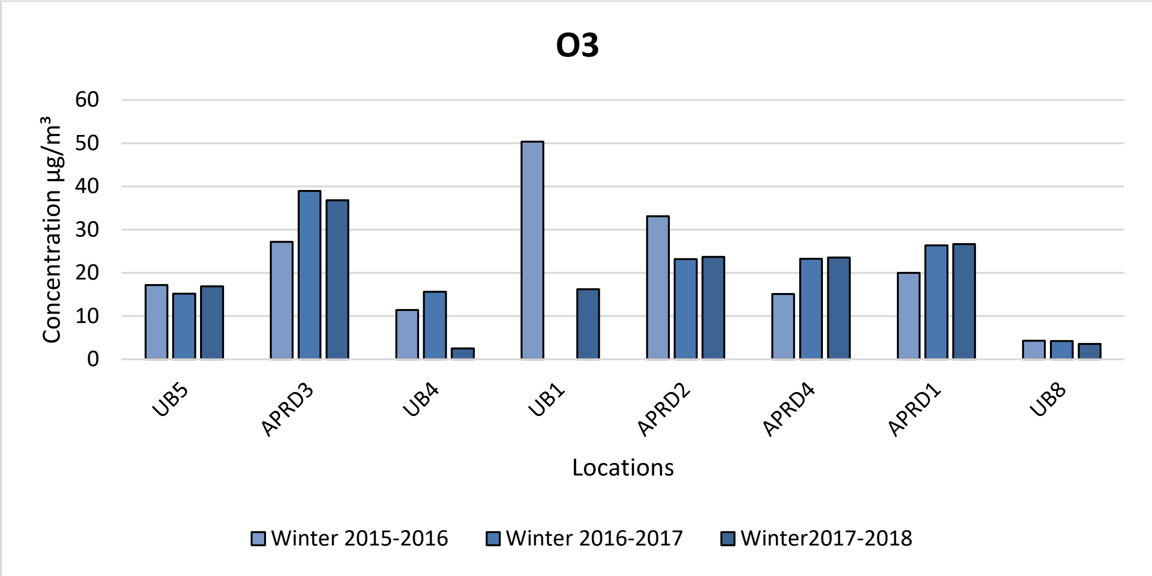




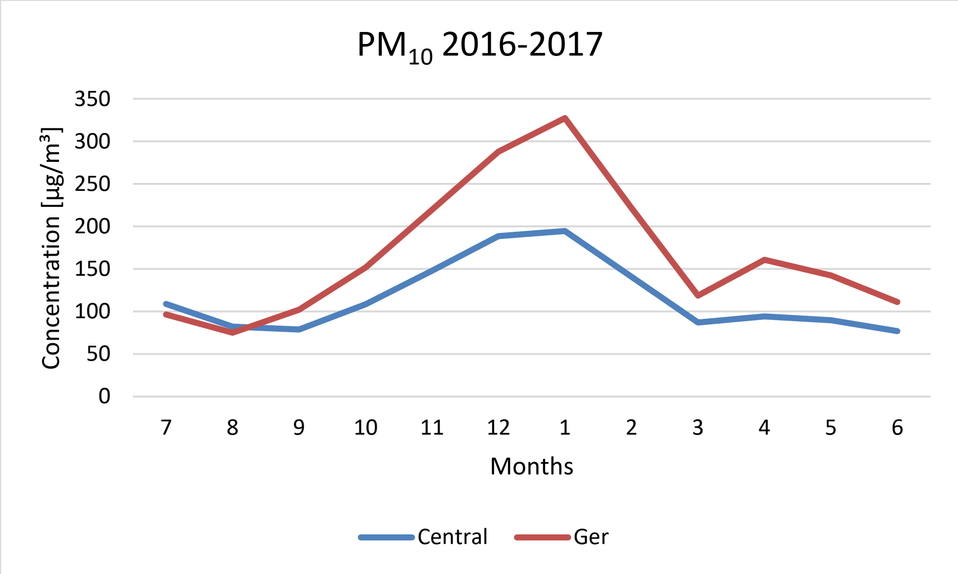

Winter-SO2
Concentration µg/m³
140
120
100
80
60
40
20
0
UB5
APRD3
UB2
APRD5
UB4
UB1
APRD2
UB7
APRD4
APRD1
UB8
Locations
Winter 2015-2016
Winter 2016-2017
Winter2017-2018
MNS, WHO Standard [20µm/m³]

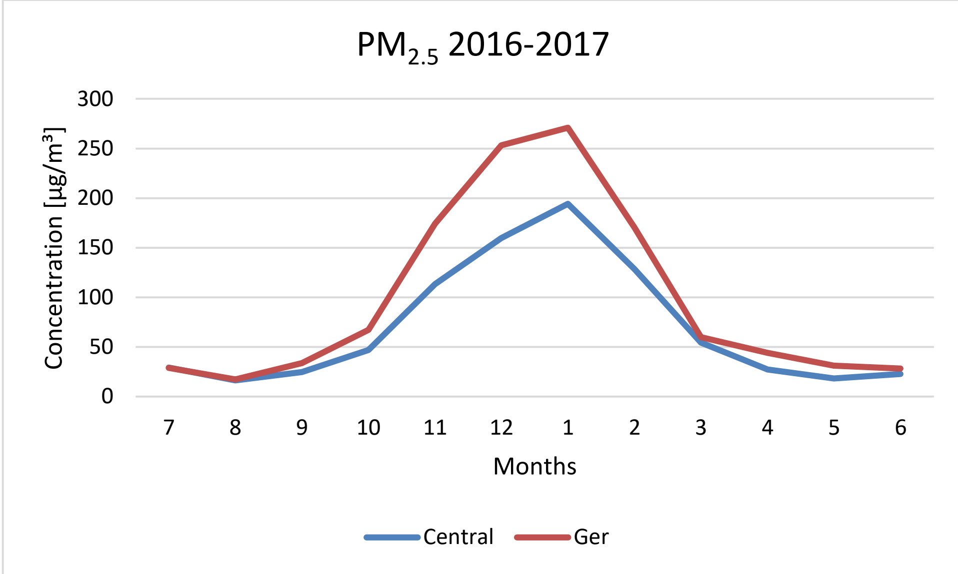

NO2
Concentration µg/m³
140
120
100
80
60
40
20
0
UB5
APRD3
UB2
UB4
UB1
APRD2
UB7
APRD4
APRD1
UB8
Locations
Winter 2015-2016
Winter 2016-2017
Winter2017-2018
MNS, WHO Standard [40µm/m³]

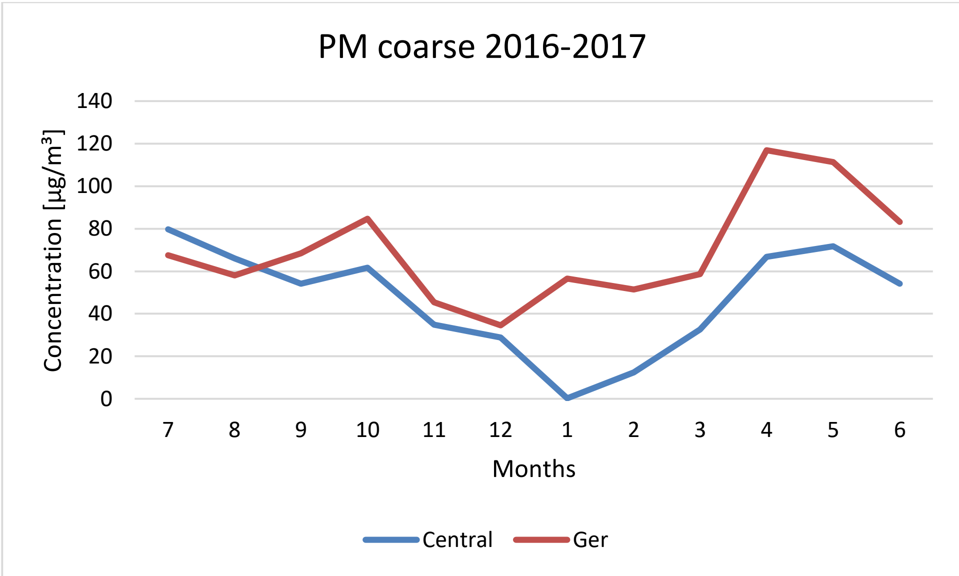

CO
Concentration µg/m³
4000
3500
3000
2500
2000
1500
1000
500
0
UB5
APRD3
UB2
UB4
APRD2
UB7
APRD4
APRD1
UB8
Locations
Winter 2015-2016
Winter 2016-2017
Winter2017-2018


O3
Concentration µg/m³
60
50
40
30
20
10
0
UB5
APRD3
UB4
UB1
APRD2
APRD4
APRD1
UB8
Locations
Winter 2015-2016
Winter 2016-2017
Winter2017-2018

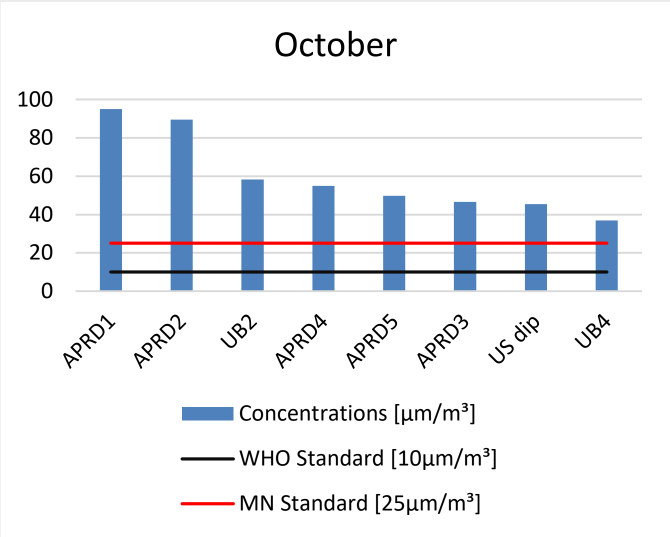
Appendix 2. Monthly average PM_{10} and $PM_{2.5}$ concentrations by ger and central area for 2016-2017

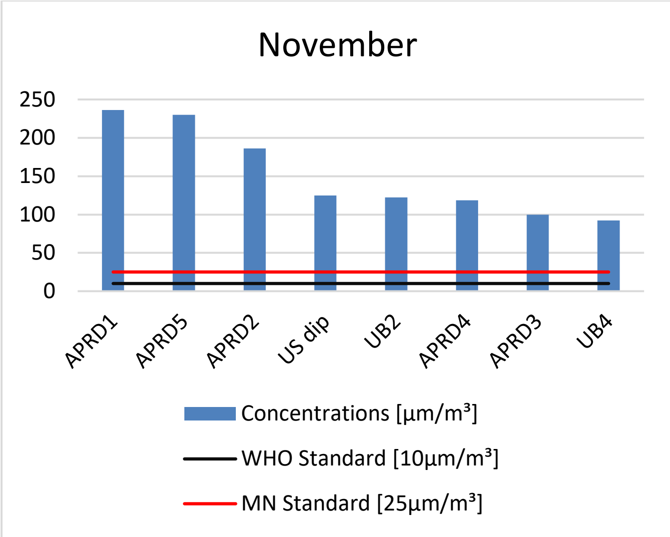


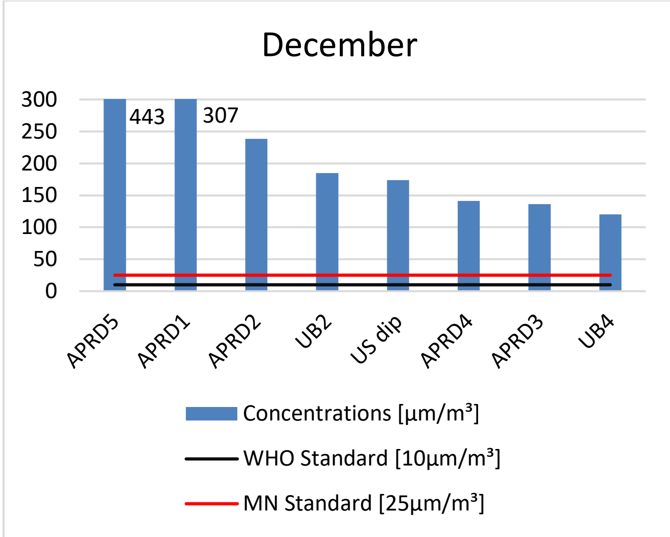


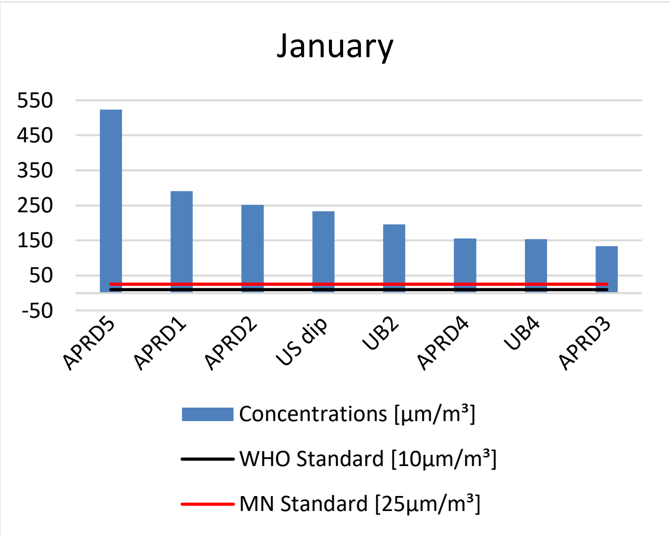


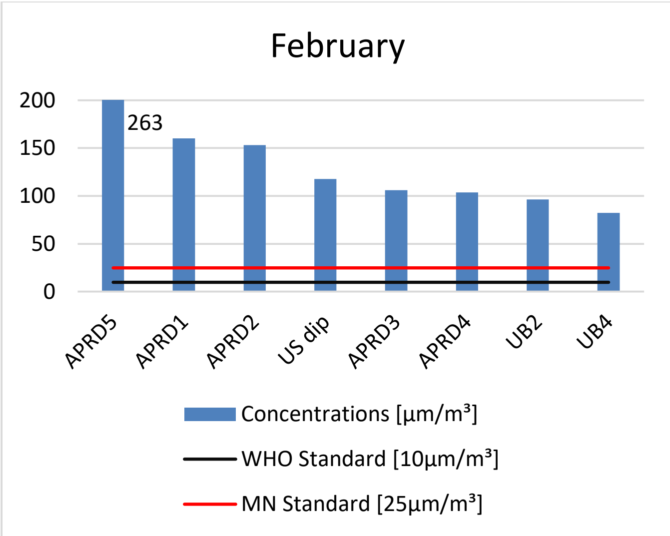
Appendix 3. Monthly $PM_{2.5}$ average concentration at all stations

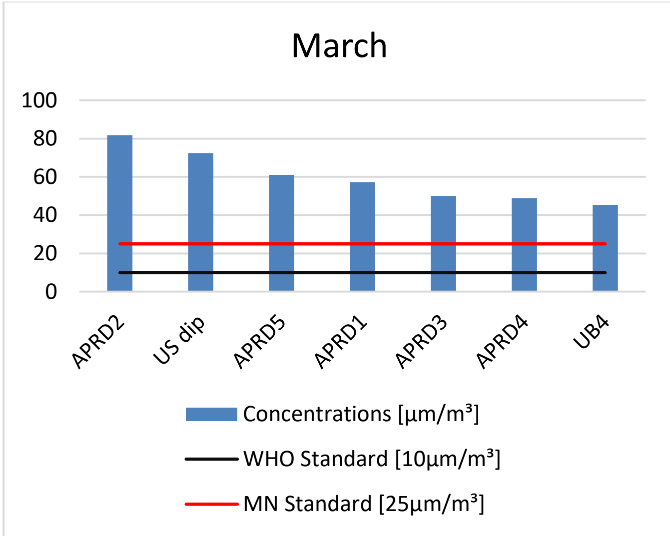


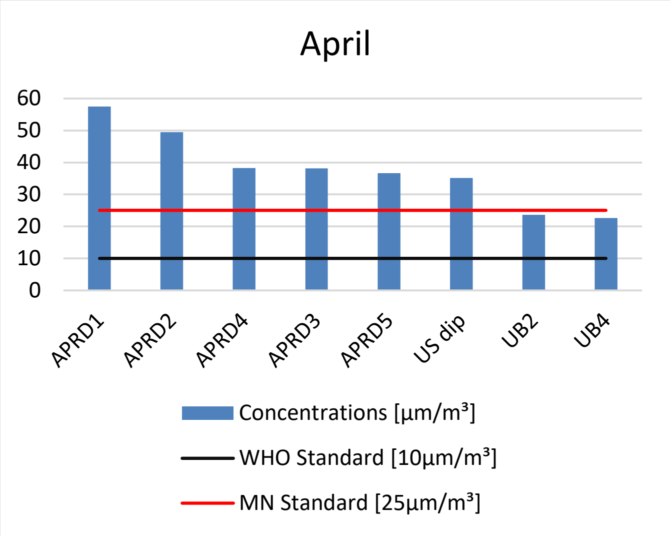


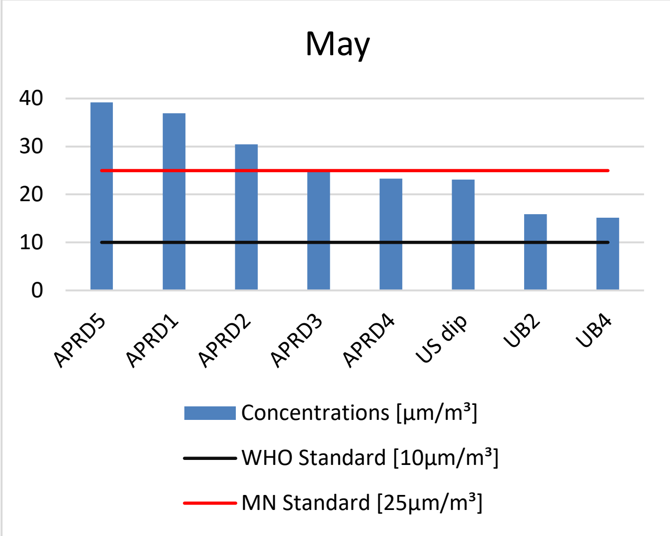


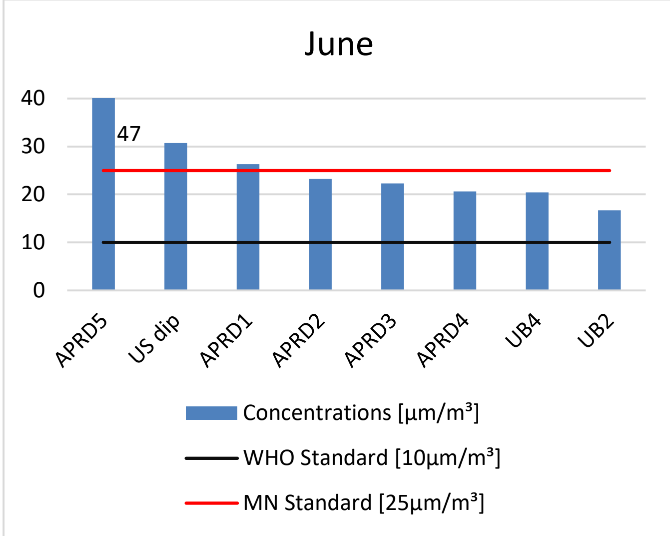


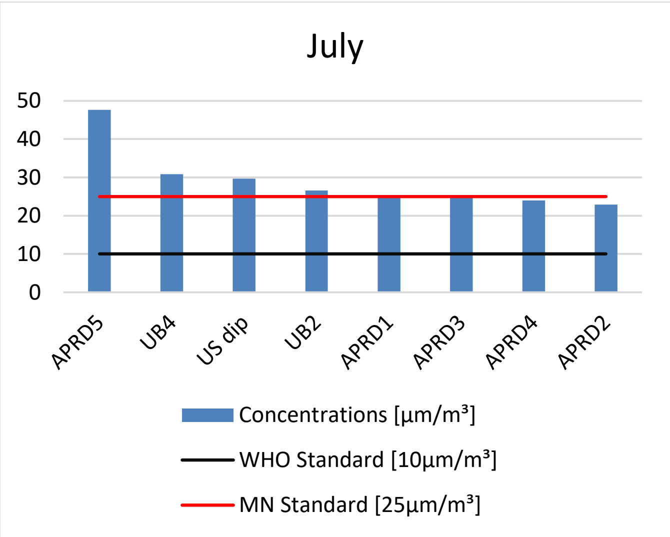


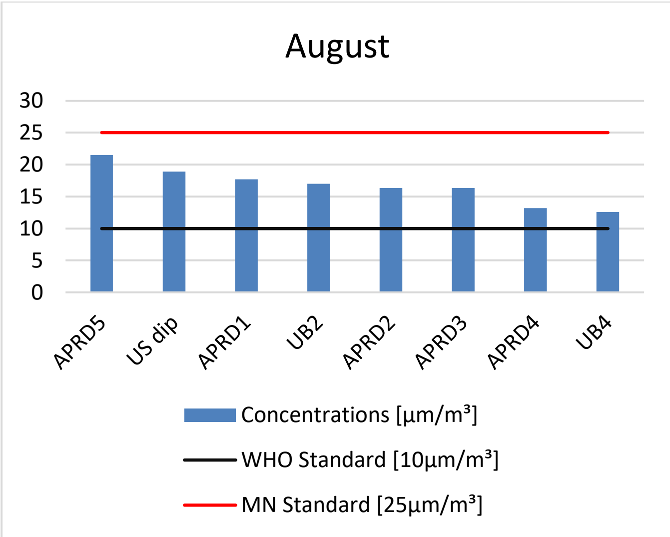


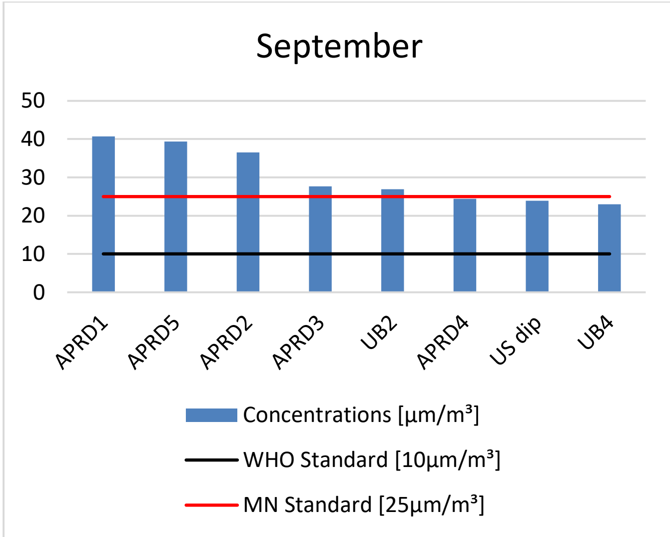

April
60
50
40
30
20
10
0
APRD1
APRD2
APRD4
APRD3
APRD5
US dip
UB2
UB4
Concentrations [µm/m³]
WHO Standard [10µm/m³]
MN Standard [25µm/m³]


May
40
30
20
10
0
APRD5
APRD1
APRD2
APRD3
APRD4
US dip
UB2
UB4
Concentrations [µm/m³]
WHO Standard [10µm/m³]
MN Standard [25µm/m³]

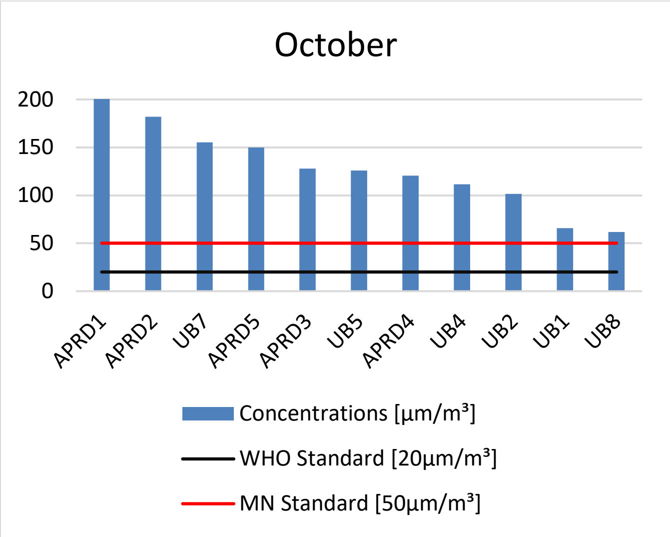

June
40
30
20
10
0
47
APRD5
US dip
APRD1
APRD2
APRD3
APRD4
UB4
UB2
Concentrations [µm/m³]
WHO Standard [10µm/m³]
MN Standard [25µm/m³]

