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Project Final Report: Sulfur isotopic approach on sources and production of urban atmospheric particulate matters in East Asia

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1. Summary

Many cities in East Asian countries suffer severe haze pollution due to rapid urbanisation, industrialising, and increasing population. Recent research shows that PM2.5 composition in Ulaanbaatar (UB) and Beijing is highly affected by coal combustion sources, which contribute to local and regional atmospheric pollution. Besides, there are many unidentified sources, which become an obstacle to haze pollution mitigation.

The main objective of this study is to assess the source contributions of PM2.5 based on approaches of isotopes and other components in PM2.5 collected at Ulaanbaatar and Beijing. We performed intensive PM2.5 sampling from Ulaanbaatar and Beijing and adopted a sample pre-treatment method for isotope analyses. Then, the analytical conditions of the N isotopes were optimised. Daily PM2.5 sampling was conducted for two weeks each season, and the chemical components of PM2.5 (ions, carbonaceous compounds, trace elements) and N isotopes in nitrate were analysed. Regional and seasonal characteristics of the chemical components of PM2.5 were clarified. Primary sources are distinguished coupling chemical components, N isotopes and simulations. Finally, N isotopes (14N and 15N) of nitrate in PM2.5 aerosols are discussed to understand better the sources and formation of nitrate, which can be crucial for improving the air quality in East Asia.

Modelling secondary organic aerosol (SOA) has remained a significant challenge due to the various precursors and complex processes. In this study, the WRF-CAMx model was also used to predict the ambient SOA concentrations in urban Beijing and the North China Plain (NCP) during a polluted period in winter. Both the volatility basis set (VBS) approach and the two-product approach (SOAP) were used for SOA simulation. Although the modelled SOA was underpredicted compared with the SOA estimated by the OC/EC method, the VBS scheme produced higher SOA than the traditional two-product scheme. According to the sensitivity tests with the VBS scheme, the emissions of volatile organic compounds (VOC), intermediate volatility organic compounds (IVOC), and oxidant levels were the key factors that affected SOA prediction.

In comparison, the predicted SOA was less affected by primary organic aerosol (POA) emission and chemical aging during the wintertime. The potential contributions from different anthropogenic sources and source areas were also identified using the brute-force method. Over 80% of SOA in urban Beijing resulted from regional transport of SOA or its precursors from the surrounding areas during the polluted period. Residential emissions in the North China Plain appeared as the dominant source of SOA in urban Beijing from the perspective of regional contribution.

During the cold season, the air pollution level in Ulaanbaatar, the capital of Mongolia, is frequently ranked as the highest in the world. However, due to the lack of air quality management, the country is suffering from a deterioration of air quality. Despite the worse air pollution situation, due to the insufficient research capacity of the country, to date, research works on characteristics of air pollution have mainly been based on current capability and/or collaboration with foreign institutes. The research gap in this area necessitates numerous investigations, which could have great importance in developing mitigating strategies and

minimising the adverse impact of air pollution on local and regional scales. We reviewed previously available studies and reports in international scientific journals on air quality in Mongolia. Based on the current research works, future needs of studies on ambient air pollution in Mongolia are suggested.

2. Objectives

The project aims to investigate the emission characteristics, distributions, and sources of atmospheric particulate matter in major cities of Mongolia and China (Ulaanbaatar and Beijing). Through the analyses of ions, carbonaceous compounds, trace elements and stable isotopes of atmospheric particulate matter, the specific objectives are:

i) To enhance the capability of early career researchers to set up isotope geochemical and model studies on atmospheric chemistry.
ii) To assess the transboundary air pollution mechanism between Mongolia and China by chemical and isotopic analyses and to identify the emission sources, transport and impacts of air pollutants on ambient air.
iii) To suggest pollution control strategies and policies via science-policy interactions and scientific publications.

3. Outputs, Outcomes and Impacts

Outputs	Outcomes	Impacts
Installed laboratory facilities for aerosol analyses at the National University of Mongolia	More laboratory capacity to perform aerosol chemistry research	Improve higher education quality in Mongolia
Developed methods for aerosol sampling, pre-treatment, and analyses	More accurate and precise analyses of the chemical composition of PM	Improve the quality of life in individuals through research result
Distinguished major sources of nitrate in PM2.5	More knowledge in nitrate sources for Ulaanbaatar and Beijing	Reduction of air pollutants emission
Predicted concentrations of secondary organic aerosols in Urban Beijing and North China plain	More knowledge sources secondary organic aerosols in Urban Beijing and North China plain	Slowing of climate change
Reviewed previously studies and suggested future needs of studies on ambient air pollution in Mongolia	Clear information of current knowledge and needs of studies	Improve achievement of air pollution measures

4. Key facts/figures

- Six laboratory basic equipment and analytical instruments were installed
- A standard method for PM sampling, preparation, pre-treatment and analyses for ionic and metal composition is tested in a lab at the National University of Mongolia (1 laboratory standard protocol)
- Two early-career professionals trained
- Three peer-reviewed publications: published (1); submitted (1); in preparation (1)
- Three events: workshops (2); training event (1)

5. Publications

Papers

Soyol-Erdene, T. O., Ganbat, G., & Baldorj, B. (2021). Urban Air Quality Studies in Mongolia: Pollution Characteristics and Future Research Needs. Aerosol and Air Quality Research, 21(12), 210163. doi: 10.4209/aaqr.210163

Dambajamts, N., Ulziibat, B., Natsagdorj, A., Tuuguu, E., Altantsetseg, D., B. Baldorj, & Soyol-Erdene, T.O. (2021). Chemical compositions of fine aerosols (PM2.5) in Ulaanbaatar, Mongolia. Issues of Mongolian Geography and Geoecology 42. (In Mongolian).

Zhang, Y., Huang, H., Qin, W., Yu, Q., Cheng, S., Ahmad, M., Ouyang, W., Soyol-Erdene, T.O. & Chen, J. (2022). Modelling of wintertime regional formation of secondary organic aerosols around Beijing: sensitivity analysis and anthropogenic contributions Carbon Research. (*under review*).

Ke Xi, Jing Chen, Tseren-Ochir Soyol-Erdene, Weihua Qin, Siming Cheng, Yuewei Sun, Qing Yu, Jing Ai, Ulziibat Bilguun, Narmandakh Dambajamts. Formation mechanism and source apportionment of nitrate in PM2.5 in Ulaanbaatar and Beijing: comparing results between Bayesian Isotopic Mixing Model and Positive Matrix Factorization Model. *(In prep).*

Presentations

Natsagdorj, A., Soyol-Erdene, T.O., Lee, Y., & Tugsbayan, B. (October 2021). Seasonal Variations of Aerosol Composition and Sources of PM2.5 in Ulaanbaatar, Mongolia, Meeting of Korean Society for Atmospheric Environment.

Dambajamts, N., Ulziibat, B., Tuuguu, E., Natsagdorj, A., Daichaa, D., Altantsetseg, D. & Soyol-Erdene, T.O. (October 14, 2021). Chemical compositions of fine aerosols (PM2.5) in Ulaanbaatar, Mongolia. 5th International Conference on Chemical Investigation and Utilisation of Natural Resources, Ulaanbaatar, Mongolia.

6. Media reports, videos and other digital content

Not available

7. Pull quotes

I did my master's thesis work on this project. I learned many things about air pollution issues in Northeast Asia. The project grant gave me an excellent opportunity to make my master's thesis successfully - D. Narmandakh (Masters's Degree student)

8. Acknowledgments

We thank the researchers at the Central Laboratory of Environmental Monitoring, National Agency of Meteorology and Environmental Monitoring, Mongolia, for supporting part of the sampling.