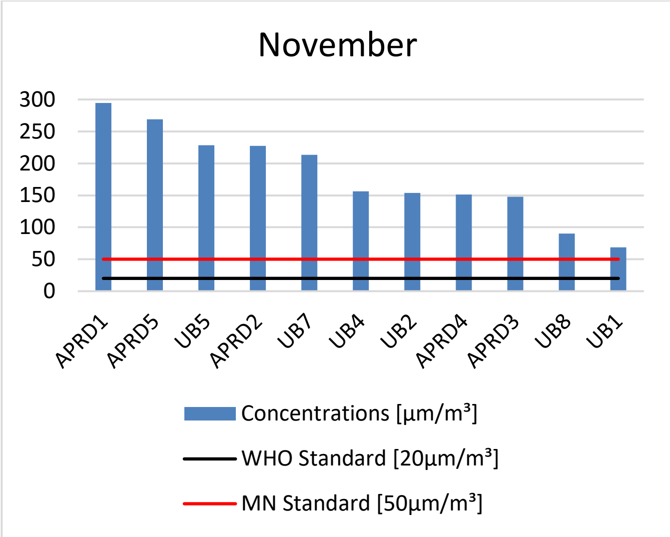

July
50
40
30
20
10
0
APRD5
UB4
US dip
UB2
APRD1
APRD3
APRD4
APRD2
Concentrations [µm/m³]
WHO Standard [10µm/m³]
MN Standard [25µm/m³]

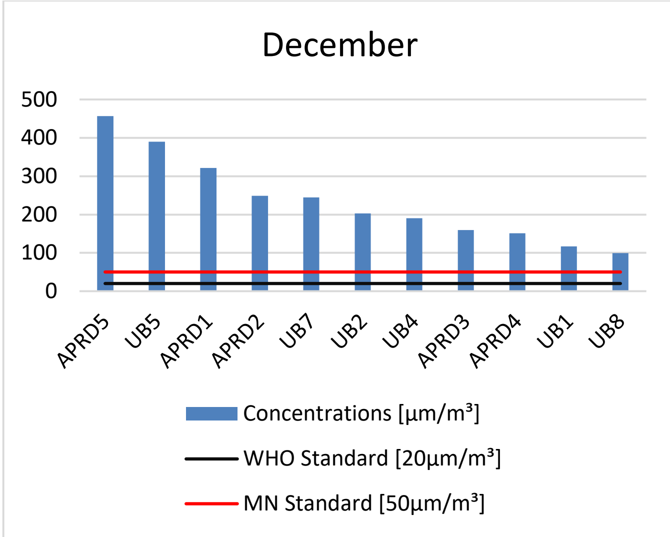

August
30
25
20
15
10
5
0
APRD5
US dip
APRD1
UB2
APRD2
APRD3
APRD4
UB4
Concentrations [µm/m³]
WHO Standard [10µm/m³]
MN Standard [25µm/m³]

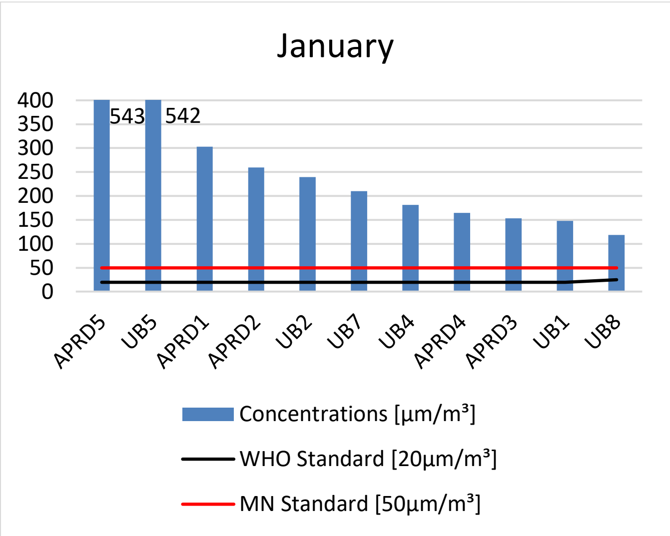

September
50
40
30
20
10
0
APRD1
APRD5
APRD2
APRD3
UB2
APRD4
US dip
UB4
Concentrations [µm/m³]
WHO Standard [10µm/m³]
MN Standard [25µm/m³]

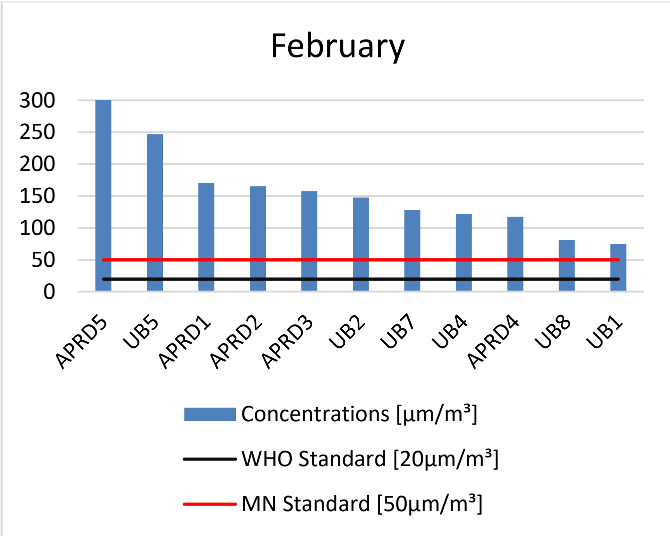
Appendix 4. Monthly PM_{10} average concentration at all stations

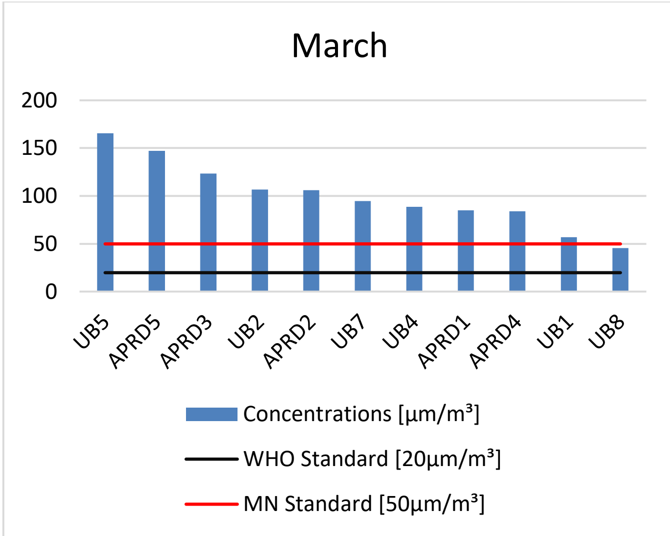


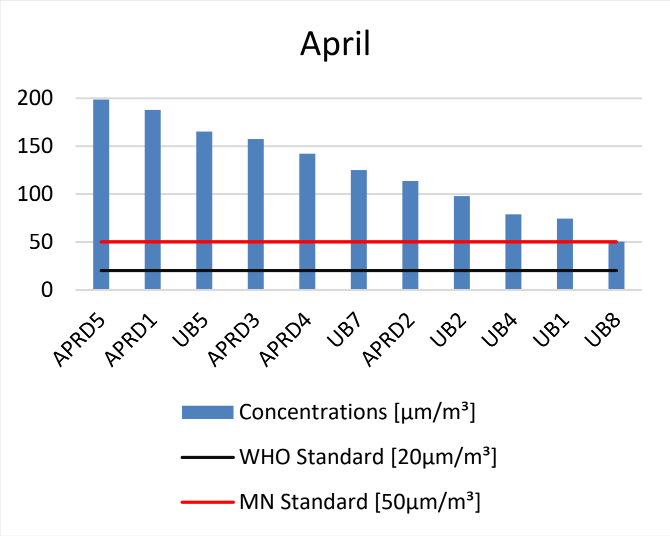


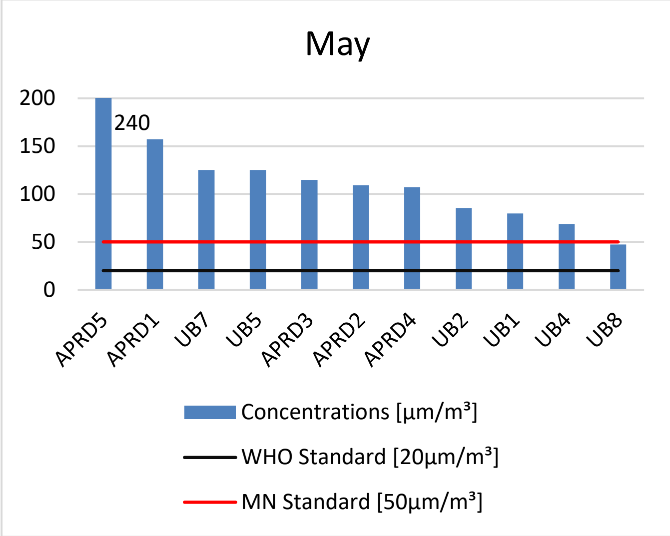


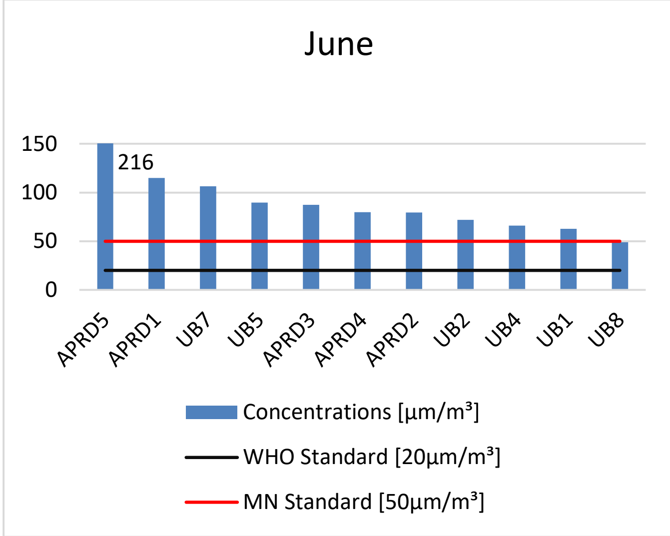


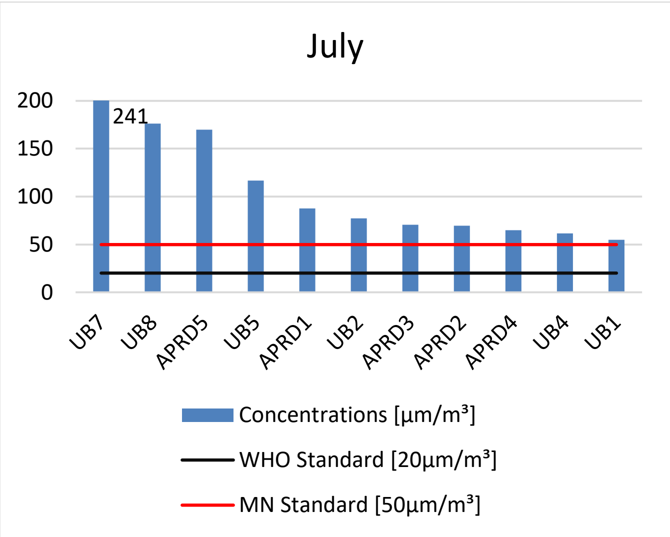


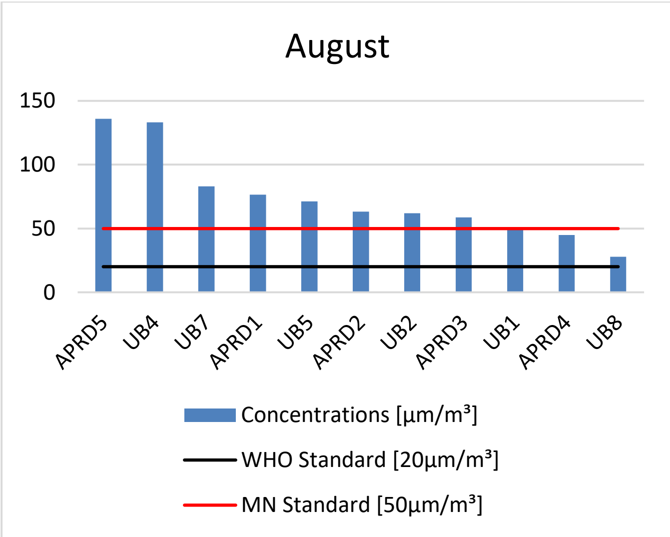


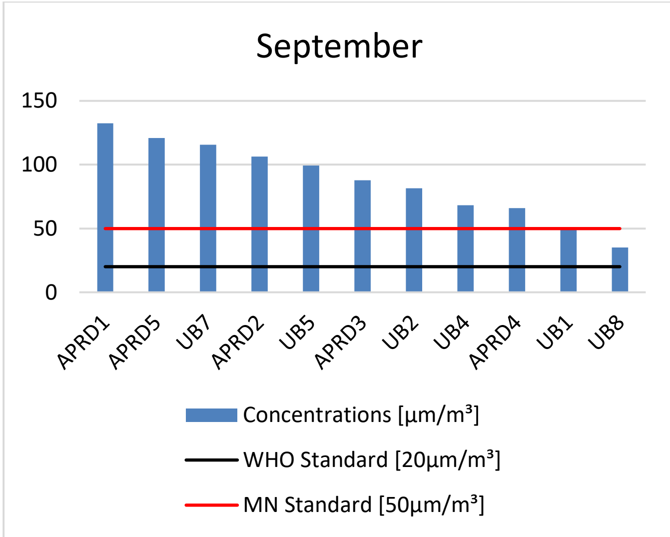

April
200
150
100
50
0
APRD5 APRD1 UB5 APRD3 APRD4 UB7 APRD2 UB2 UB4 UB1 UB8
Concentrations [µm/m³]
WHO Standard [20µm/m³]
MN Standard [50µm/m³]


May
200
150
100
50
0
240
APRD5 APRD1 UB7 UB5 APRD3 APRD2 APRD4 UB2 UB1 UB4 UB8
Concentrations [µm/m³]
WHO Standard [20µm/m³]
MN Standard [50µm/m³]

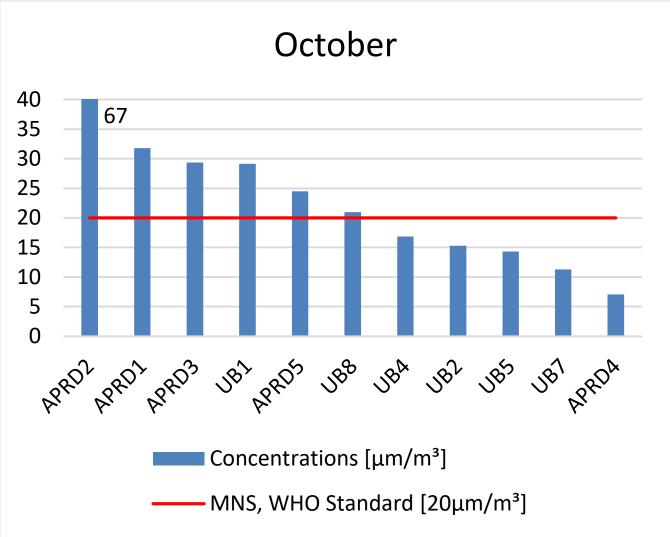

June
150
100
50
0
216
APRD5 APRD1 UB7 UB5 APRD3 APRD4 APRD2 UB2 UB4 UB1 UB8
Concentrations [µm/m³]
WHO Standard [20µm/m³]
MN Standard [50µm/m³]

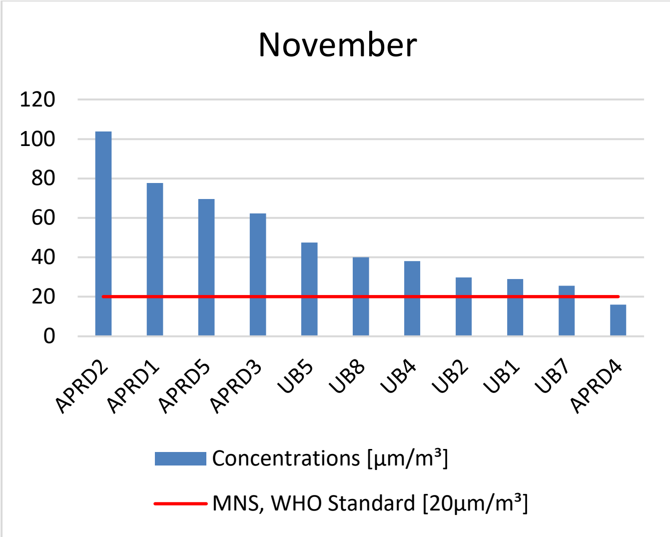

July
200
150
100
50
0
241
UB7 UB8 APRD5 UB5 APRD1 UB2 APRD3 APRD2 APRD4 UB4 UB1
Concentrations [µm/m³]
WHO Standard [20µm/m³]
MN Standard [50µm/m³]

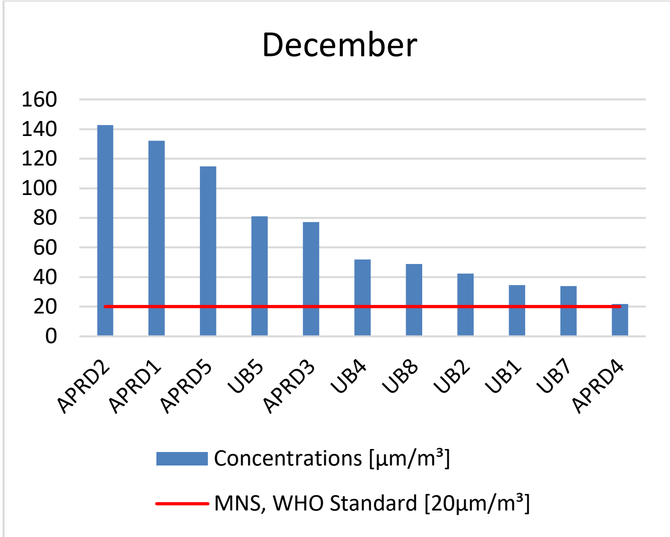

August
150
100
50
0
APRD5 UB4 UB7 APRD1 UB5 APRD2 UB2 APRD3 UB1 APRD4 UB8
Concentrations [µm/m³]
WHO Standard [20µm/m³]
MN Standard [50µm/m³]

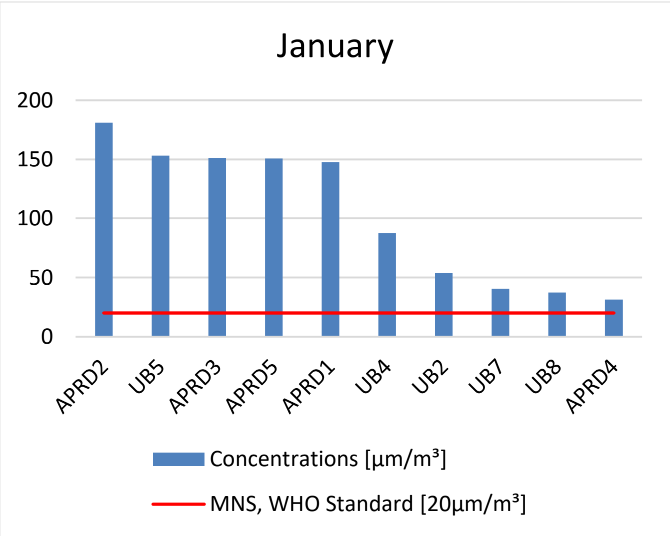

September
150
100
50
0
APRD1 APRD5 UB7 APRD2 UB5 APRD3 UB2 UB4 APRD4 UB1 UB8
Concentrations [µm/m³]
WHO Standard [20µm/m³]
MN Standard [50µm/m³]

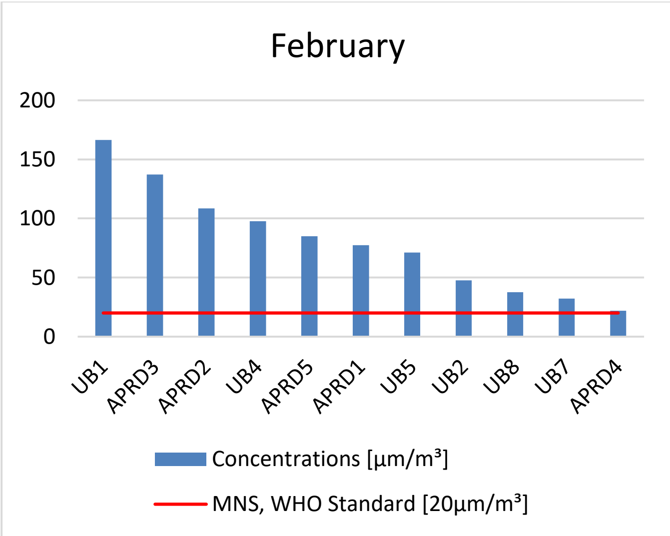
Appendix 5. Monthly SO_2 average concentration at all stations

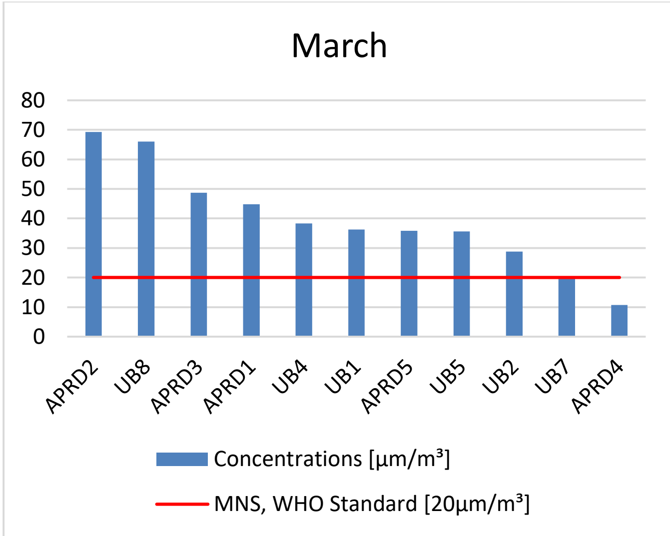


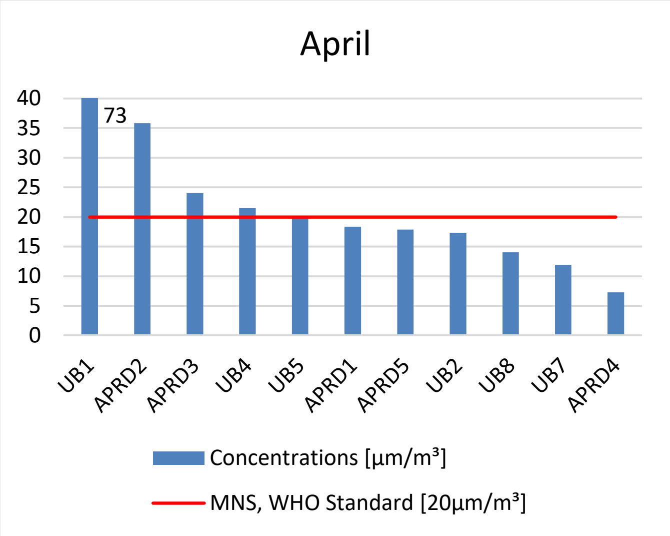


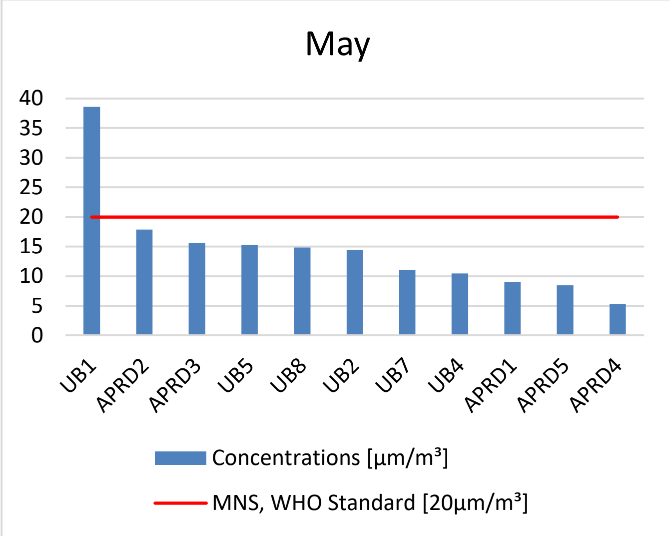


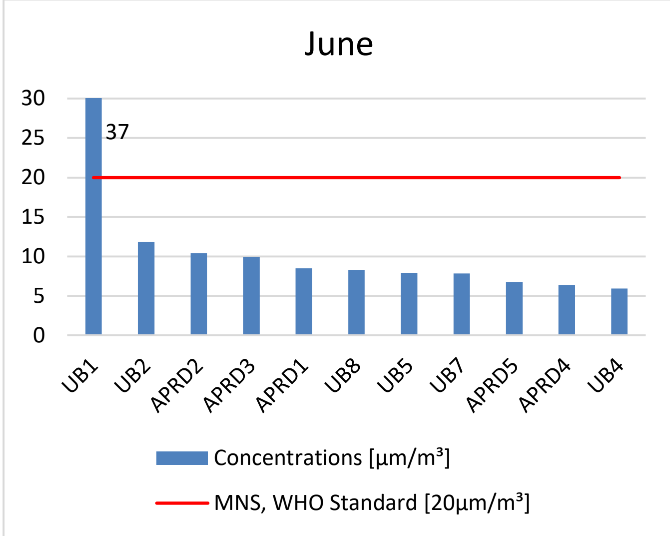


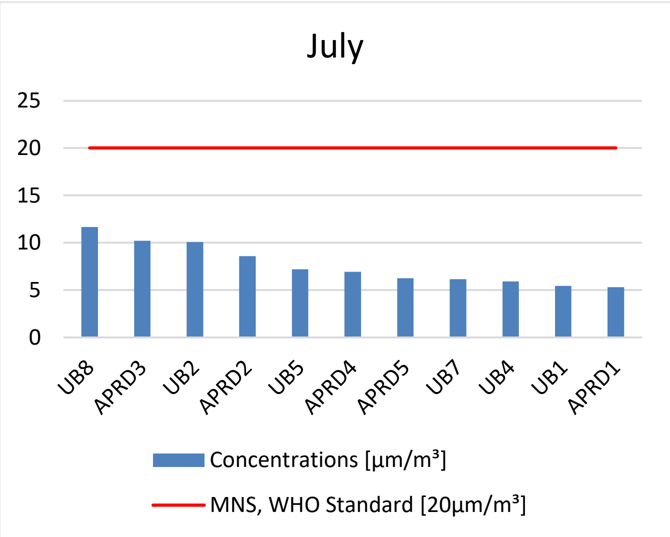


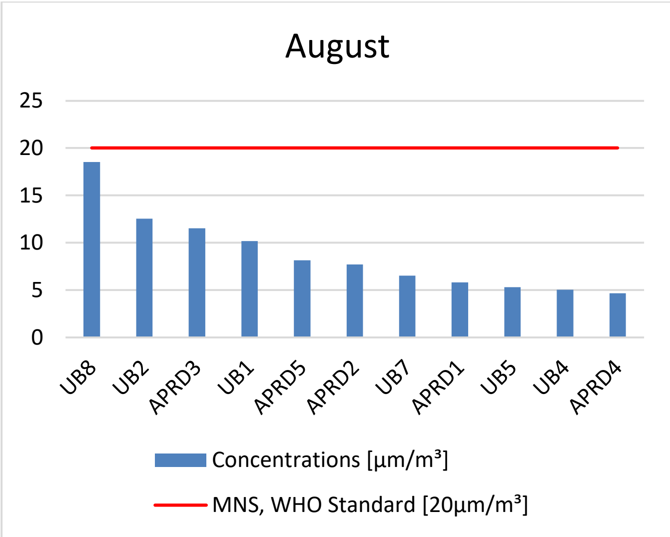


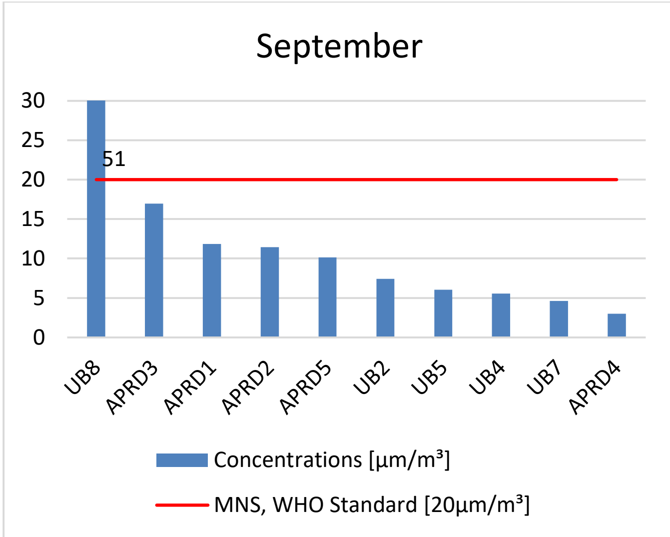

April
40
35
30
25
20
15
10
5
0
73
UB1
APRD2
APRD3
UB4
UB5
APRD1
APRD5
UB2
UB8
UB7
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [20µm/m³]


May
40
35
30
25
20
15
10
5
0
UB1
APRD2
APRD3
UB5
UB8
UB2
UB7
UB4
APRD1
APRD5
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [20µm/m³]

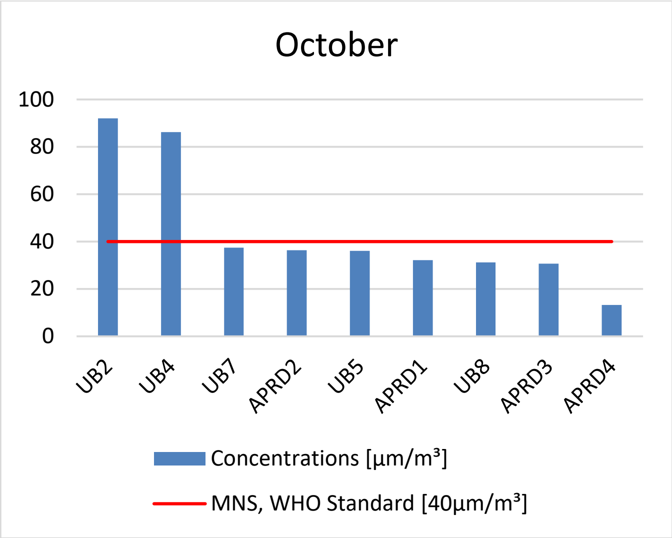

June
30
25
20
15
10
5
0
37
UB1
UB2
APRD2
APRD3
APRD1
UB8
UB5
UB7
APRD5
APRD4
UB4
Concentrations [µm/m³]
MNS, WHO Standard [20µm/m³]

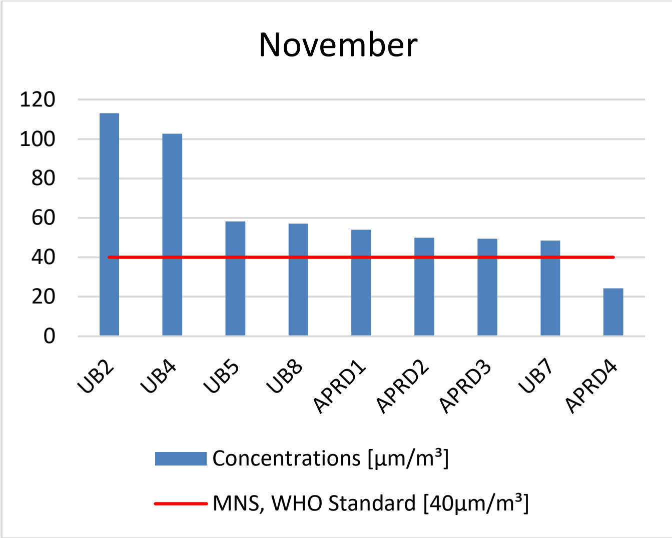

July
25
20
15
10
5
0
UB8
APRD3
UB2
APRD2
UB5
APRD4
APRD5
UB7
UB4
UB1
APRD1
Concentrations [µm/m³]
MNS, WHO Standard [20µm/m³]

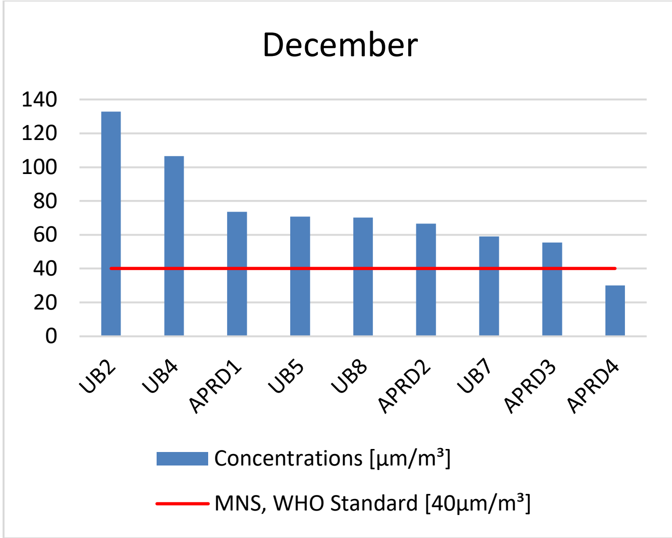

August
25
20
15
10
5
0
UB8
UB2
APRD3
UB1
APRD5
APRD2
UB7
APRD1
UB5
UB4
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [20µm/m³]

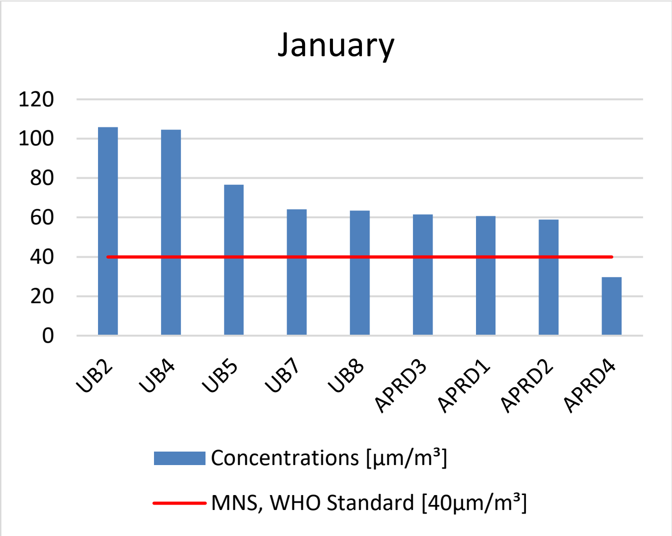

September
30
25
20
15
10
5
0
51
UB8
APRD3
APRD1
APRD2
APRD5
UB2
UB5
UB4
UB7
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [20µm/m³]

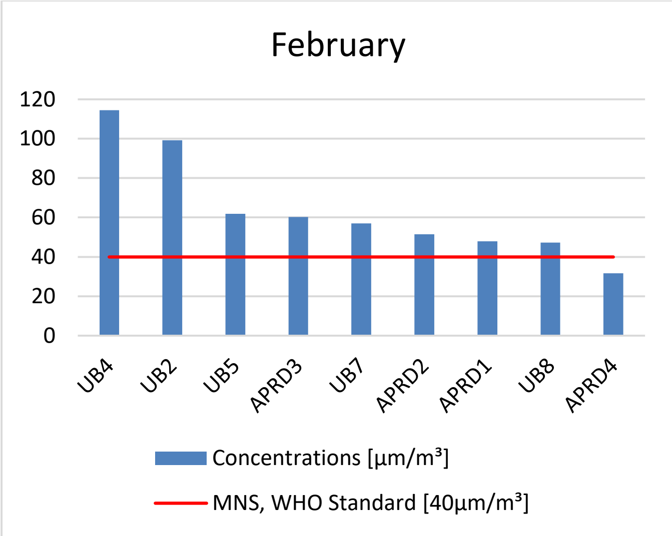
Appendix 6. Monthly NO_2 average concentration at all stations

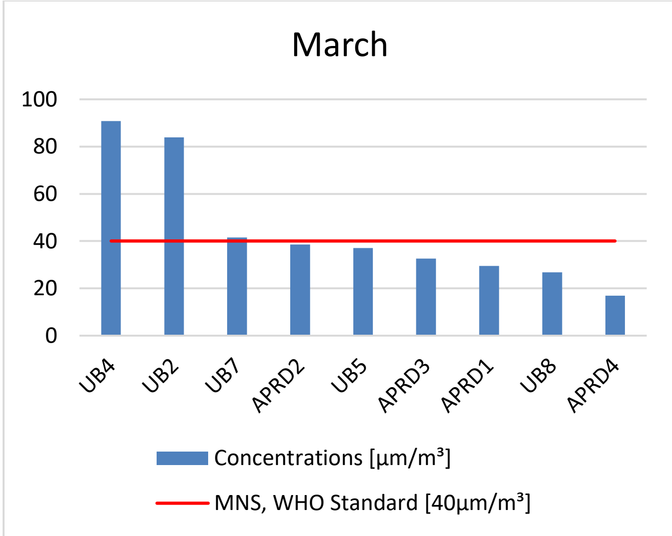


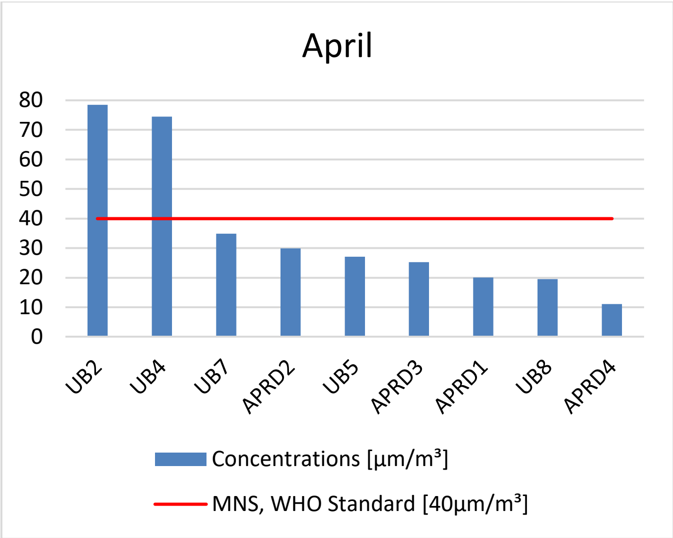


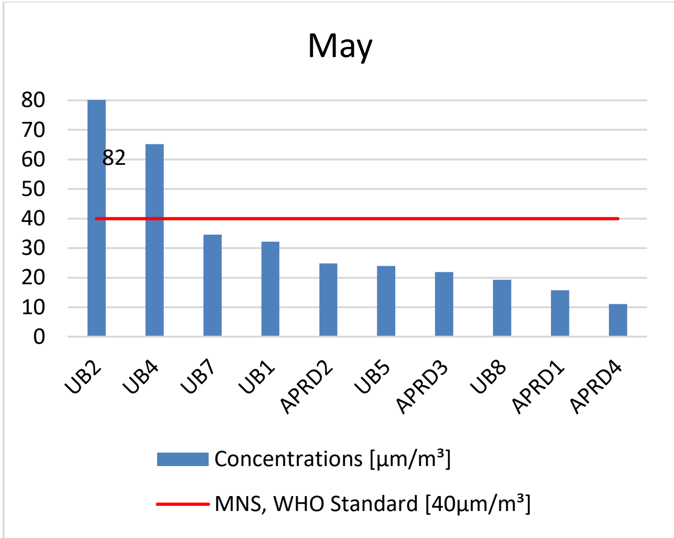


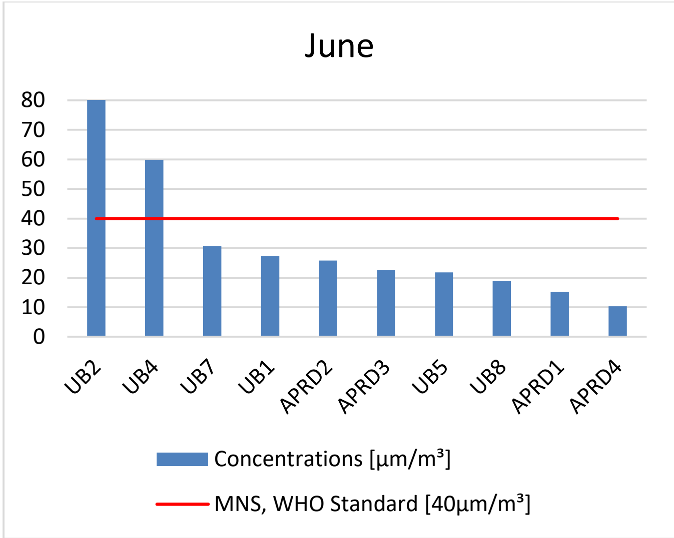


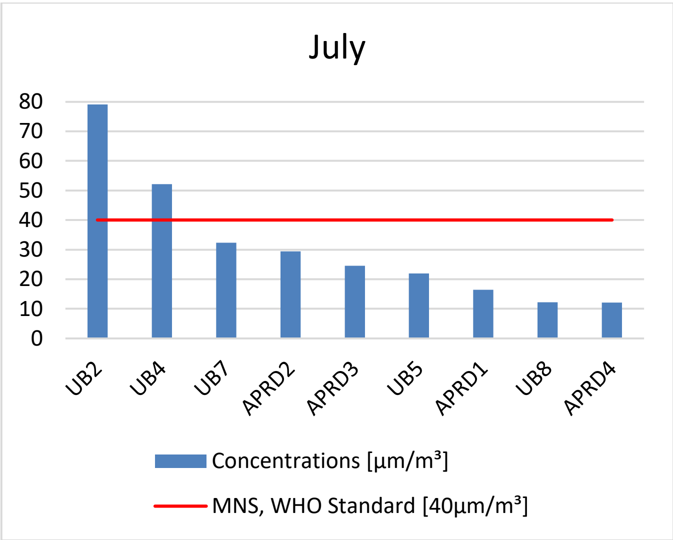


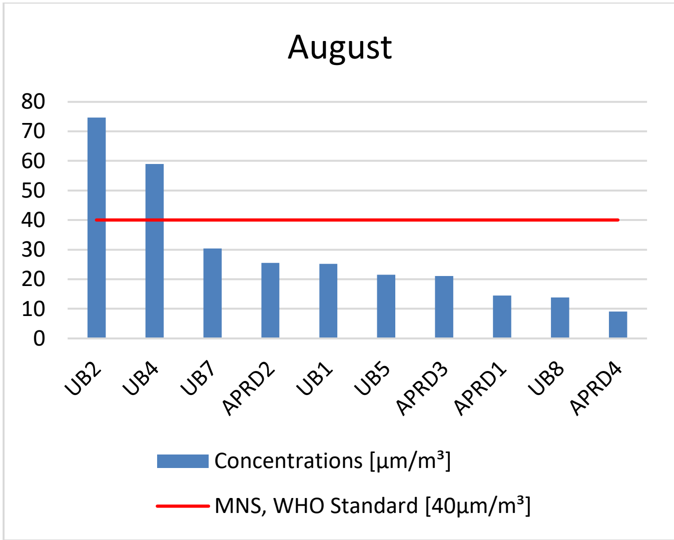


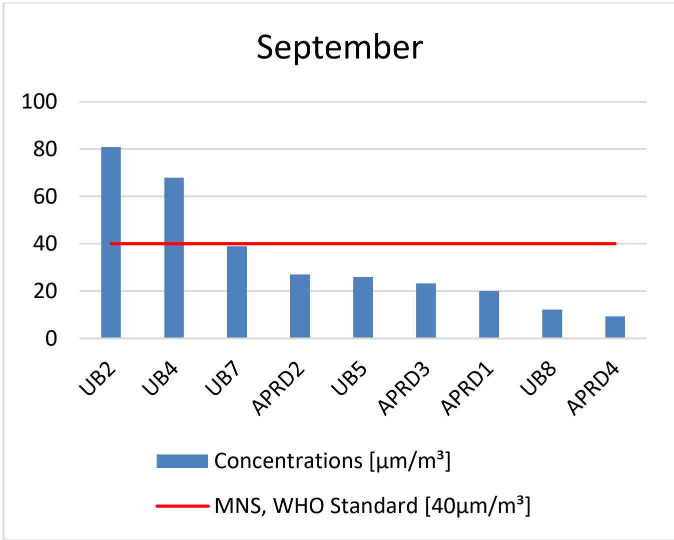

April
80
70
60
50
40
30
20
10
0
UB2
UB4
UB7
APRD2
UB5
APRD3
APRD1
UB8
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [40µm/m³]


May
80
70
60
50
40
30
20
10
0
82
UB2
UB4
UB7
UB1
APRD2
UB5
APRD3
UB8
APRD1
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [40µm/m³]

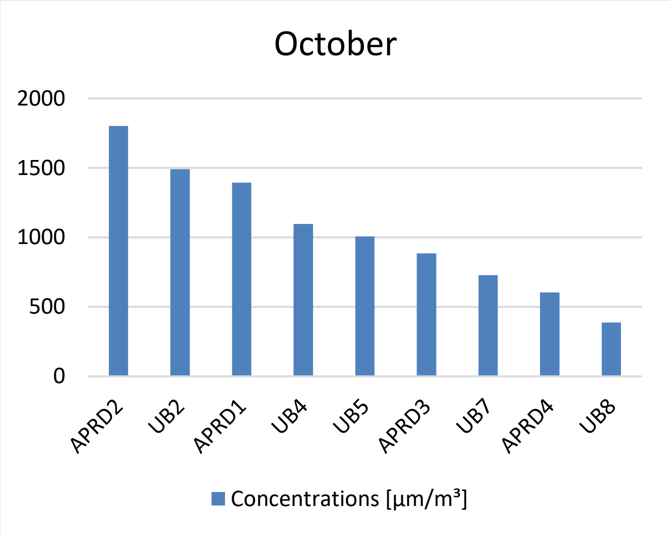

June
80
70
60
50
40
30
20
10
0
UB2
UB4
UB7
UB1
APRD2
APRD3
UB5
UB8
APRD1
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [40µm/m³]

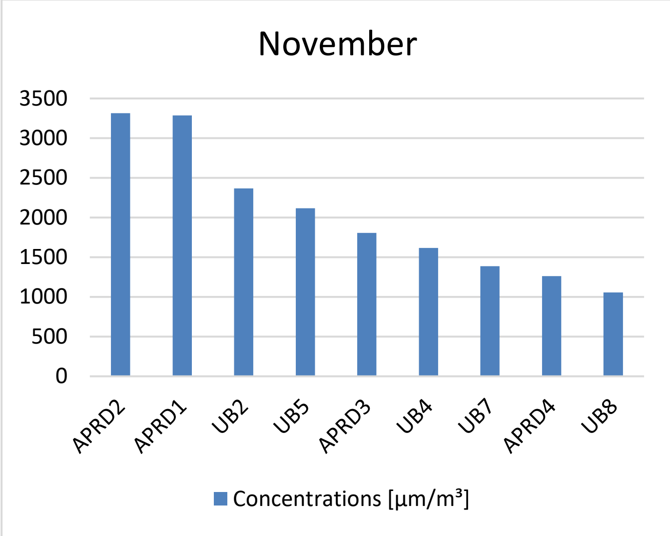

July
80
70
60
50
40
30
20
10
0
UB2
UB4
UB7
APRD2
APRD3
UB5
APRD1
UB8
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [40µm/m³]

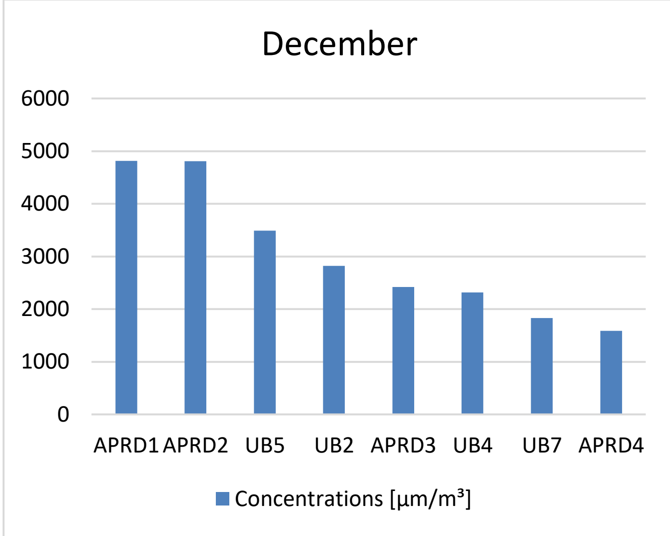

August
80
70
60
50
40
30
20
10
0
UB2
UB4
UB7
APRD2
UB1
UB5
APRD3
APRD1
UB8
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [40µm/m³]

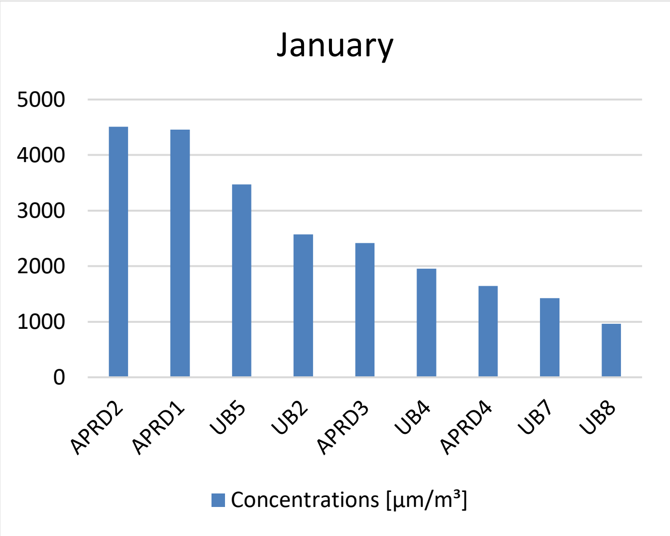

September
100
80
60
40
20
0
UB2
UB4
UB7
APRD2
UB5
APRD3
APRD1
UB8
APRD4
Concentrations [µm/m³]
MNS, WHO Standard [40µm/m³]