9. Appendices

Appendix 1. PM sampling and treatment protocol

Appendix 2. Abstract of domestic conference (paper title: *Sources and chemical composition of atmospheric fine particulate matter in Ulaanbaatar, Mongolia*)

Appendix 3. Domestic paper (paper title: *Chemical composition of atmospheric fine particulates (PM2.5) in Ulaanbaatar, Mongolia*)

Appendix 4. SCI paper

Appendix 5. Manuscript SCI paper (in preparation)

Appendix 6. Manuscript SCI paper (under review)

Appendix 7. Abstract of international conference

Appendix 1. PM sampling and treatment protocol

ОРЧНЫ АГААРААС НАРИЙН ШИРХЭГЛЭЛТ ТООСОНЦРЫН СОРЬЦ ЦУГЛУУЛАХ, СОРЬЦЫГ ХАДГАЛАХ, ШИНЖИЛГЭЭНД БЭЛТГЭХ СТАНДАРТ АЖЛЫН ЗААВАР

Хүрээлэн буй орчны хими, геохимийн лаборатори	**Тодорхойлох үзүүлэлт**	**Шинэчлэгдсэн дугаар**	**Огноо**	**Сорил туршилтын аргын НТББ**
	PM2.5 масс агууламж Органик бохирдуулагчид (ПАН) Металл Уусдаг органик биш ионууд	01	2020.10.21	ISO16362 USEPA13A USEPA I.O. 3.1

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ОРЧНЫ АГААРААС НАРИЙН ШИРХЭГЛЭЛТ ТООСОНЦРЫН СОРЬЦ ЦУГЛУУЛАХ, СОРЬЦЫГ ХАДГАЛАХ, ШИНЖИЛГЭЭНД БЭЛТГЭХ СТАНДАРТ АЖЛЫН ЗААВАР

Хүрээлэн буй орчны хими, геохимийн лаборатори	Тодорхойлох элемент	Шинэчлэгдсэн дугаар	Огноо	Сорил туршилтын аргын НТББ
	PM2.5 масс агууламж Органик бохирдуулагчид (ПАН) Металл Уусдаг органик биш ионууд	01	2020.10.21	ISO16362 USEPA13A USEPA I.O. 3.1

Хамрах хүрээ: Энэ арга нь агаар дахь тоосонцрын сорьц цуглуулах, тоосонцорт агуулагдах уусдаг ионууд, хүнд металлууд, органик бохирдуулагчид (олон цагирагт үнэрт нүүрсустөрөгчид)-ын агууламжийг тодорхойлоход зориулж усан ханд бэлтгэх, бичил болгионы зууханд хүчлээр хандлах, органик уусгагчаар хандлах үйл явцад хамаарна.

1. ОРЧНЫ АГААРААС ИХ ЭЗЭЛХҮҮНТЭЙ СОРЬЦ АВАГЧ АШИГЛАН НАРИЙН ШИРХЭГЛЭЛТ ТООСОНЦОР (PM2.5)-ЫН СОРЬЦ ЦУГЛУУЛАХ АРГА

Аргын зарчим: Агаарыг насосоор тодорхой хурдтайгаар соруулан, фильтр дундуур нэвтрүүлж тоосонцрыг фильтрийн цаасанд тогтоон барихад үндэслэнэ. Хоосон ба сорьцтой фильтрийн жингийн зөрүү, сорсон агаарын эзэлхүүнд үндэслэж агаар дахь тоосонцрын агууламжийг тооцоолно.

Саад болох хүчин зүйлс: Агаарын тоосонцрыг аэродинамик диамертээр ялган сорьцлоход ялгагч чухал үүрэгтэй тул ялгагч зөв ажиллаж буй эсэхийг тогтмол хянах хэрэгтэй. Агаарын бохирдуулагчдын (тоосонцрын болон түүнд агуулагдах химийн бүрэлдэхүүний) агууламжийг тоуоооход сорьцолсон агаарын эзэлхүүн чухал тул агаар сорогчийн хурд тогтмол бөгөөд зөв хэмжигдэж байх шаардлагатай.