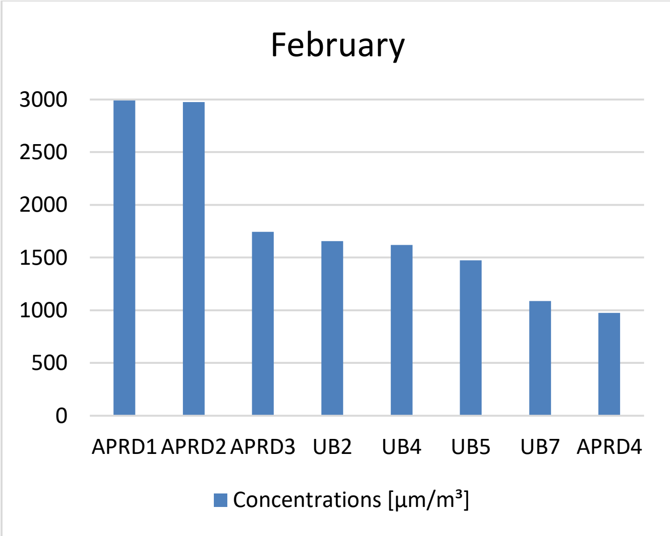
CO

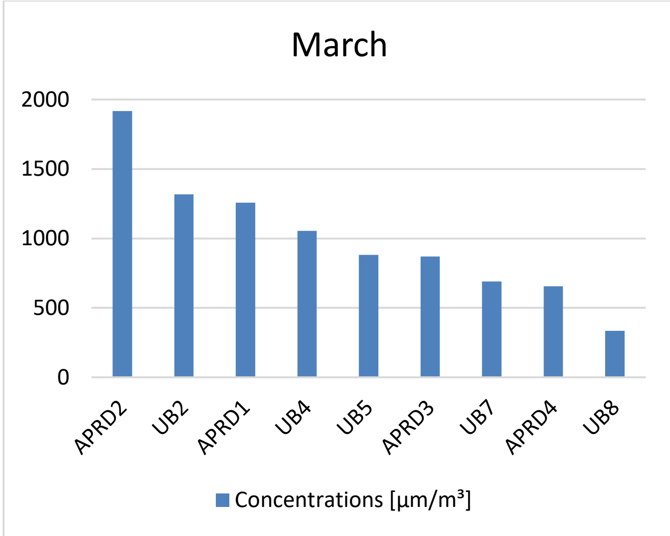

October
2000
1500
1000
500
0
APRD2
UB2
APRD1
UB4
UB5
APRD3
UB7
APRD4
UB8
Concentrations [µm/m³]

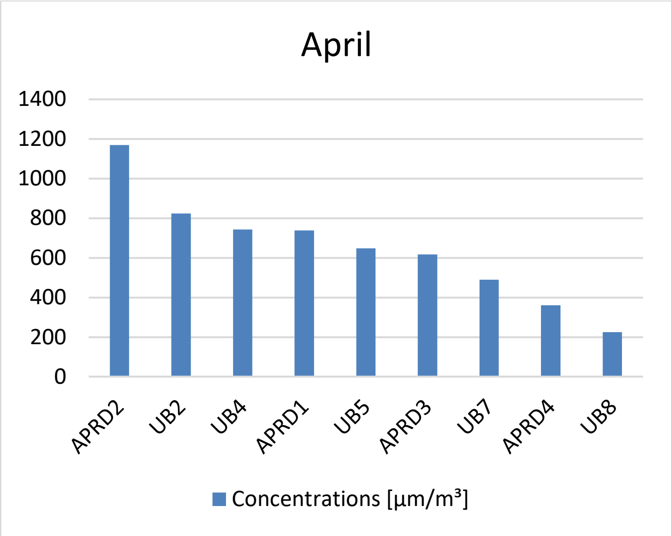

November
3500
3000
2500
2000
1500
1000
500
0
APRD2
APRD1
UB2
UB5
APRD3
UB4
UB7
APRD4
UB8
Concentrations [µm/m³]

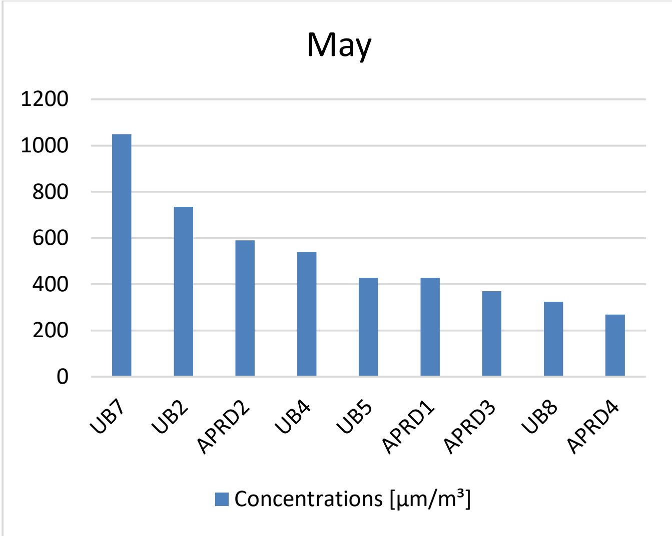

December
6000
5000
4000
3000
2000
1000
0
APRD1
APRD2
UB5
UB2
APRD3
UB4
UB7
APRD4
Concentrations [µm/m³]

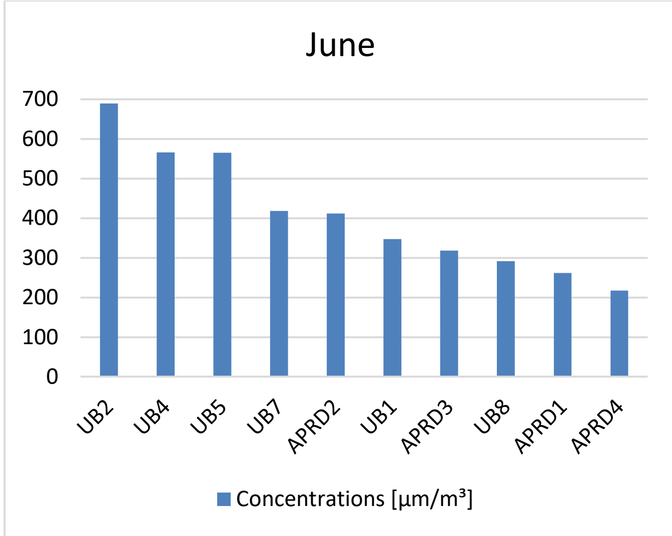

January
5000
4000
3000
2000
1000
0
APRD2
APRD1
UB5
UB2
APRD3
UB4
APRD4
UB7
UB8
Concentrations [µm/m³]

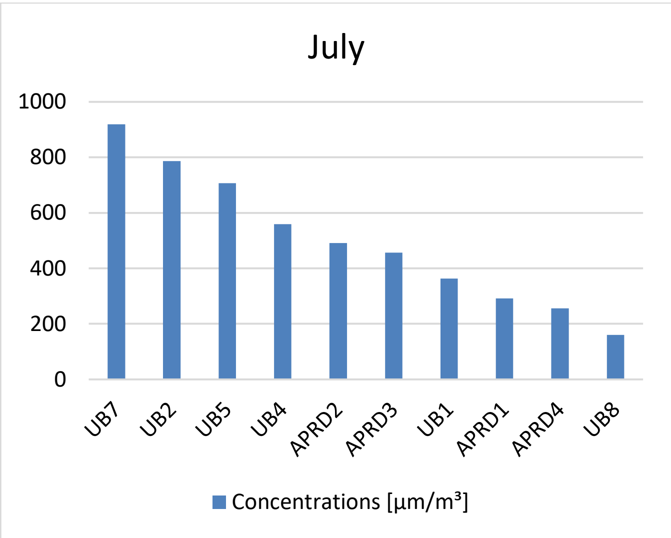

February
3000
2500
2000
1500
1000
500
0
APRD1
APRD2
APRD3
UB2
UB4
UB5
UB7
APRD4
Concentrations [µm/m³]

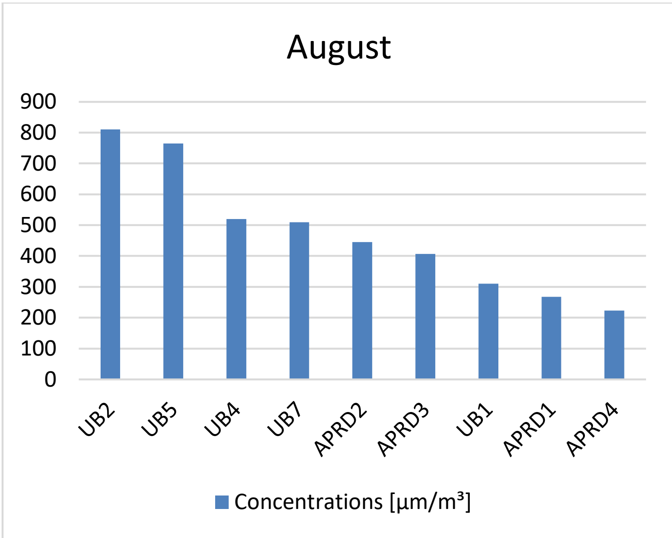

March
2000
1500
1000
500
0
APRD2
UB2
APRD1
UB4
UB5
APRD3
UB7
APRD4
UB8
Concentrations [µm/m³]

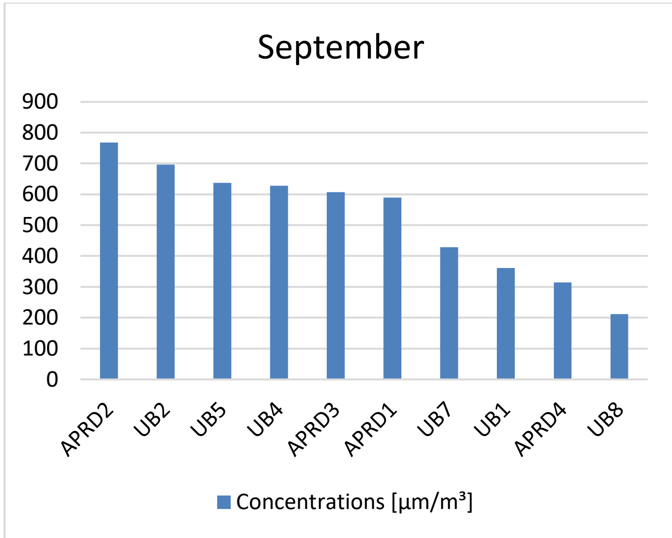

April
1400
1200
1000
800
600
400
200
0
APRD2
UB2
UB4
APRD1
UB5
APRD3
UB7
APRD4
UB8
Concentrations [µm/m³]


May
1200
1000
800
600
400
200
0
UB7
UB2
APRD2
UB4
UB5
APRD1
APRD3
UB8
APRD4
Concentrations [µm/m³]

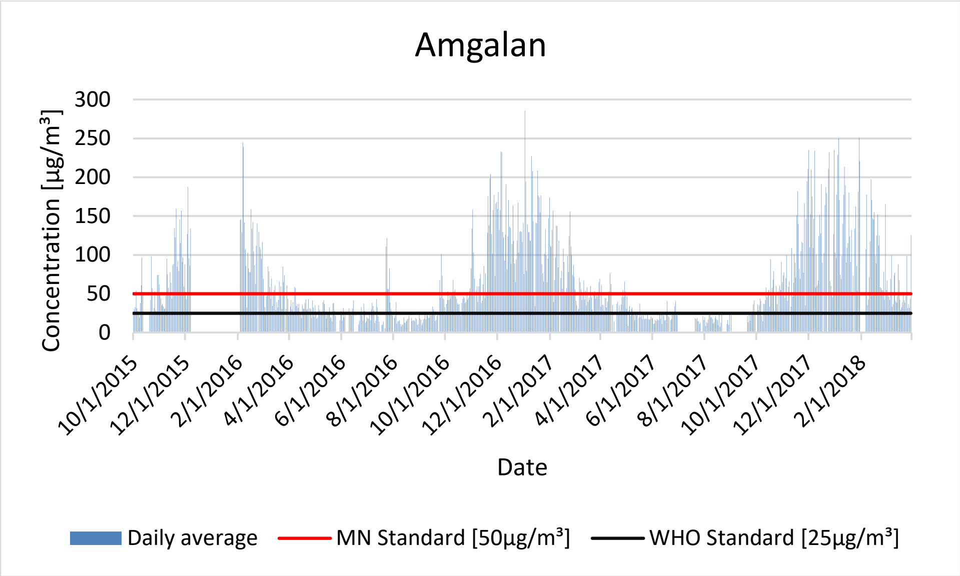

June
700
600
500
400
300
200
100
0
UB2
UB4
UB5
UB7
APRD2
UB1
APRD3
UB8
APRD1
APRD4
Concentrations [µm/m³]

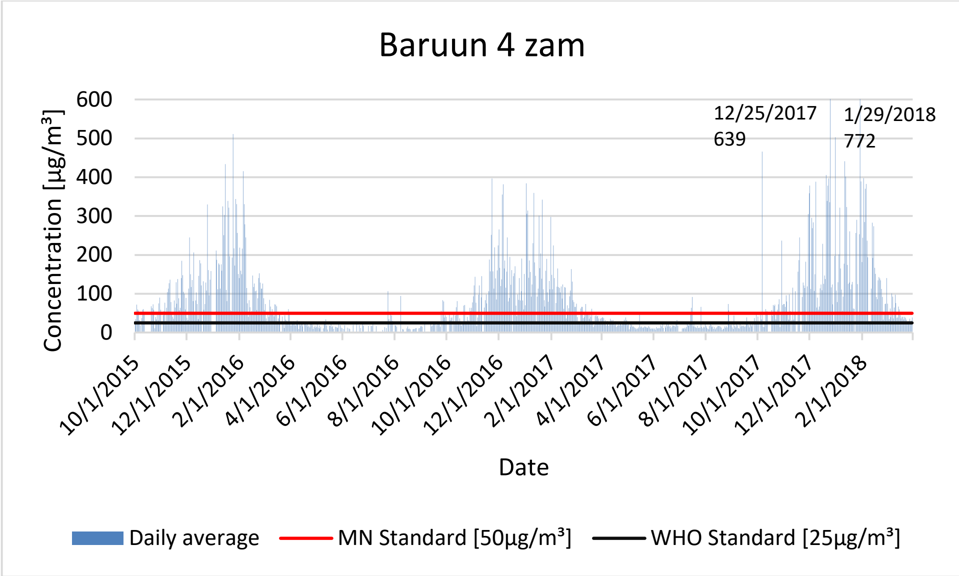

July
1000
800
600
400
200
0
UB7
UB2
UB5
UB4
APRD2
APRD3
UB1
APRD1
APRD4
UB8
Concentrations [µm/m³]

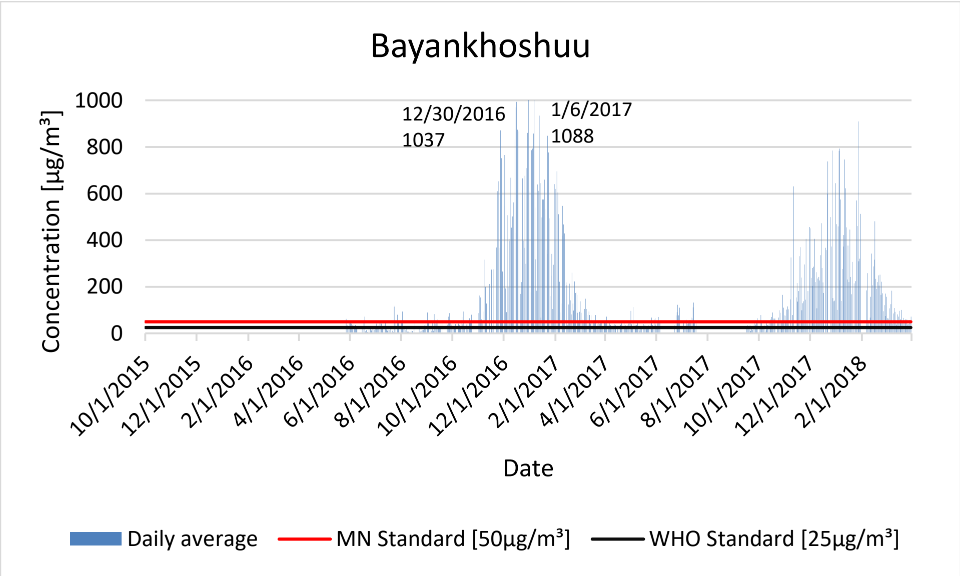

August
900
800
700
600
500
400
300
200
100
0
UB2
UB5
UB4
UB7
APRD2
APRD3
UB1
APRD1
APRD4
Concentrations [µm/m³]

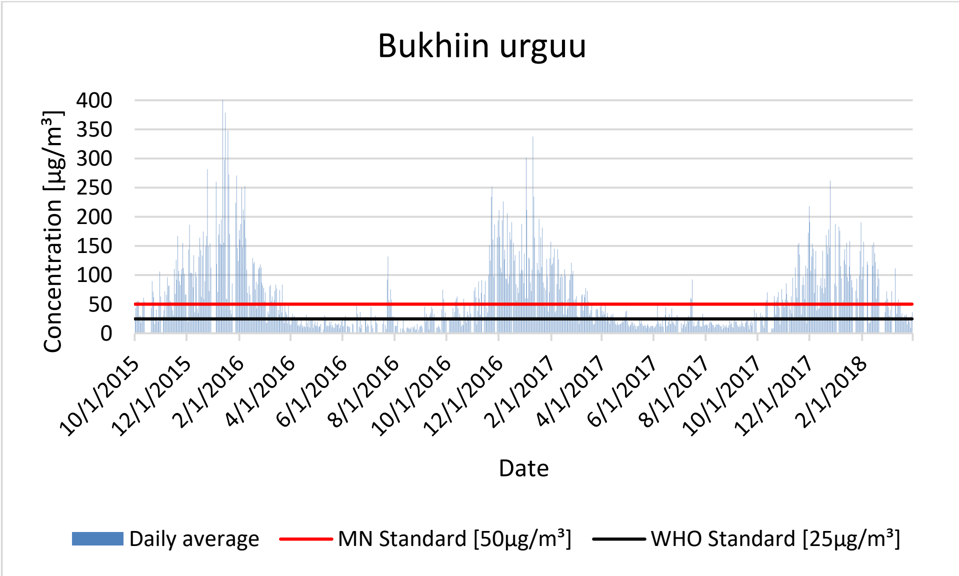

September
900
800
700
600
500
400
300
200
100
0
APRD2
UB2
UB5
UB4
APRD3
APRD1
UB7
UB1
APRD4
UB8
Concentrations [µm/m³]

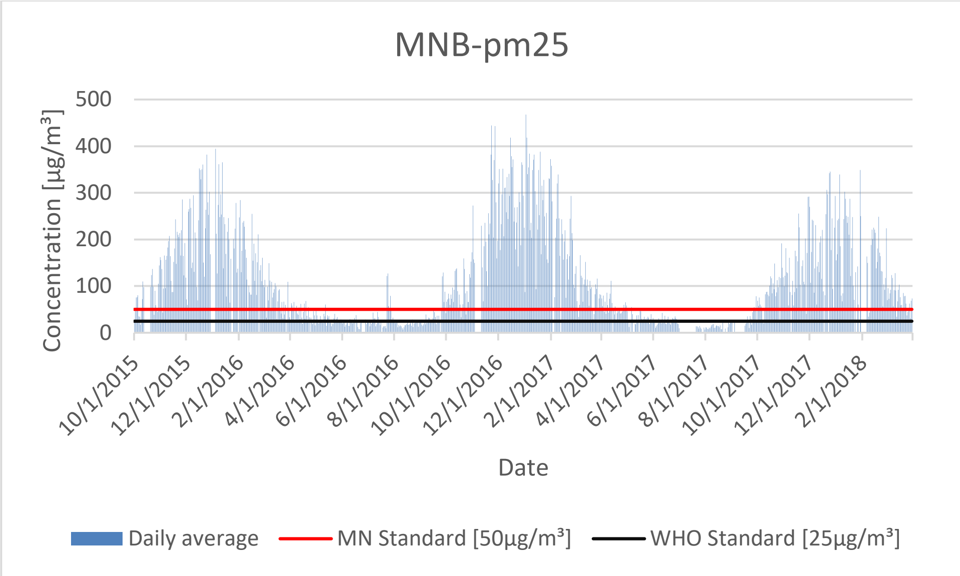
Appendix 7. Daily average $PM_{2.5}$ concentration levels at each station for October 2015-March 2018

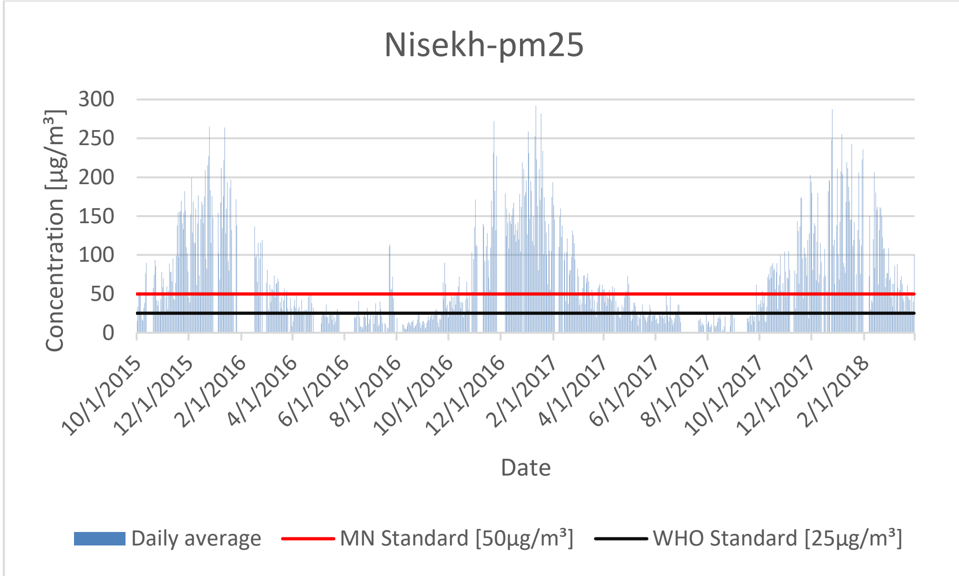


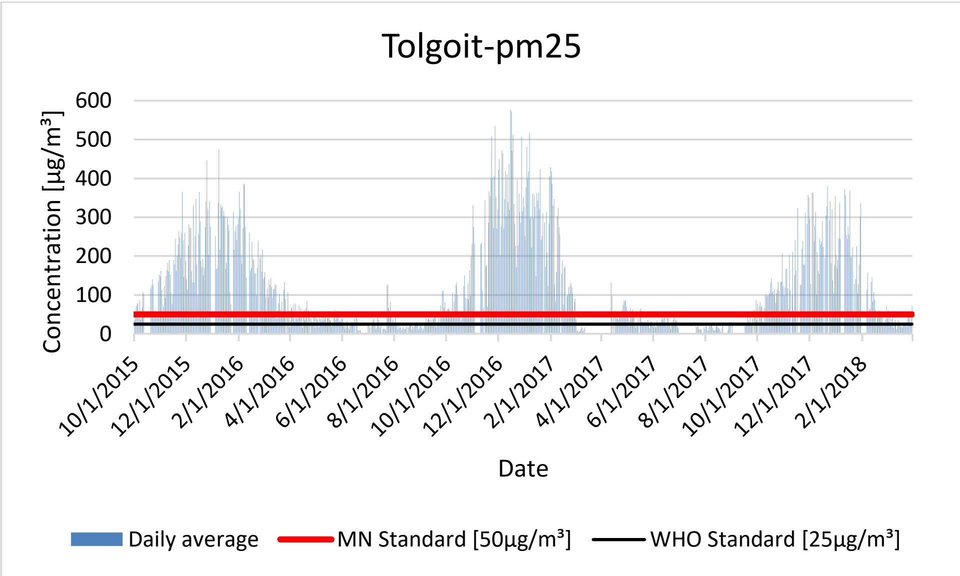


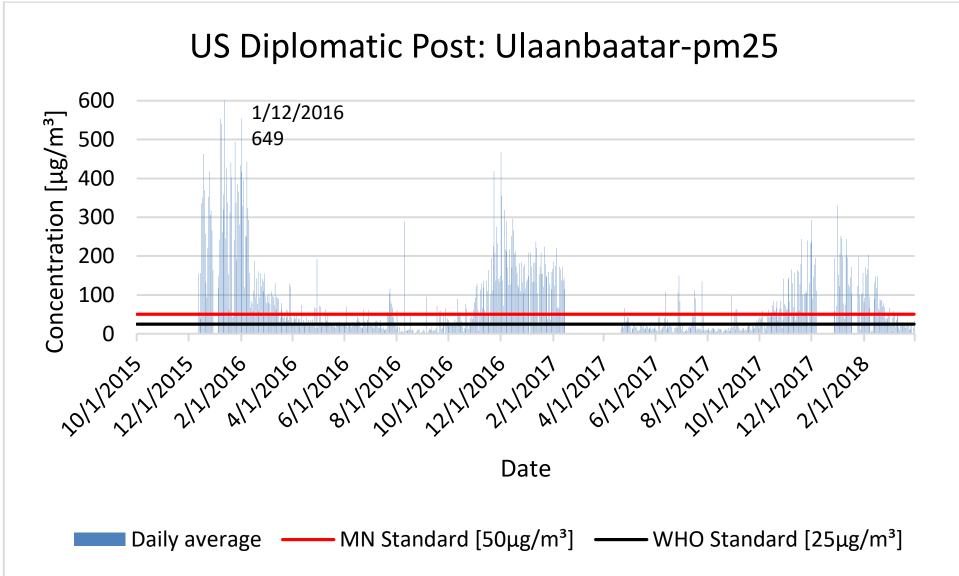




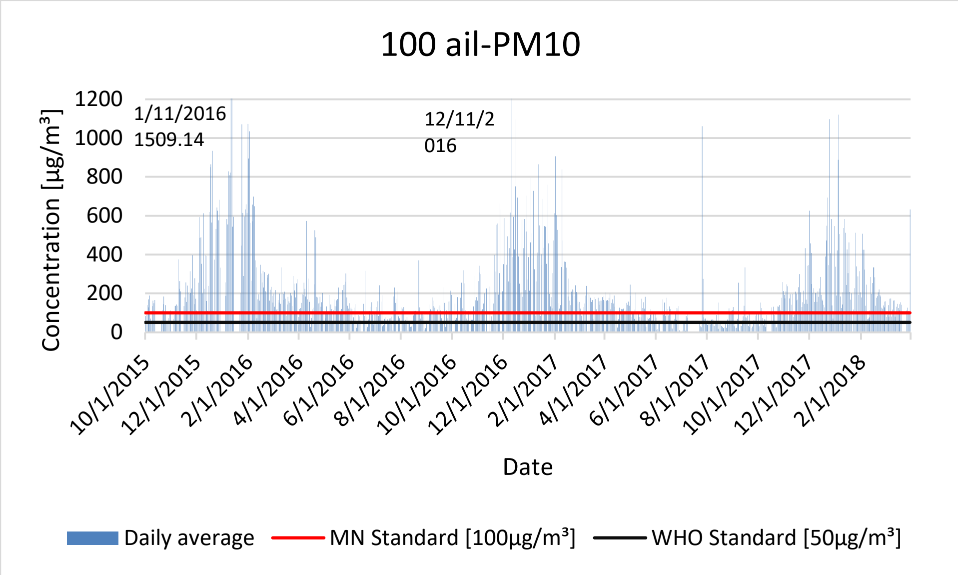

MNB-pm25
Concentration [µg/m³]
500
400
300
200
100
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]
WHO Standard [25µg/m³]