1.1 Хэрэглэгдэх материал, урвалжууд

- Сорьц авах филтьр
- Хямсаа
- Бээлий
- Сорьцын гэр (мөнгөлөг цаас)
- Сорьц тээвэрлэх хайрцаг
- Сорьц хадгалах хайрцаг

1.2 Тоног төхөөрөмж

- Электрон жин

- Шатаах зуух
- Десикатор (Хавсралт 1, Зураг 1)
- Их эзэлхүүнт сорьц авагч (Хавсралт 1, Зураг 2)

1.3 Фильтрийг сорьц авахад бэлдэх, жинлэх

- Шинжилгээнд тохирсон материалтай фильтрийг сонгоно (Хавсралт 2).
- Бүх төрлийн фильтрүүдийг ашиглан сорьц авахын тулд урьдчилсан боловсруулж бэлтгэх шаардлагатай байдаг. Үүнд: массын хэмжилтэд чийгийн нөлөөллийг арилгахын тулд фильтрийг нөхцөлжүүлэх үйл ажиллагаа, кварц фильтрт шингэсэн байж болзошгүй органик уурыг арилгахад урьдчилан жигнэх үйл ажиллагаанууд хамаарна.

1.3.1 ***Фильтрийг нөхцөлжүүлэх/filter conditioning/***

- Фильтрт цугларсан тоосонцрын масс агууламжийг тодорхойлохын тулд сорьц авахын өмнө болон сорьц авсны дараа температур чийгийн хяналттай орчинд фильтрийг өндөр нарийвчлалтайгаар жинлэх шаардлагатай байдаг. Тоосонцрыг хэмжих стандарт аргачлалын дагуу тогтмол температур (20°C ~ 23°C) ± 2°C чийгшилтэй (30% ~ 40%) ± 5% орчинд 24-48 цагийн турш нөхцөлжүүлэх шаардлагатай гэж үздэг. Энэ нь сорьц дахь ууршимтгай нэгдлүүдийн алдагдлыг багасгах болон усны уурын нөлөөллийг багасгах зорилготой юм. Сорьц авахад ашиглах шинэ фильтрийг зориулалтын саванд хийж (савны тагийг нээж фильтрийн орчим агаар чөлөөтэй сэлгэж байхаар байрлуулна) тоосгүй орчинд нөхцөлжүүлнэ. Фильтрийн нөхцөлжүүлэх хугацаанд савны тагийг хагас нээлттэй байлгана. Энэ үйл ажиллагааны үед хөндлөнгийн нөлөөлөлд өртсөн эсэхийг тогтоохын тул лабораторийн бланк фильтрийг ашиглана.

1.3.2 ***Кварц фильтрийг хатаах/filter baking/***

- Кварц материалаар хийгдсэн фильтр нь органик уурыг үргэлж шингээж байдаг. Иймд фильтр шингэсэн органик уурыг арилгахын тулд хэмжилтэнд ашиглахын өмнө шатаах зууханд 550℃ температурт 4 цагийн турш шатаана. Хатаасан/жигнэсэн фильтрүүдийг органик уур дахин шингээхээс сэргийлж мөнгөлөг цаасаар доторлосон зориулалтын саванд хийж тагийг сайтар битүүмжлэн сорьц авах хүртэл хөргөгчинд хадгална.

1.4 Фильтрийг жинлэх

- Жинг чичиргээ доргион, агаарын урсгалаас сайтар тусгаарласан, мөн лабораторийн өөрийн агаараас тоос тоосонцор, хий шинжилж буй фильтр нөлөөлөхгүй байх нөхцөлийг бүрдүүлсэн байдаг.
- Жингийн аргаар фильтрийн массыг тодорхойлох ажилд саад бологч хүчин зүйл нь статик цэнэгийн нөлөөлөл байдаг. Фильтр дээрх үлдэгдэл цэнэг нь статик цэнэг үүсгэж жингийн металл хэсгүүдтэй үйлчлэлцсэнээр хүндийн хүчний бус нөлөөллийг үүсгэдэг. Иймд фильтрийг жинлэхийн өмнө статик цэнэг арилгагч ашиглаж хэмжлийн алдааг багасгана.
- Фильтрийг электрон жин дээр 3 удаа жигнэж, жинг тэмдэглэж авна. Тооцоонд дундаж утга ашиглана.

1.5 Сорьц авах

- Сорьц цуглуулах фильтр бүрийг лабораторид шошголж, хямсаа ашиглан тохирох фильтрийн гэрэнд байрлуулна. Шошго бүрэн, тод, зөв хийгдсэн эсэхийг шалгана.
- Агаар нэвтрэхгүй саванд (хайрцагт) байрлуулж сорьц авах газар руу аваачина.
- Сорьц авах цэг дээр фильтрийг гэрнээс гаргаж, сорох хоолойтой холбогдсон сорьц авагчийн толгойд хийж бэхэлнэ.
- Зорилгоос хамаарч сорьц авах хугацааг 1-ээс 24 цаг хүртэл тохируулна.
- Сорогч насос болон хугацаа хэмжигчийг ажиллуулна.
- Хэрэв урсгал хянах төхөөрөмжийг нийт эзэлхүүн хэмжигчтэй хослуулан хэрэглэвэл сорьцийн эзэлхүүнийг сорьц авах хугацааны эхэн ба төгсгөлд эзэлхүүний тоолуурын заалтын зөрүүгээр гаргана.
- Хэрэв урсгал хянах төхөөрөмжийг урсгалын хурдыг хэмжих төхөөрөмжтэй хослуулсан бол сорьцийн эзэлхүүнийг дундаж урсгалын хурд (хэмжилтийн хугацааны эхэн ба төгсгөлд хамгийн багадаа урсгалын хурднаас тооцоолно) ба сорьцилсэн хугацаанаас тооцоолно.
- Сорьц авах хугацааны эхэн ба төгсгөлд урсгал хэмжих төхөөрөмжийн ажиллагааг шалгахын тулд урсгалын хурд хэмжигч төхөөрөмжийг ашиглах хэрэгтэй.
- Сорьц авсны дараа насосыг унтраана.
- Сорьц авагчийн толгойноос фильтртэй фильтр тогтоогчийг гаргаж авна.
- Сорьц бүхий фильтрийг мөнгөлөг цаасан гэрэнд буцаан хийж, агаар нэвтрэхгүй тээвэрлэх саванд (тээвэрлэх хайрцагт) байрлуулан, сорьц бүхий талыг дээш харуулан тээвэрлэнэ.
- Тээвэрлэх сав (хайрцаг) -ыг хэвтээ байдлаар тээвэрлэх хэрэгтэй.
- Лабораторид ирсний дараа сорьц бүхий фильтрийг гэрнээс хямсаа ашиглан гаргана.

1.6 Сорьц бүхий фильтрийг хадгалах, жинлэх

- Сорьц авсан фильтрийн тоос хуримтлагдсан талыг дээш харуулан зориулалтын саванд хийж жинлэх хүртэл лабораторийн хөргөгчинд (4°C) хадгалж болно. Дэгдэмхий органик бохирдуулагч (ПАН зэрэг) тодорхойлох бол сорьцийг -20ºC-ээс бага температурт хадгална.
- Сорьц бүхий савны тагийг нээхээс өмнө тасалгааны температурт 1-2 минут байлгах хэрэгтэй. Учир нь тагийг шууд нээвэл хөргөгчнөөс гарч ирсэн хүйтэн фильтр дээр усны уур конденсацлагдах сөрөг нөлөөтэй байдаг.
- Сорьц авснаас хойш нэг жилийн дотор шинжилгээ хийнэ.
- Сорьцын 10-аас доошгүй хувьд, эсвэл тухайн цэгт 10-аас цөөн сорьц авсан бол багадаа нэг ширхэг хоосон (бланк) сорьц авна. Бланк сорьцийн фильтрийн сорьцтой адил нөхцөлжүүлнэ.
- Сорьц бүхий фильтрийг жинлэхийн өмнө мөн өмнөхтэй ижил нөхцөлд нөхцөлжүүлэх ба савны тагийг нээхээс өмнө тасалгааны температурт 1-2 минут байлгах хэрэгтэй. Учир нь тагийг шууд нээвэл хөргөгчнөөс гарч ирсэн хүйтэн фильтр дээр усны уур конденсацлагдах сөрөг нөлөөтэй байдаг.