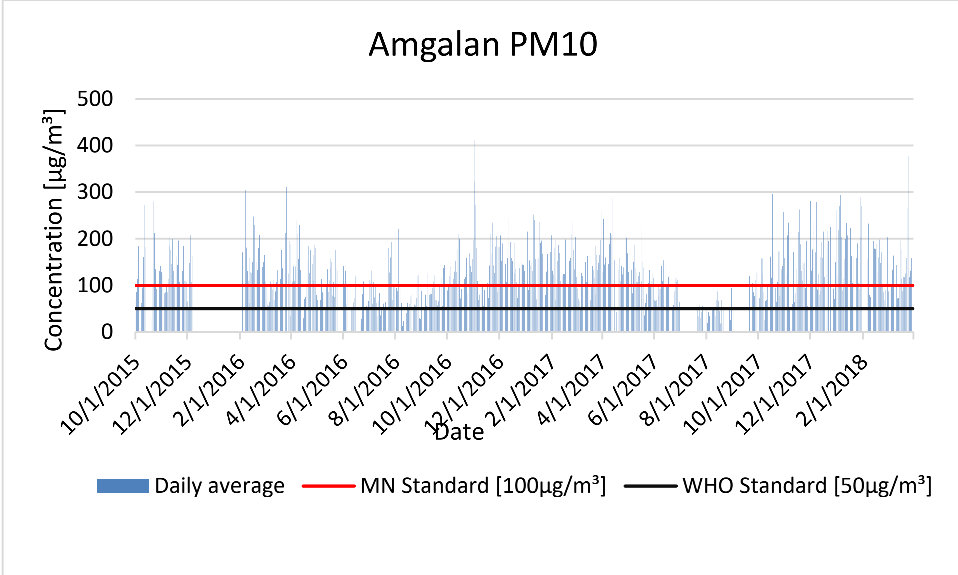

Nisekh-pm25
Concentration [µg/m³]
300
250
200
150
100
50
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]
WHO Standard [25µg/m³]

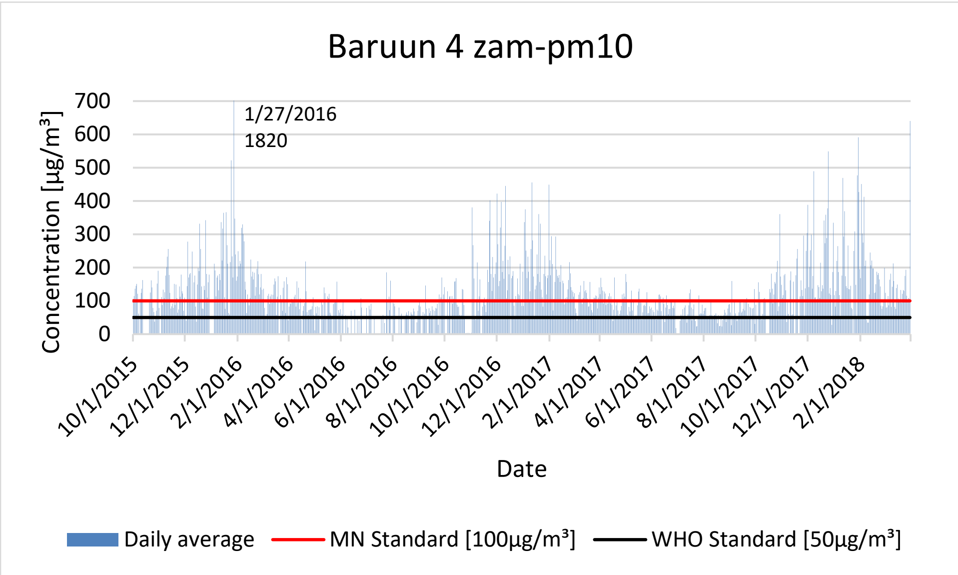

Tolgoit-pm25
Concentration [µg/m³]
600
500
400
300
200
100
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]
WHO Standard [25µg/m³]

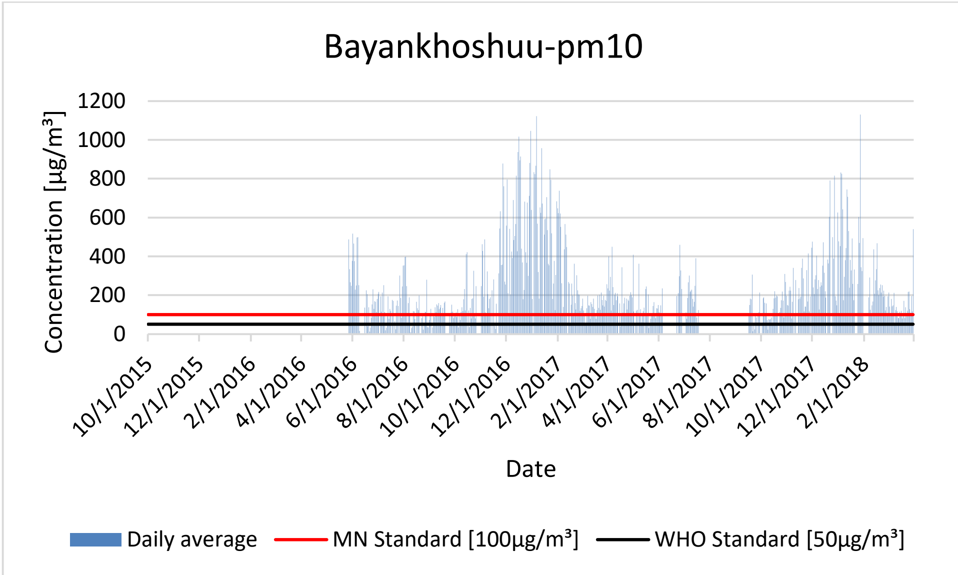

US Diplomatic Post: Ulaanbaatar-pm25
1/12/2016
649
Concentration [µg/m³]
600
500
400
300
200
100
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]
WHO Standard [25µg/m³]

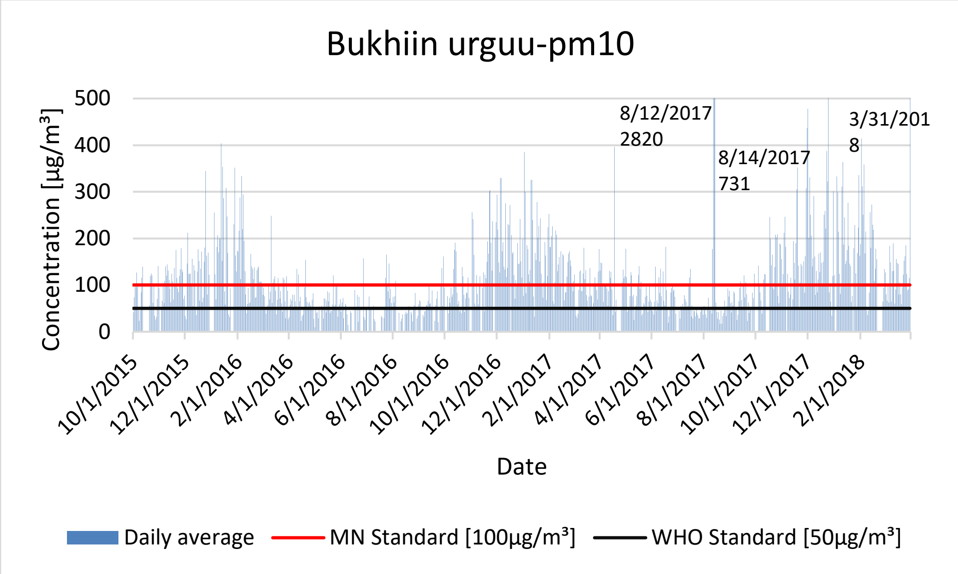
Appendix 8. Daily average PM_{10} concentration levels at each station for October 2015-March 2018

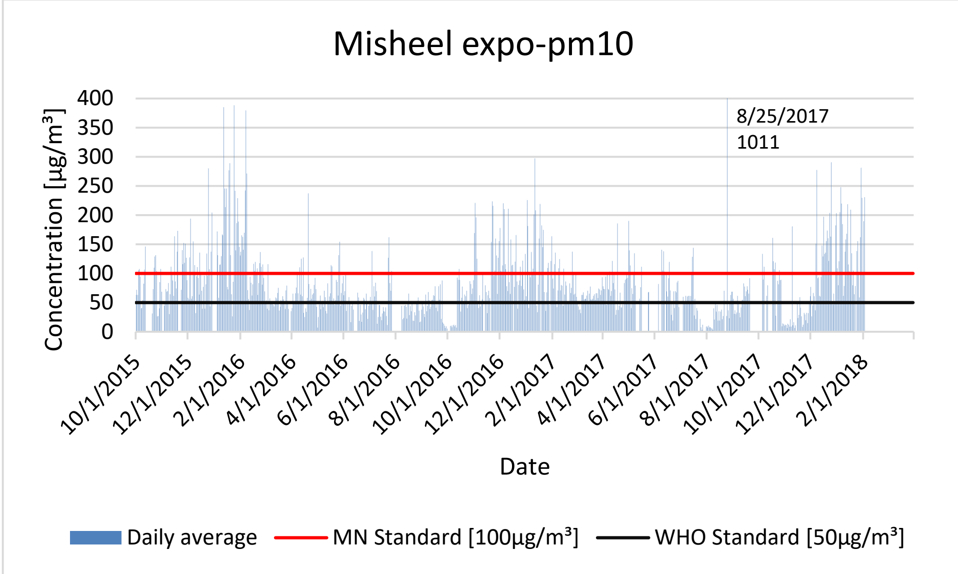


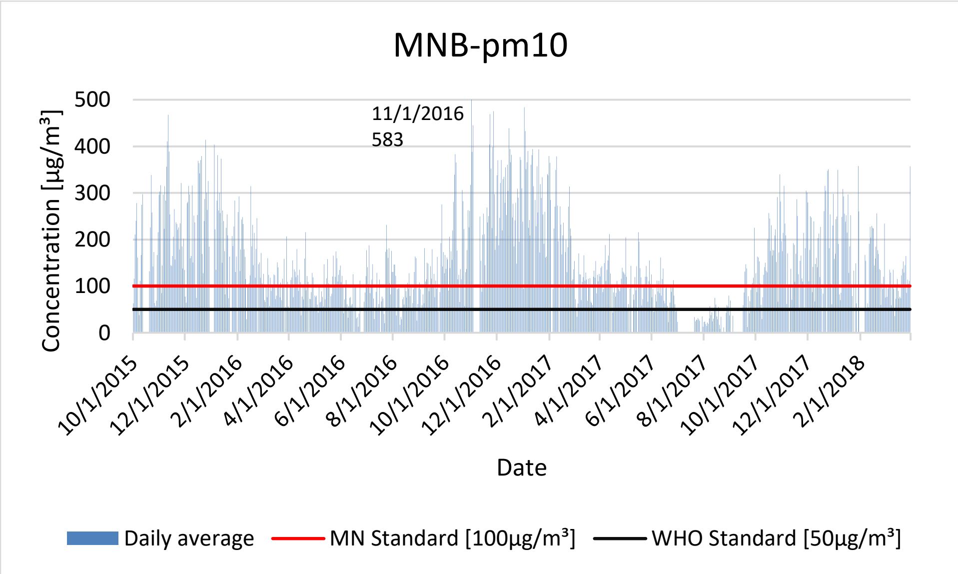


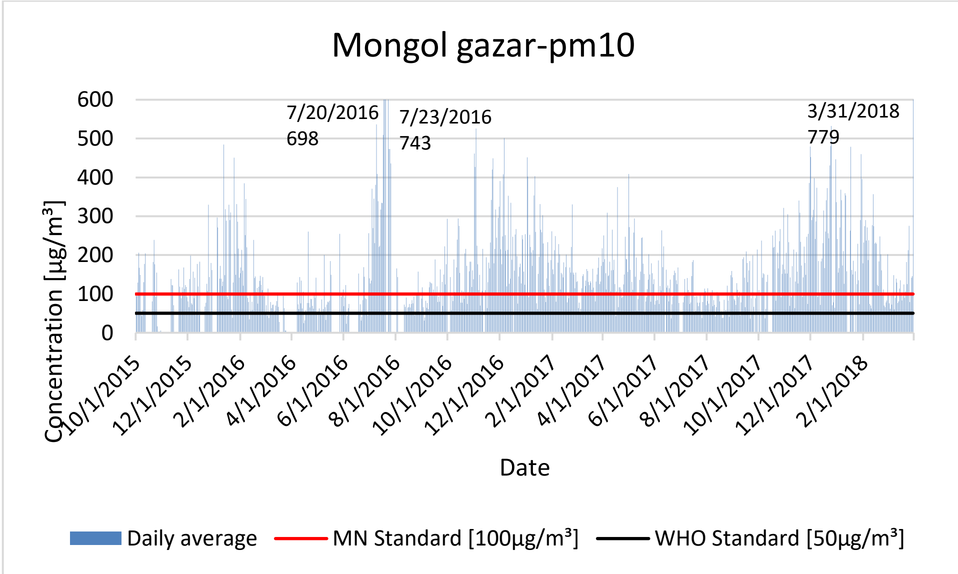


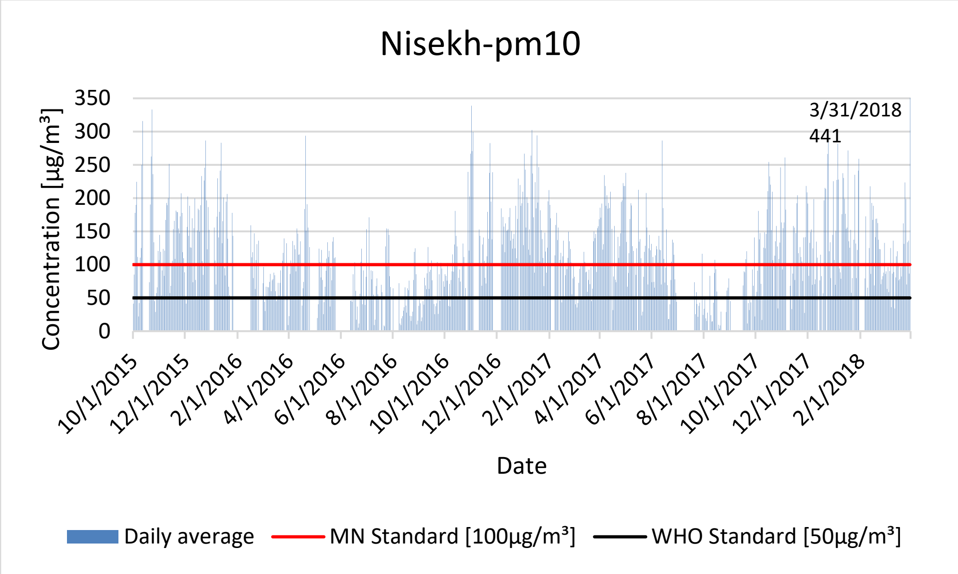


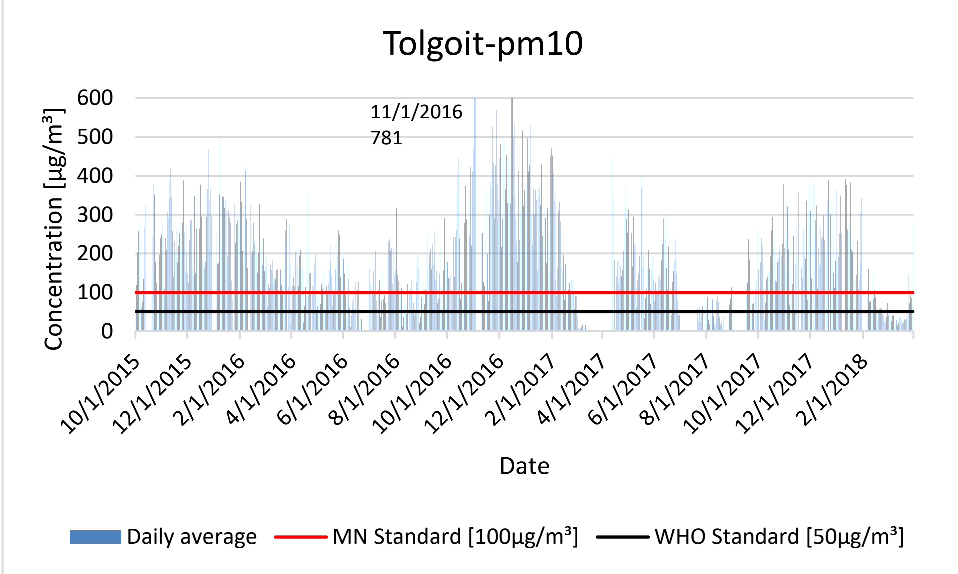

Bukhiin urguu-pm10
Concentration [µg/m³]
500
400
300
200
100
0
8/12/2017
2820
8/14/2017
731
3/31/201
8
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [100µg/m³]
WHO Standard [50µg/m³]

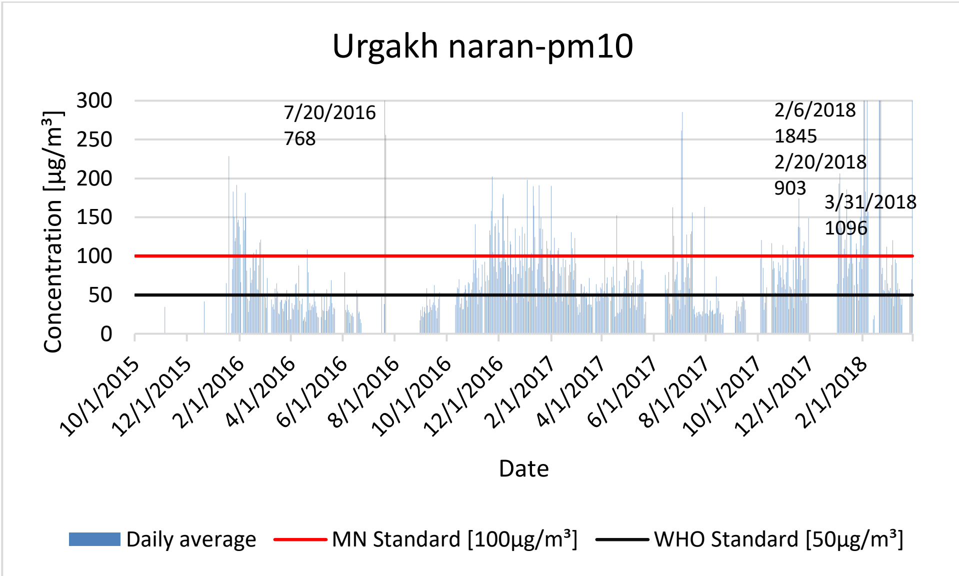

Misheel expo-pm10
Concentration [µg/m³]
400
350
300
250
200
150
100
50
0
8/25/2017
1011
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [100µg/m³]
WHO Standard [50µg/m³]


MNB-pm10
Concentration [µg/m³]
500
400
300
200
100
0
11/1/2016
583
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [100µg/m³]
WHO Standard [50µg/m³]

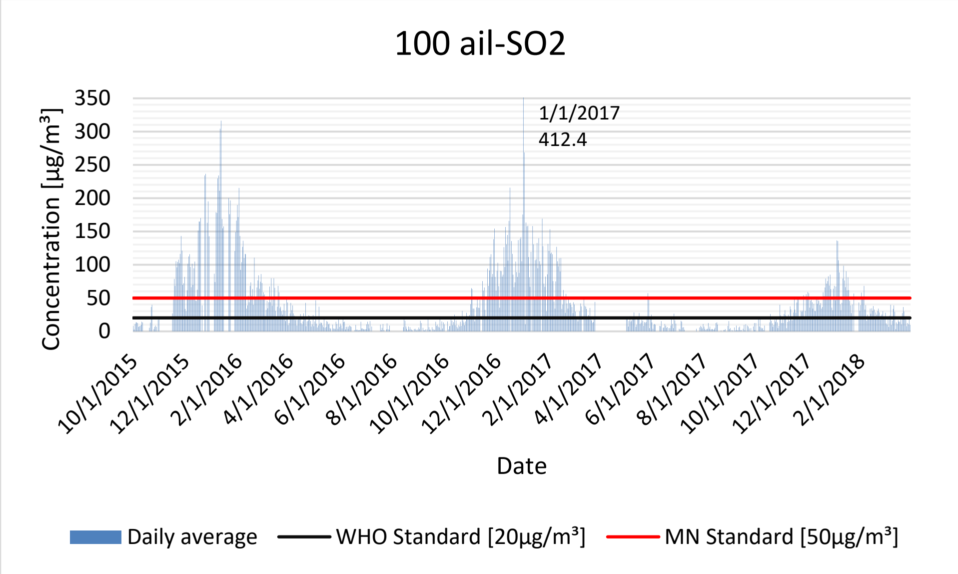

Mongol gazar-pm10
Concentration [µg/m³]
600
500
400
300
200
100
0
7/20/2016
698
7/23/2016
743
3/31/2018
779
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [100µg/m³]
WHO Standard [50µg/m³]

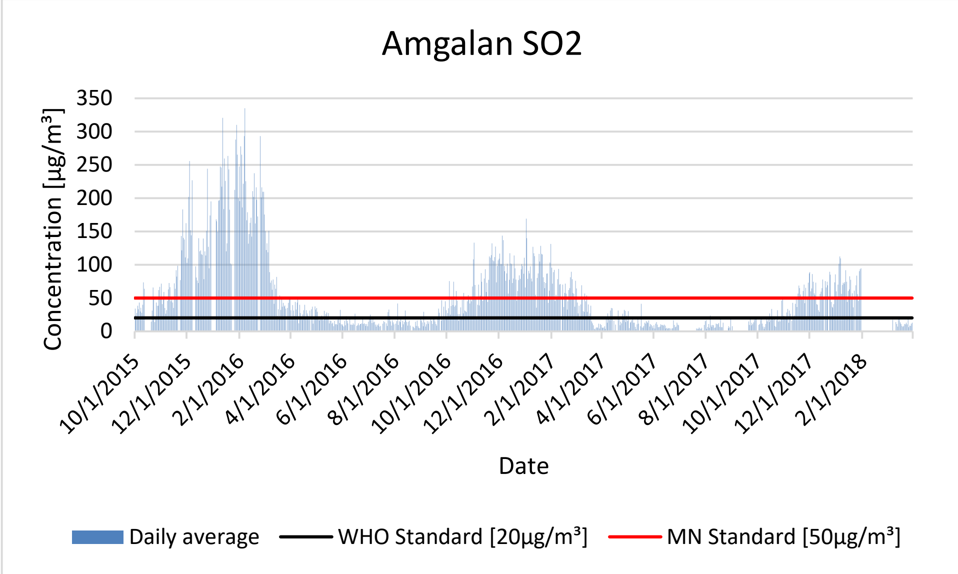

Nisekh-pm10
Concentration [µg/m³]
350
300
250
200
150
100
50
0
3/31/2018
441
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [100µg/m³]
WHO Standard [50µg/m³]

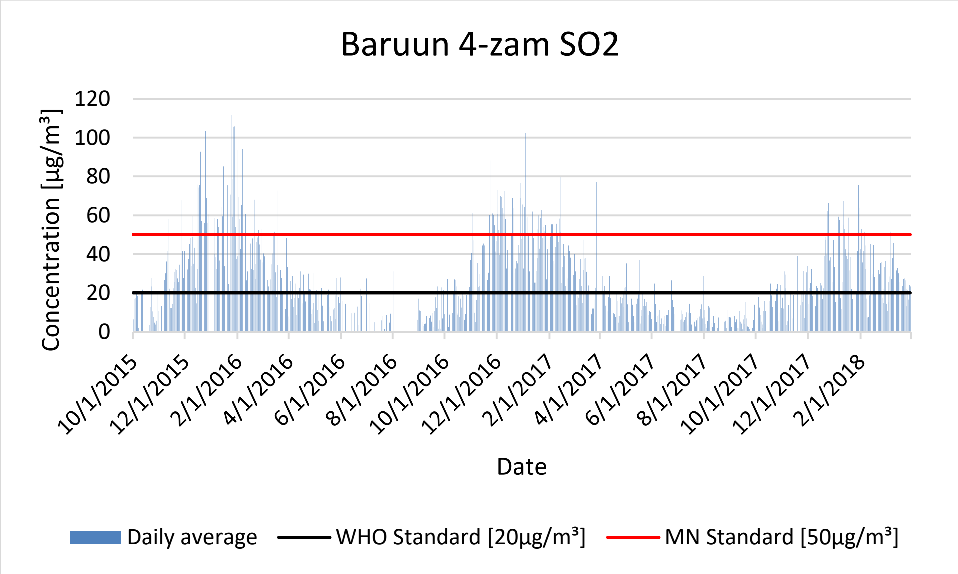

Tolgoit-pm10
Concentration [µg/m³]
600
500
400
300
200
100
0
11/1/2016
781
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [100µg/m³]
WHO Standard [50µg/m³]

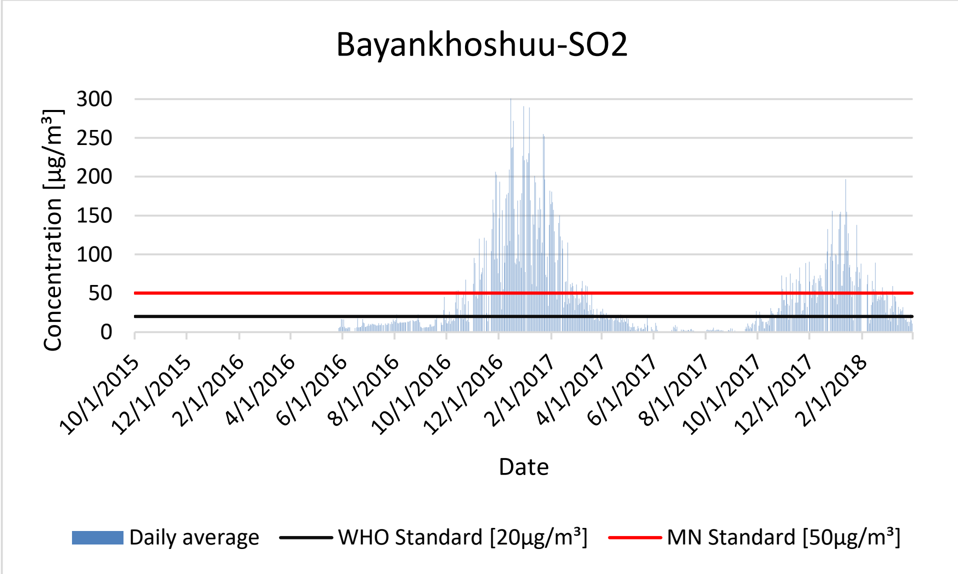

Urgakh naran-pm10
Concentration [µg/m³]
300
250
200
150
100
50
0
7/20/2016
768
2/6/2018
1845
2/20/2018
903
3/31/2018
1096
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [100µg/m³]
WHO Standard [50µg/m³]

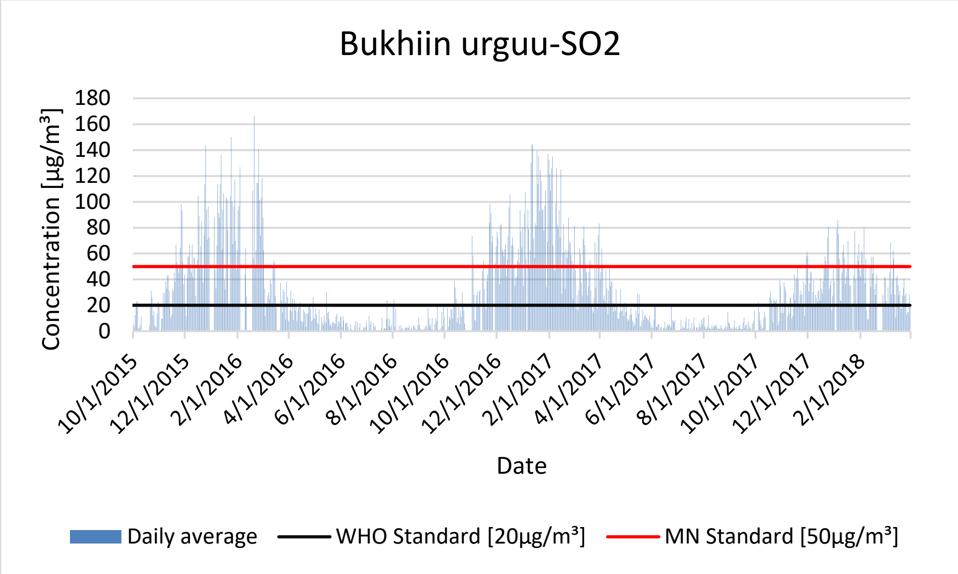
Appendix 9. Daily average SO_2 concentration levels at each station for October 2015-March 2018

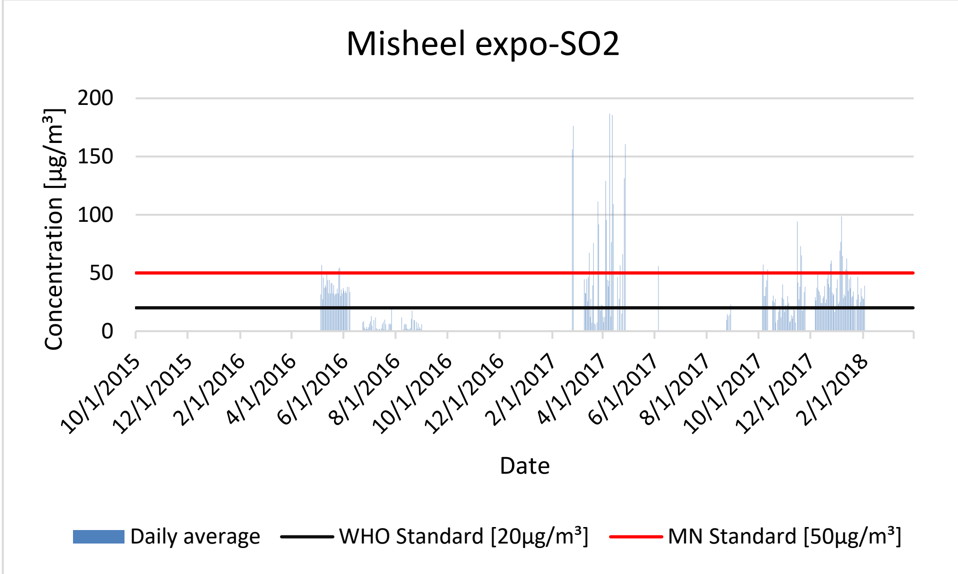


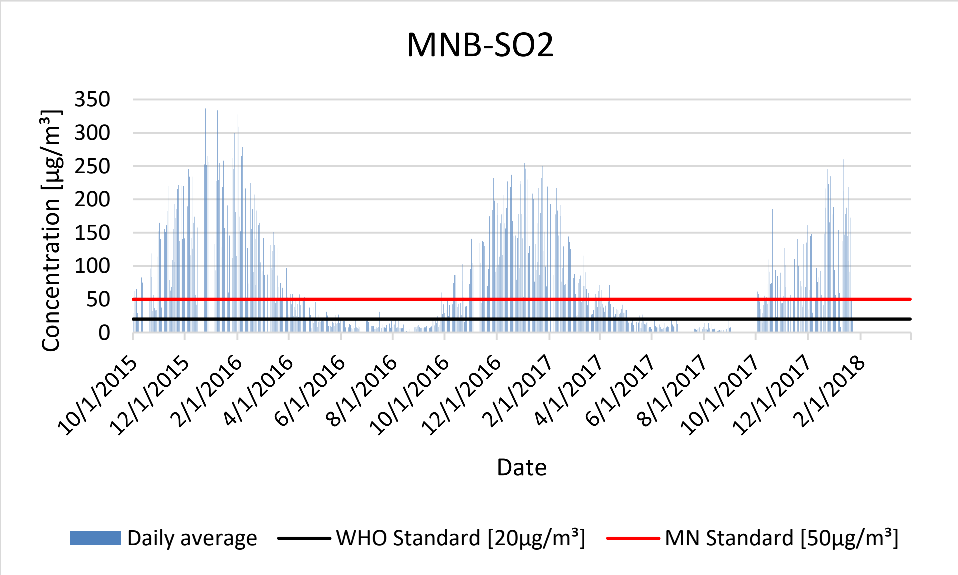


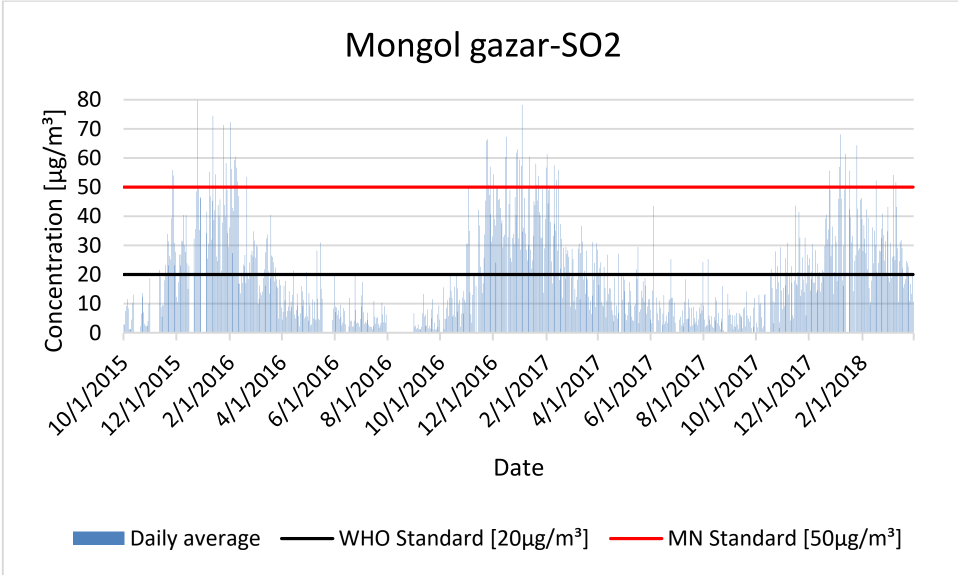


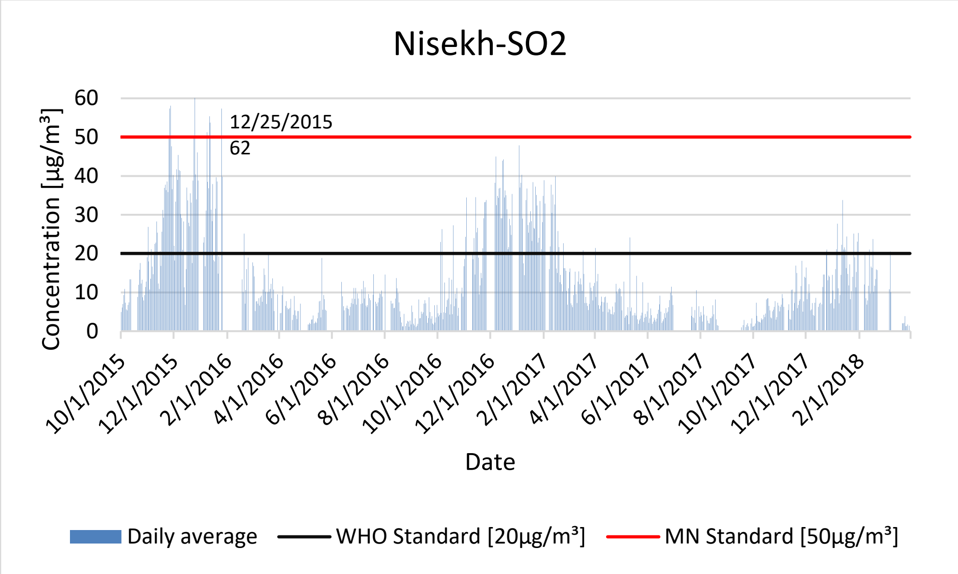


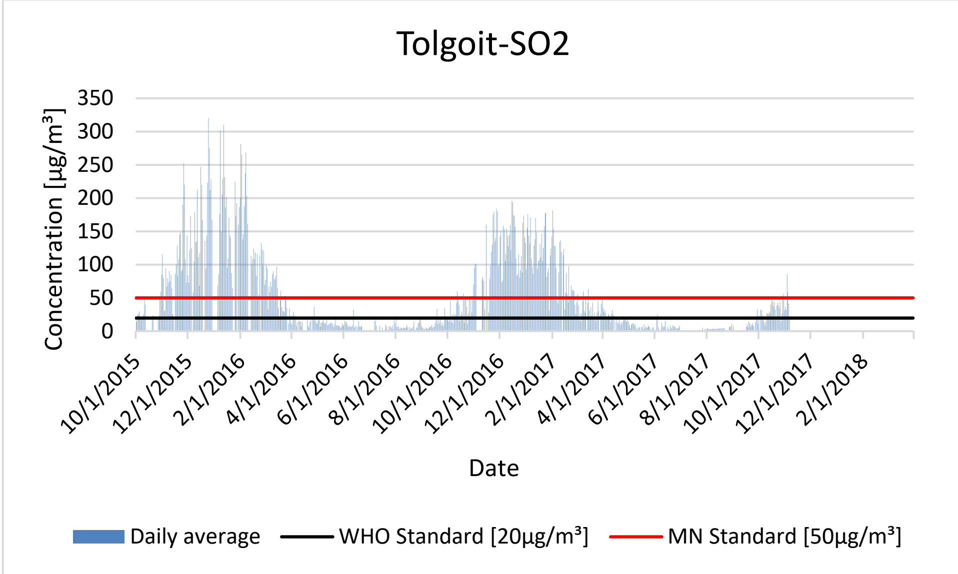

Bukhiin urguu-SO2
Concentration [µg/m³]
180
160
140
120
100
80
60
40
20
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
WHO Standard [20µg/m³]
MN Standard [50µg/m³]

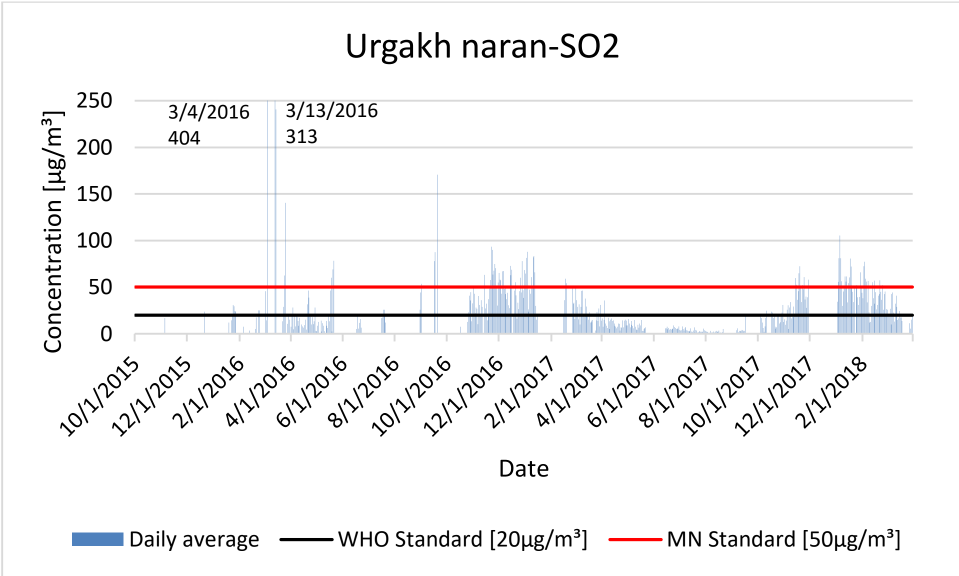

Misheel expo-SO2
Concentration [µg/m³]
200
150
100
50
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
WHO Standard [20µg/m³]
MN Standard [50µg/m³]


MNB-SO2
Concentration [µg/m³]
350
300
250
200
150
100
50
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
WHO Standard [20µg/m³]
MN Standard [50µg/m³]

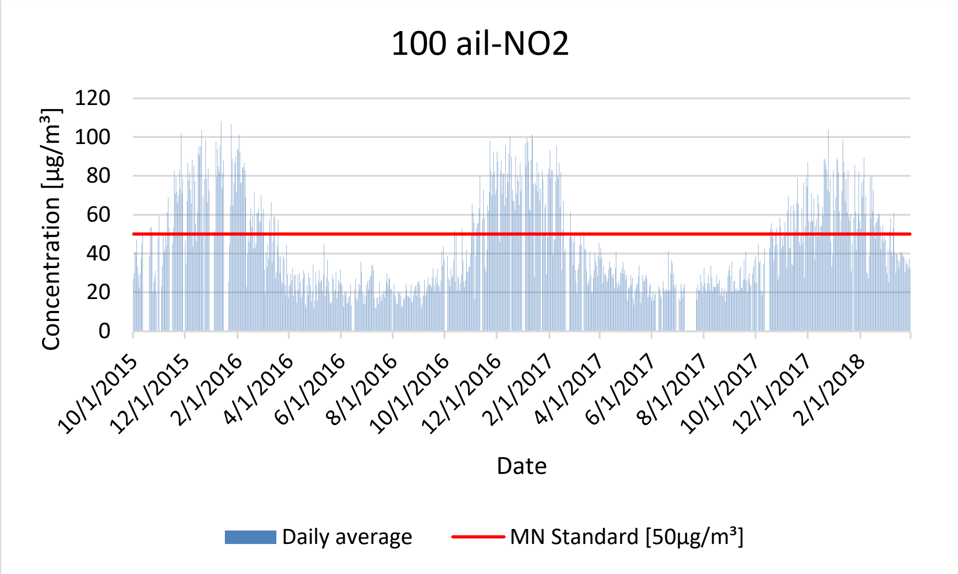

Mongol gazar-SO2
Concentration [µg/m³]
80
70
60
50
40
30
20
10
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
WHO Standard [20µg/m³]
MN Standard [50µg/m³]

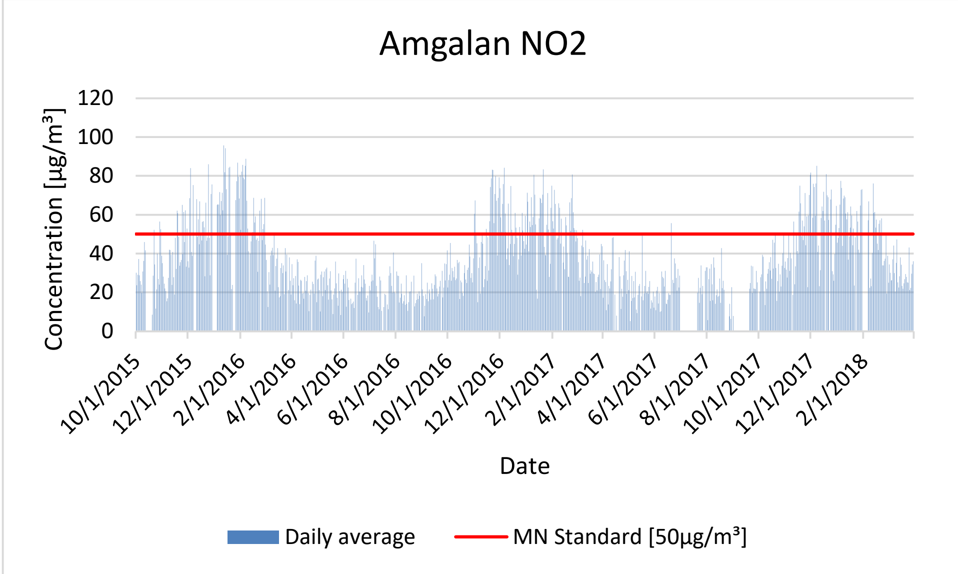

Nisekh-SO2
Concentration [µg/m³]
60
50
40
30
20
10
0
12/25/2015
62
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
WHO Standard [20µg/m³]
MN Standard [50µg/m³]

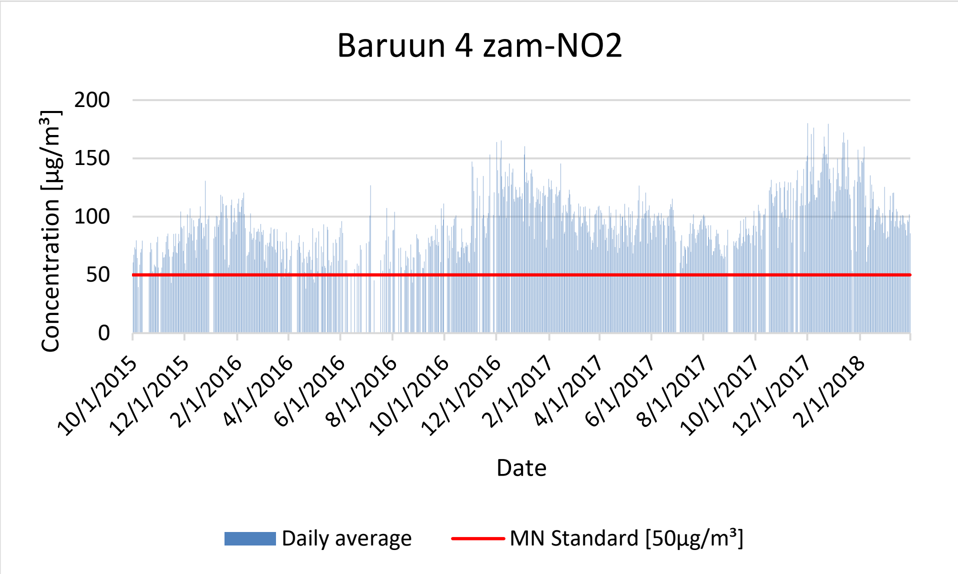

Tolgoit-SO2
Concentration [µg/m³]
350
300
250
200
150
100
50
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
WHO Standard [20µg/m³]
MN Standard [50µg/m³]

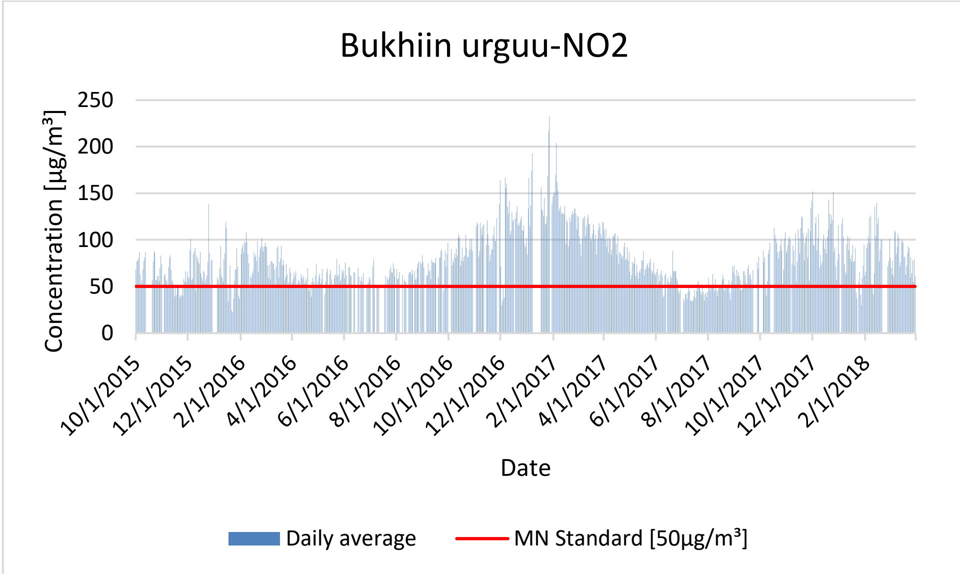

Urgakh naran-SO2
Concentration [µg/m³]
250
200
150
100
50
0
3/4/2016
404
3/13/2016
313
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
WHO Standard [20µg/m³]
MN Standard [50µg/m³]

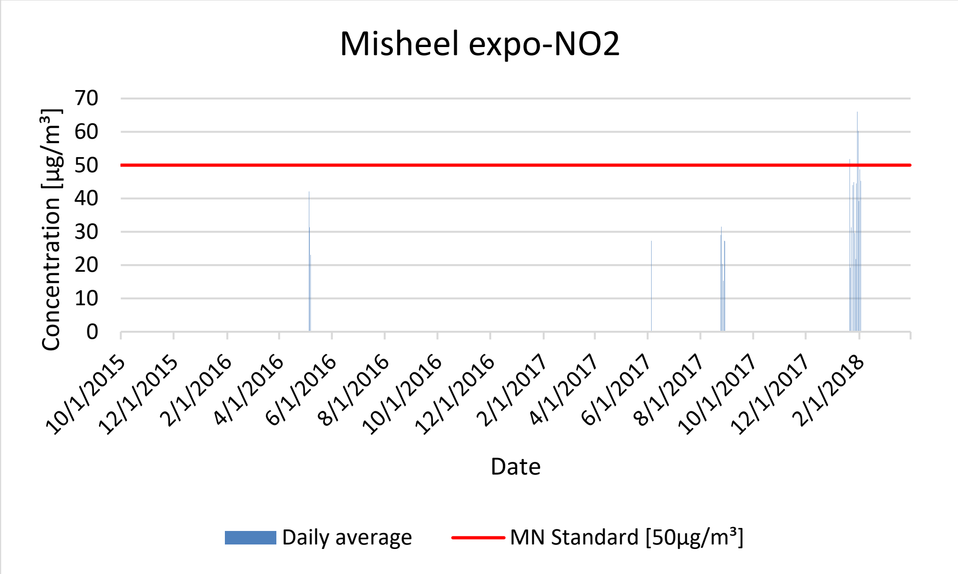
Appendix 10. Daily average NO_2 concentration levels at each station for October 2015-March 2018

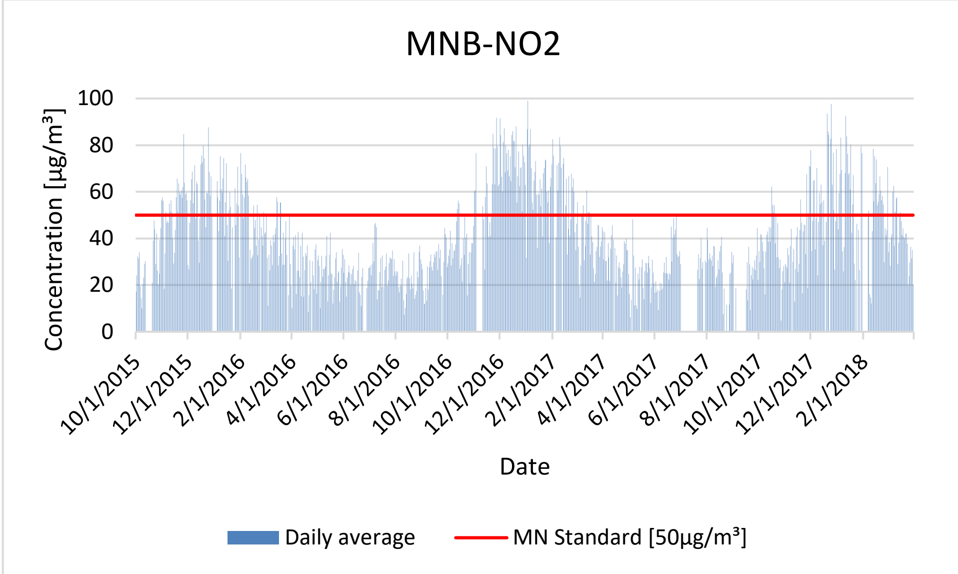


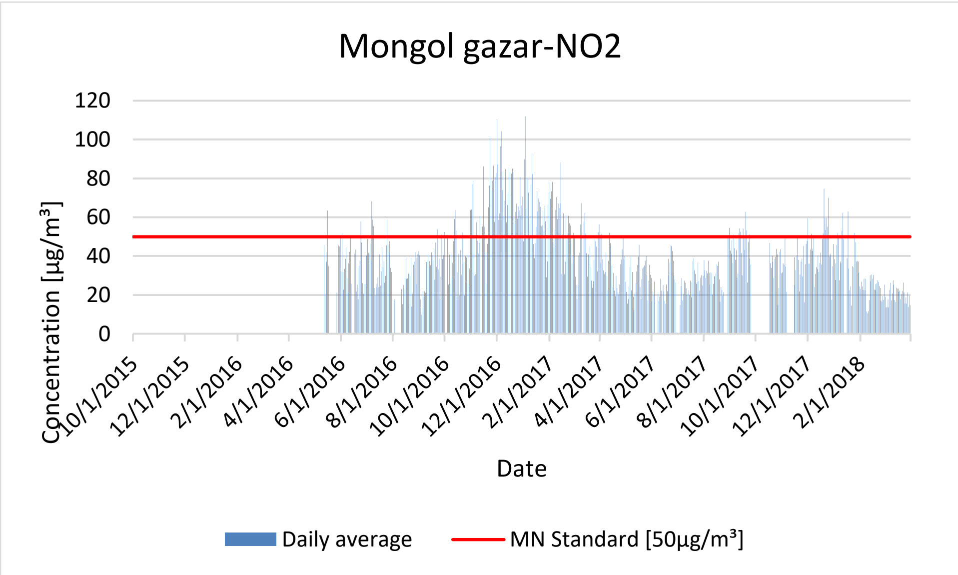


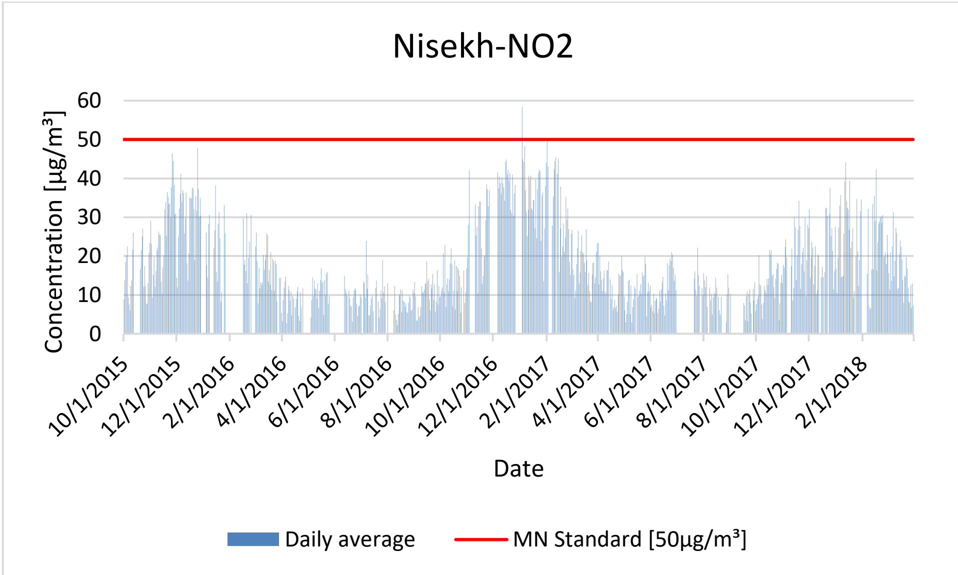


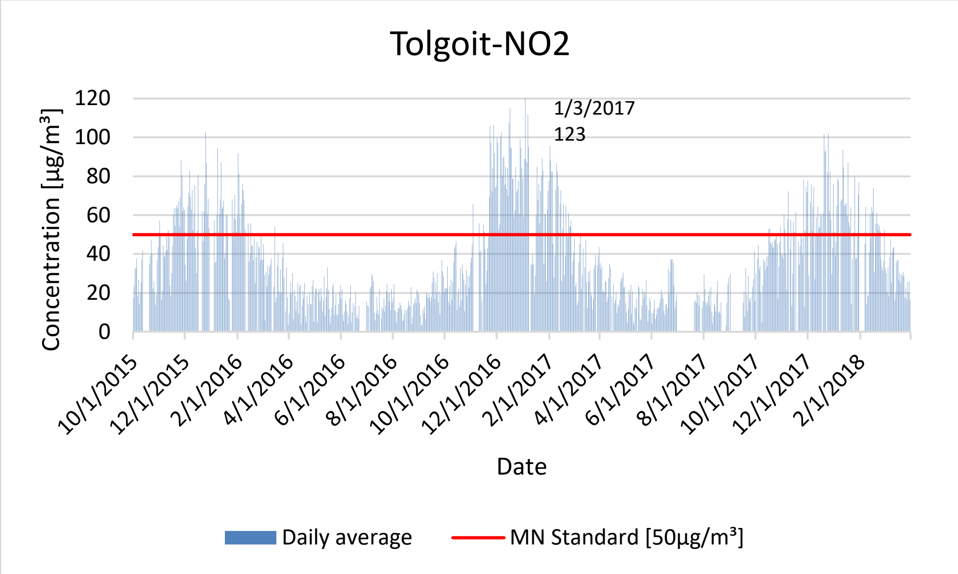


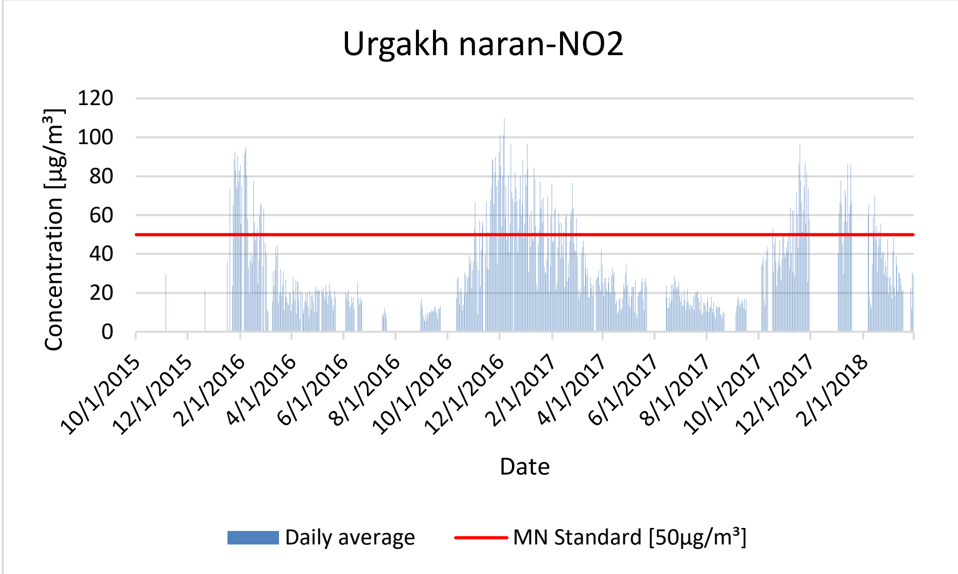

Misheel expo-NO2
Concentration [µg/m³]
70
60
50
40
30
20
10
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]


MNB-NO2
Concentration [µg/m³]
100
80
60
40
20
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]

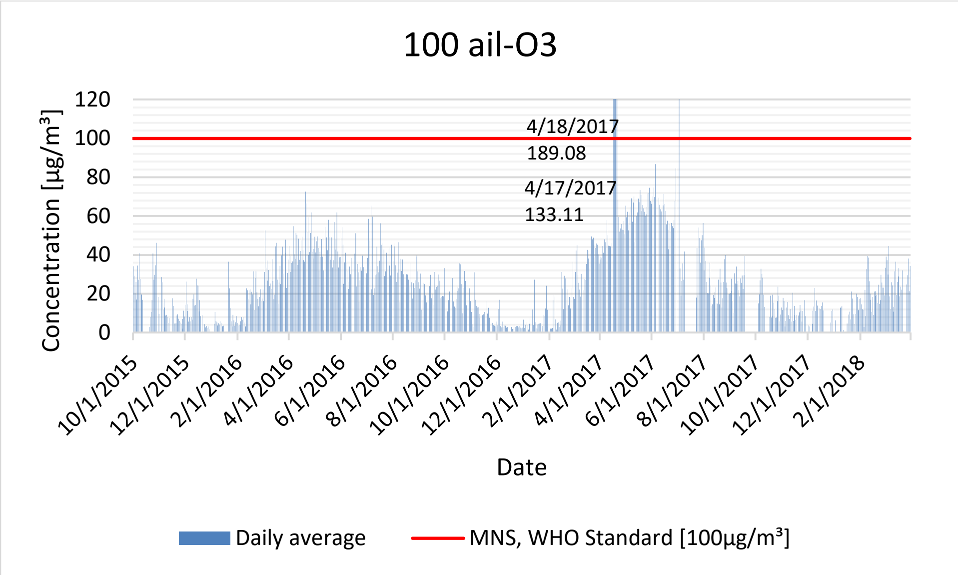

Mongol gazar-NO2
Concentration [µg/m³]
120
100
80
60
40
20
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]

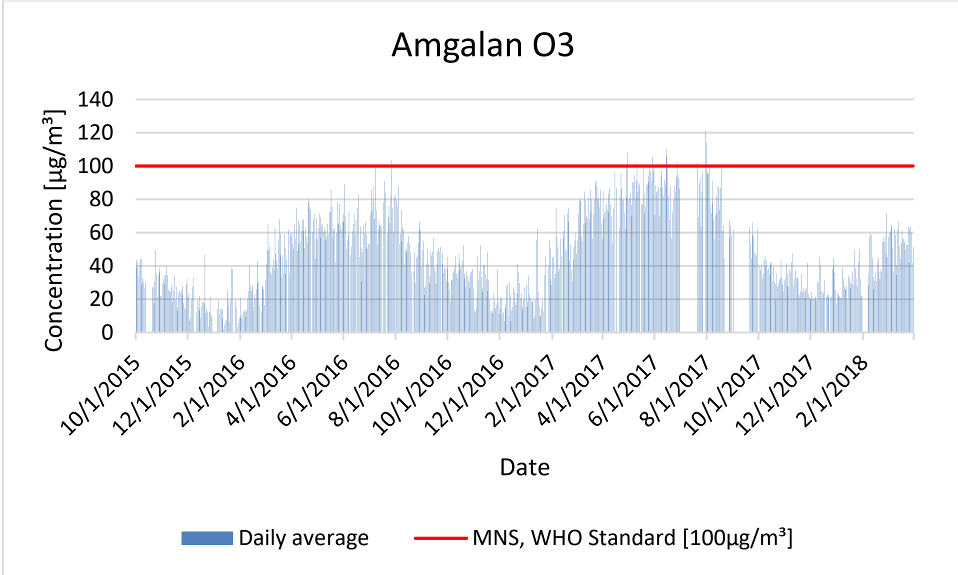

Nisekh-NO2
Concentration [µg/m³]
60
50
40
30
20
10
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]

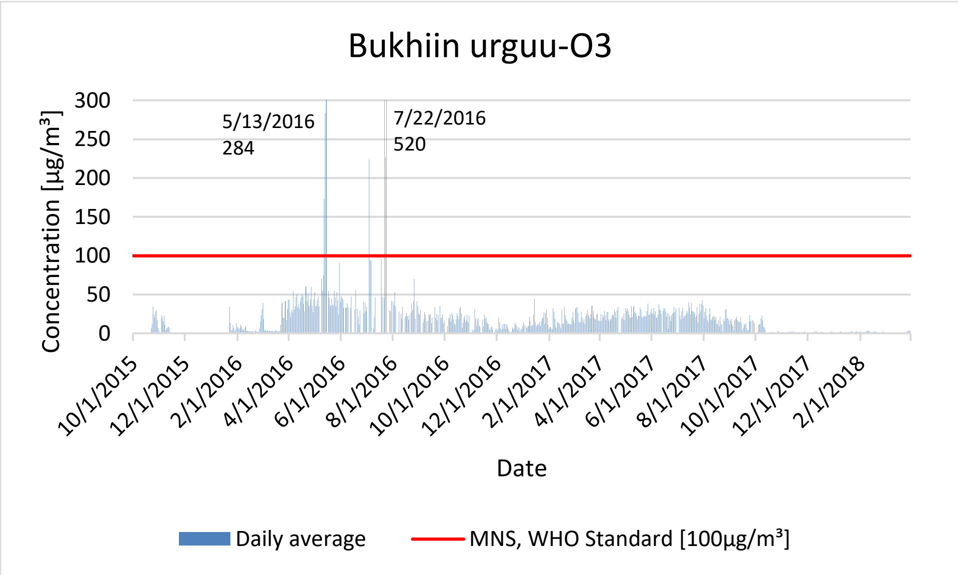

Tolgoit-NO2
Concentration [µg/m³]
120
100
80
60
40
20
0
1/3/2017
123
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]

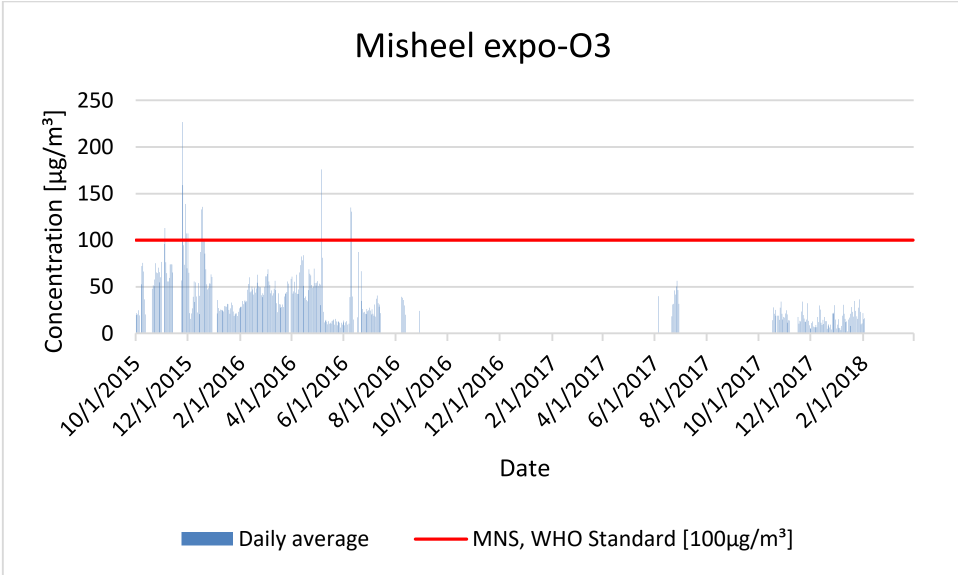

Urgakh naran-NO2
Concentration [µg/m³]
120
100
80
60
40
20
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [50µg/m³]

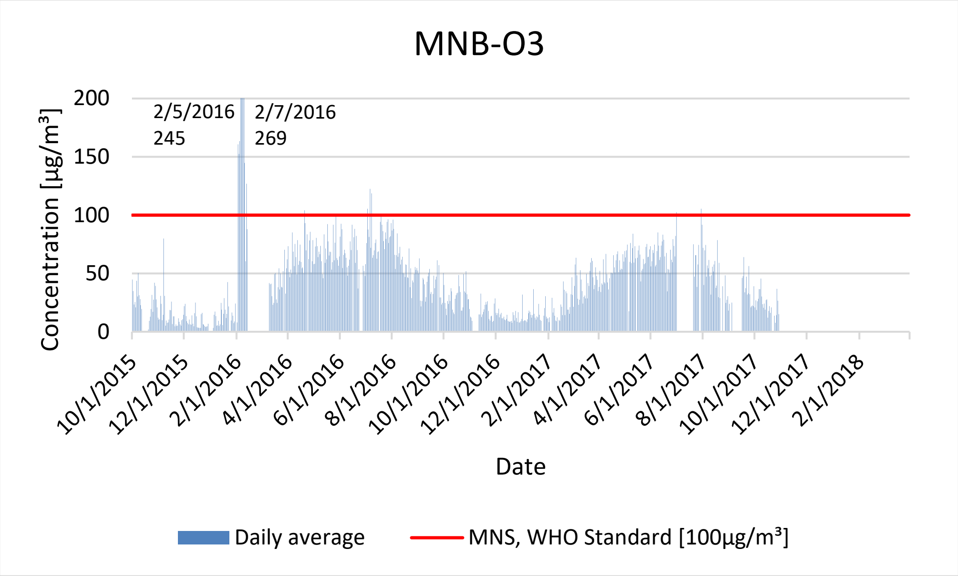
Appendix 11. Daily average O_3 concentration levels at each station for October 2015-March 2018

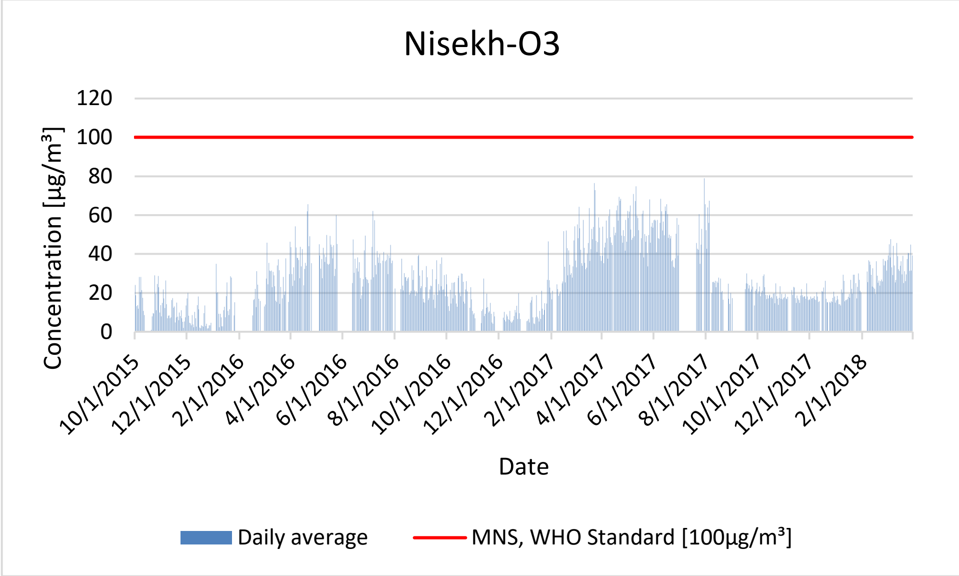


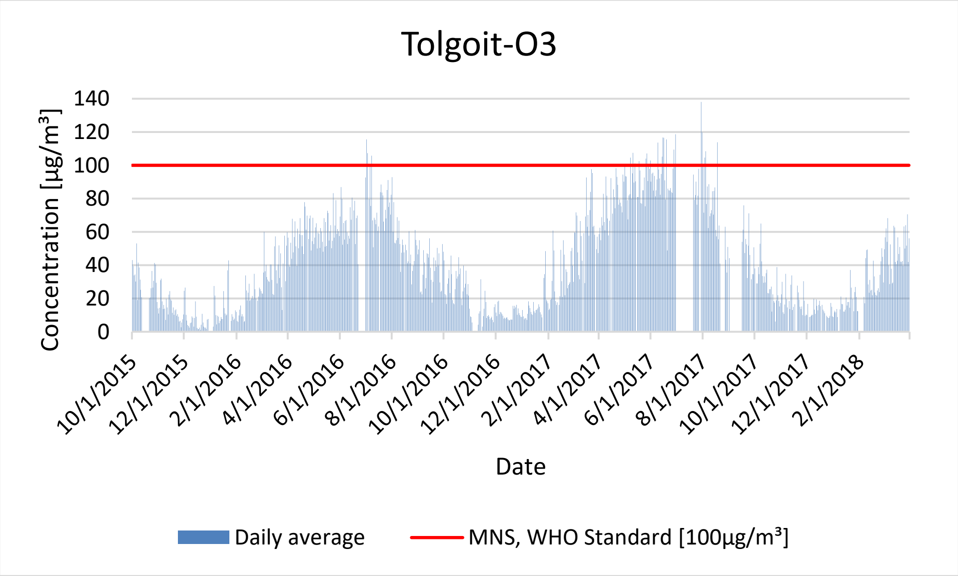


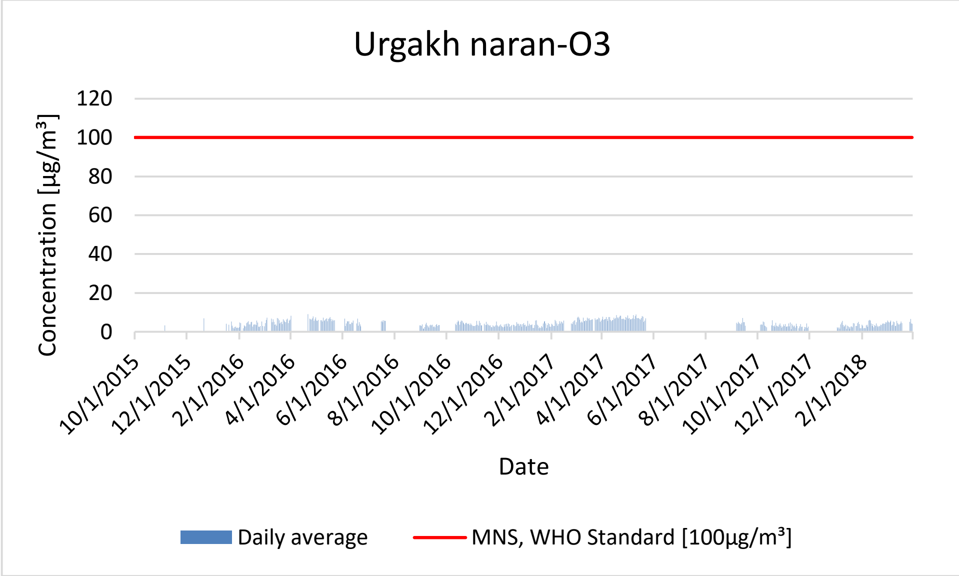




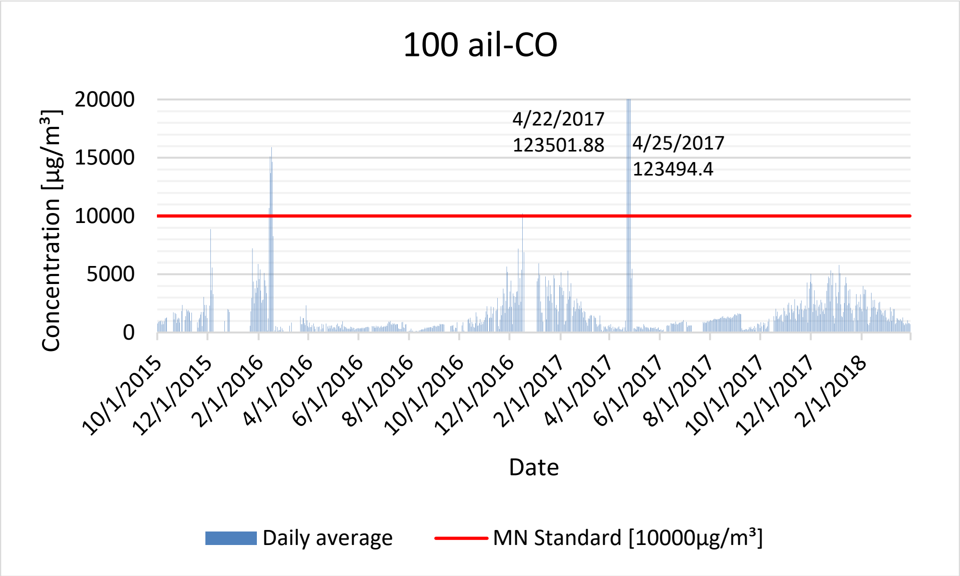

MNB-O3
2/5/2016
245
2/7/2016
269
Concentration [µg/m³]
200
150
100
50
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MNS, WHO Standard [100µg/m³]

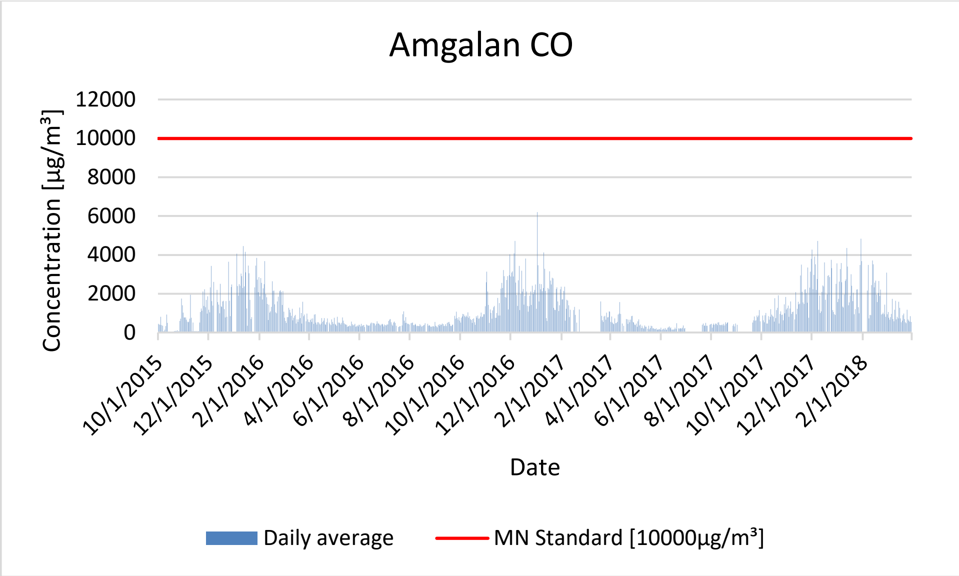

Nisekh-O3
Concentration [µg/m³]
120
100
80
60
40
20
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MNS, WHO Standard [100µg/m³]

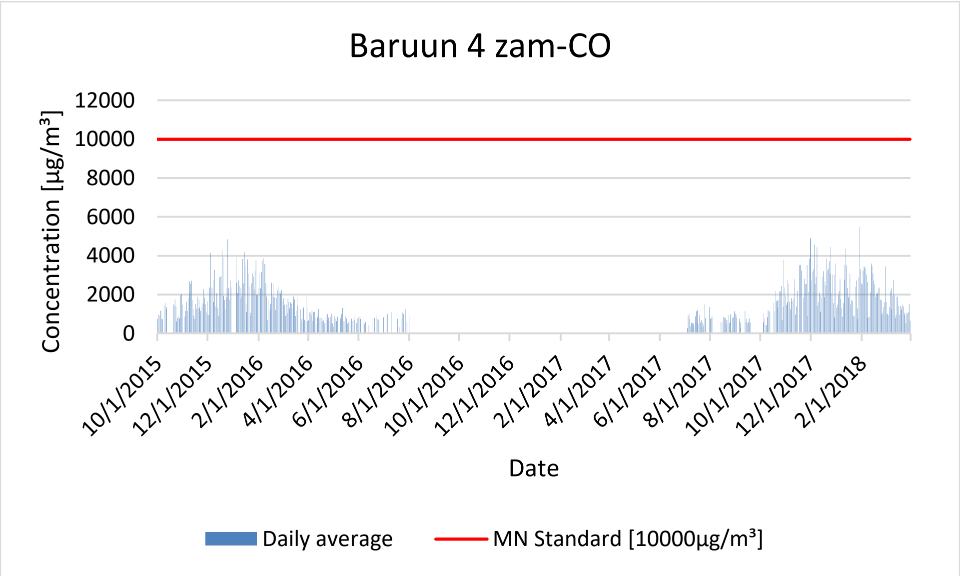

Tolgoit-O3
Concentration [µg/m³]
140
120
100
80
60
40
20
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MNS, WHO Standard [100µg/m³]

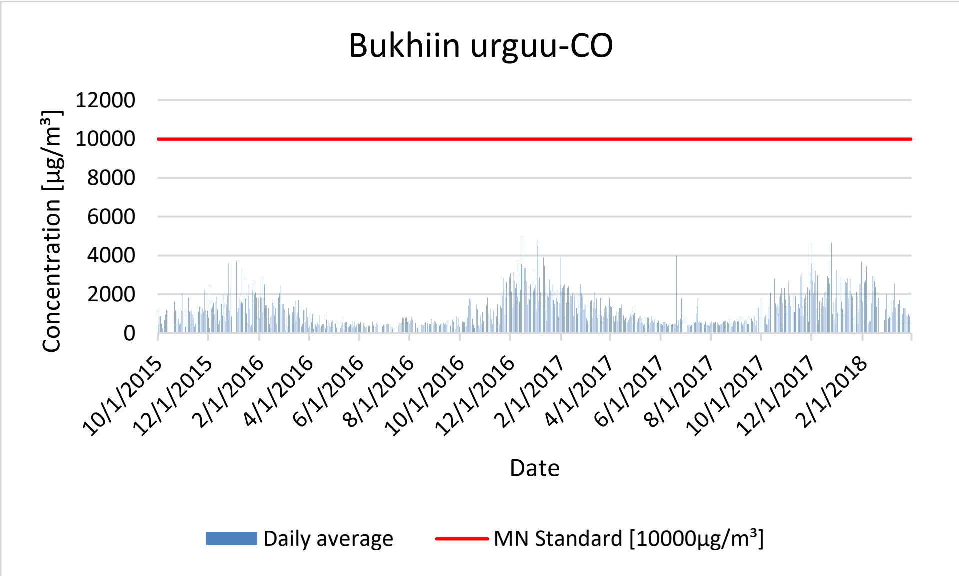

Urgakh naran-O3
Concentration [µg/m³]
120
100
80
60
40
20
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MNS, WHO Standard [100µg/m³]

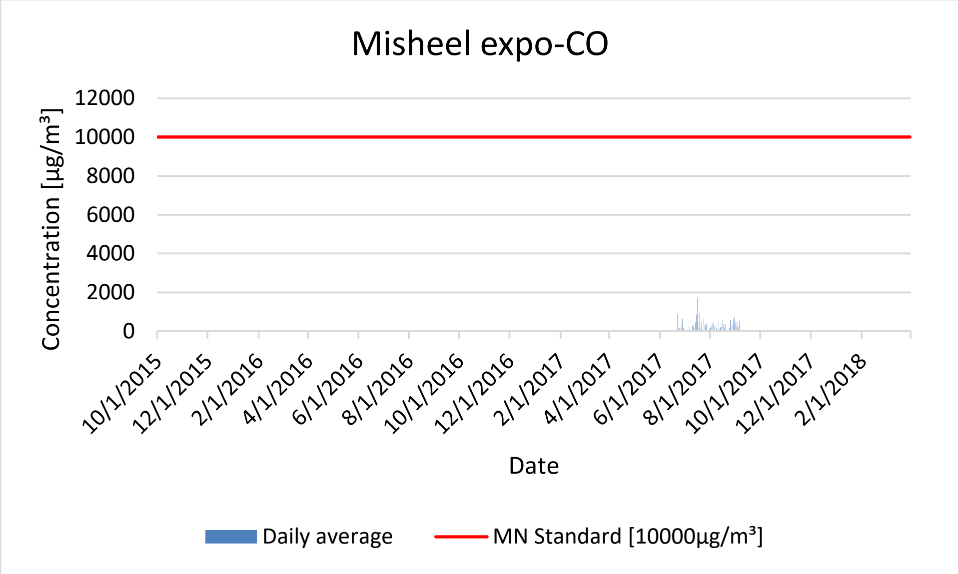
Appendix 12. Daily average CO concentration levels at each station for October 2015-March 2018

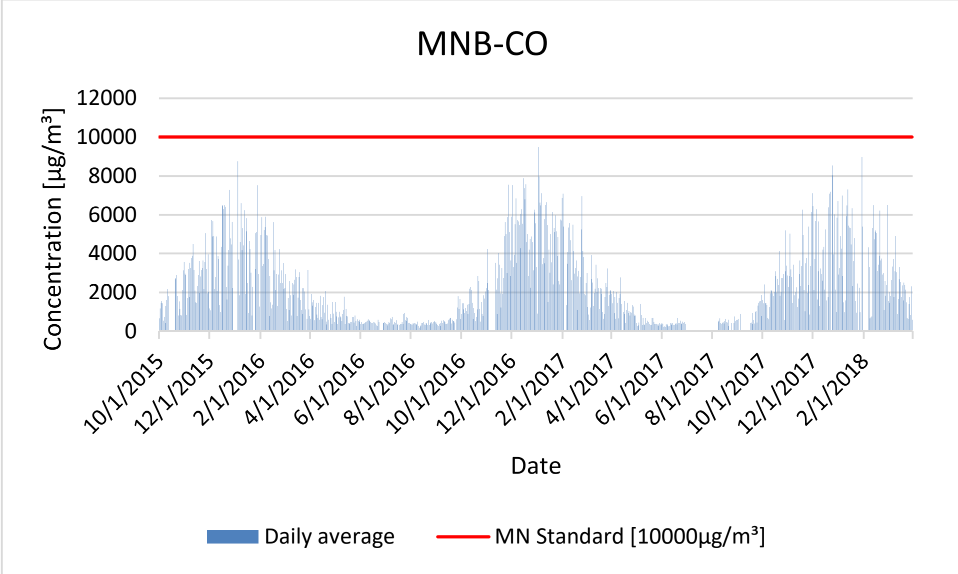


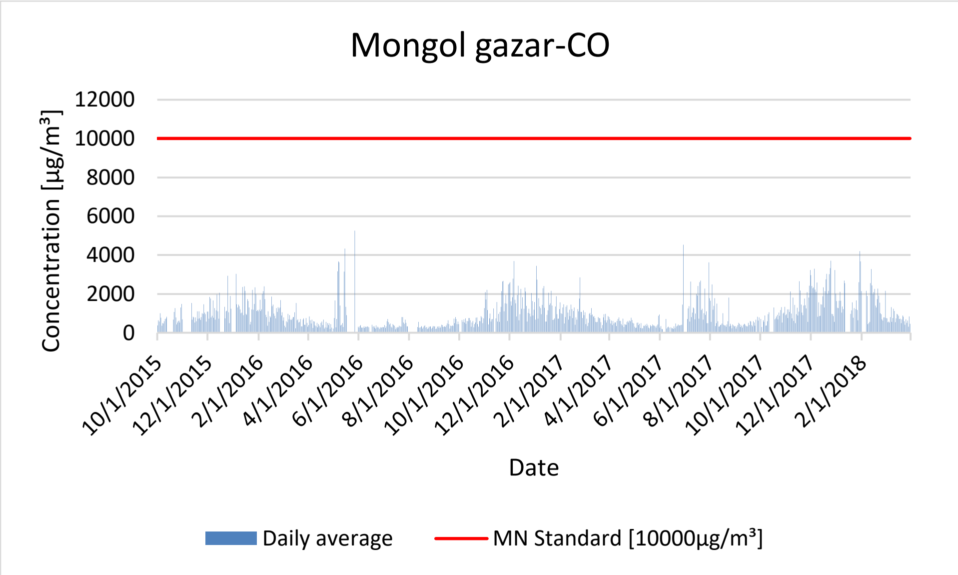


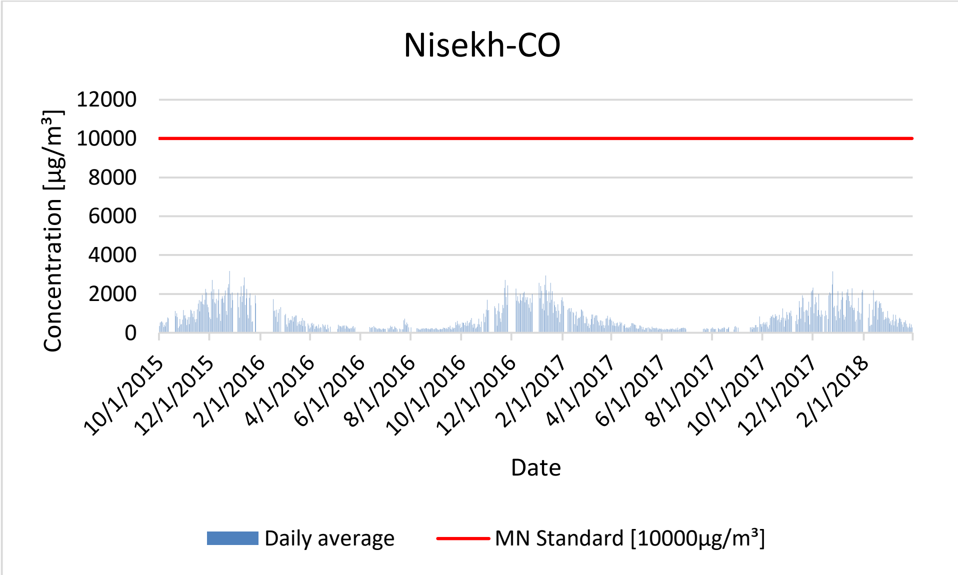


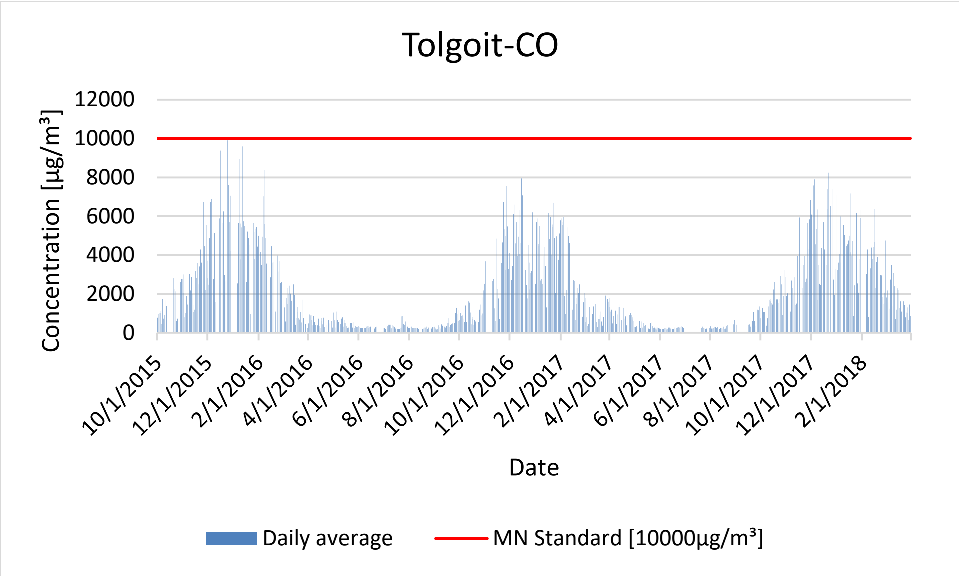


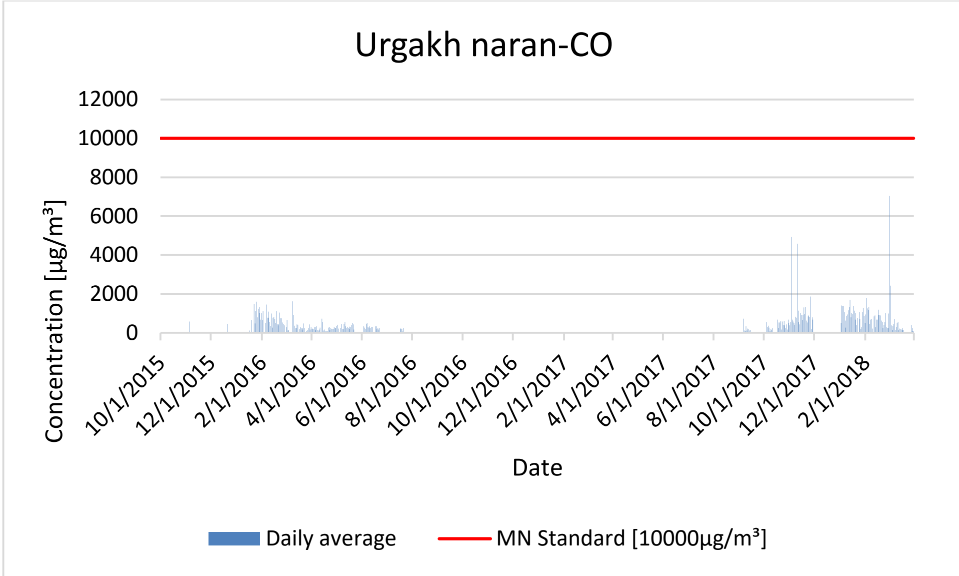

Misheel expo-CO
Concentration [µg/m³]
12000
10000
8000
6000
4000
2000
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [10000µg/m³]


MNB-CO
Concentration [µg/m³]
12000
10000
8000
6000
4000
2000
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [10000µg/m³]


Mongol gazar-CO
Concentration [µg/m³]
12000
10000
8000
6000
4000
2000
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [10000µg/m³]


Nisekh-CO
Concentration [µg/m³]
12000
10000
8000
6000
4000
2000
0
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [10000µg/m³]


Tolgoit-CO
12000
10000
8000
6000
4000
2000
0
Concentration [µg/m³]
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [10000µg/m³]


Urgakh naran-CO
12000
10000
8000
6000
4000
2000
0
Concentration [µg/m³]
10/1/2015
12/1/2015
2/1/2016
4/1/2016
6/1/2016
8/1/2016
10/1/2016
12/1/2016
2/1/2017
4/1/2017
6/1/2017
8/1/2017
10/1/2017
12/1/2017
2/1/2018
Date
Daily average
MN Standard [10000µg/m³]

Appendix 13. OpenAQ and NAMEM data

		PM10, Difference=NAMEM-OPENAQ [μg/m³]												
		Locations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2016	UB1	**Misheel expo**	-6	1	1	0	1	2	2	0	0	-5	-9	0
	UB2	**Baruun 4 zam**		3	-2	-1	-2	3	-8	-10	-18	20	-1	3
	UB4	**Bukhiin urgoo**	-14	6	2	0	0	13	-6	-6	-7	-1	-12	-4
	UB5	**100 ail**	-227	6	1	0	0	0	0	-11	-3	1	-9	-15
	UB7	**Mongol gazar**	-14	1	5	-1	-16	-1		-5	-2	-2	-8	-6
	UB8	**Urgakh naran**	6	2	4	1	3	6	0	0	0	-4	-4	-2
	APRD4	**Nisekh**	1	2	0	-2	1	0	-6	-1	0	-6	-20	-5
	APRD1	**Tolgoit**	-9	-19	0	1	-3	15	0	-2	1	-3	-40	1
	APRD2	**MNB**	-8	4	0	-1	-1	18	0	1	1	-2	-21	0
	APRD3	**Amgalan**	0	0	2	-2	-2	7	24	-5	-2	-1	-1	2
2017	UB1	**Misheel expo**	-4	-1	1	0	2	4	1	-35	0	5	-2	-3
	UB2	**Baruun 4 zam**	-3	4	1	0	-1	4	0	-1	-1	-2	-9	-27
	UB4	**Bukhiin urguu**	-1	0	-1	-1	0	6	-1		0	-2	-7	-2
	UB5	**100 ail**	-12	-14	-2	-2	-1	22	-70	3	-9	-6	4	-14
	UB7	**Mongol gazar**	3	0	6	0	-5	7	0	0	-1	6	-12	8
	UB8	**Urgakh naran**	0	-1	0	0	0	12	-16	-2	-2	-5	-2	116
	APRD4	**Nisekh**	0	1	0	2	2	0	11	-3	-8	-12	-7	17
	APRD1	**Tolgoit**	0	10	3	-12	-1	9	34	-16	-8	-14	4	11
	APRD2	**MNB**	2	13	1	1	-1	3	15	4	-7	-32	-4	-8
	APRD3	**Amgalan**	-1	-2	0	-7	8	6	22	-4	-7	0	-7	3
	APRD5	**Bayankhoshuu**	-24	18	-1	0	-6	-39	13	0	1	-45	-2	-2

		PM2.5, Difference=NAMEM-OPENAQ [μg/m³]												
		Locations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2016	UB2	**Baruun 4 zam**	-13	1	1	1	1	5	-2	-4	-2	-3	-5	2
	UB4	**Bukhiin urgoo**	-13	6	2	1	1	1	-6	-1	-2	0	-9	-2
	APRD4	**Nisekh**	0	-1	0	1	0	1	1	0	0	-3	-19	-5
	APRD1	**Tolgoit**	-9	-22	1	1	0	4	-1	-1	0	-2	-36	2
	APRD2	**MNB**	-8	3	4	0	0	3	0	0	1	-1	-18	0
	APRD3	**Amgalan**	0	-2	1	0	0	2	11	-1	0	-1	0	1
2017	UB2	**Baruun 4 zam**	-19	4	1	0	-1	0	-2	-3	-2	-21	-15	-17
	UB4	**Bukhiin urgoo**	2	0	1	1	1	-1	0	0	0	5	-4	2
	APRD4	**Nisekh**	-1	1	0	1	0	0	4	-1	-3	-4	-4	17
	APRD1	**Tolgoit**	0	9	3	-3	0	1	7	0	-4	-7	6	11
	APRD2	**MNB**	2	12	1	1	0	0	7	1	-4	-12	-2	-7
	APRD3	**Amgalan**	0	0	79	-1	1	0	8	1	-6	-1	-4	3
	APRD5	**Bayankhoshuu**	-24	18	85	0	-1	-4	2	0	-5	-20	-17	-1