- Сорьц бүхий фильтрийг электрон жин дээр 3 удаа жигнэж, жинг тэмдэглэж авна. Тооцоонд дундаж утга ашиглана.

Фильтртэй ажиллах

- Фильтртэй зөвхөн зориулалтын хуруувч эсвэл винил (нунтаггүй)-ийн бээлийтэй ажиллана. Энэ журмыг хээрийн сорьцлолтийн үед болон жингийн өрөөнд заавал мөрдөнө.
- Фильтр дэх сорьцонд металлын шинжилгээ хийх бол металл хямсаа ашиглахаас зайлсхийнэ. Бээлийтэй хуруугаар эсвэл ямар нэгэн төрлийн хямсаагаар фильтртэй ажиллах тохиолдолд сорьц цугларсан хэсэгт хүрэхээс зайлсхийнэ.

1.7 Масс агууламжийг тодорхойлох

Тоосонцрын масс агууламжийг дараах байдлаар тооцоолно.

$$C = \frac{(M_2 - M_1) - (B_2 - B_1)}{Vo}, \quad мг/м^3$$

- Энд С- тоос, тоосонцрын масс агууламж, мг/м3
- M_2- тоос цуглуулсны дараах фильтрийн жин, мг
- M_1- тоос цуглуулахын өмнөх фильтрийн жин, мг
- B_2- тоос цуглуулсан фильтрийг жигнэх үеийн бланк фильтрийн жин, мг
- B_1- тоос цуглуулах фильтрийн жигнэх үеийн бланк фильтрийн жин, мг
- V_o- Хэвийн нөхцөлд шилжүүлсэн соруулсан агаарын нийт эзэлхүүн, $м^3$

Тоос тоосонцрын масс агууламжийг тодорхойлсоны дараа сорьц бүхий фильтрт бусад химийн задлан шинжилгээг хийж болно.

2. АГААРЫН ТООСОНЦОРТ ОЛОН ЦАГИРАГТ ҮНЭРТ НҮҮРСУСТӨРӨГЧИД ТОДОРХОЙЛОХОД ЗОРИУЛЖ СОРЬЦЫГ ХАНДЛАХ АРГА

2.1. Уусгагчид

Ул мөрийн төдий агуулагдах бодисын шинжилгээнд хэрэглэгддэг өндөр цэвэршилттэй толуол, циклогексан, дихлорметан, ацетонитрил зэрэг уусгагчдыг ашиглана.

2.2. Хандлалт

Сорьцыг дараах аргуудаар хандална:

- Нэрлэгийн хандлалт
- Сосклетын хандлалт
- Түргэсгэсэн уусгагчийн хандлалт
- Ультрасоник чичиргээн хандлалт
- Богино долгионы хандлалт

Эдгээр аргуудын талаар доор тайлбарлав.

Дээрхи аргууд бүгд агаарын тоосонцорт агуулагдах олон цагирагт үнэрт нүүрстөрөгч болон бусад бодисыг органик уусгагчид уусгана. Хэрэв хандын эцсийн эзэлхүүн мэдэгдэж байгаа бөгөөд нэмэлт цэвэрлэх шат шаардлагагүй тохиолдолд масс детектортой хийн хроматограф (GC-MS) багаж ашиглан шинжилгээг шууд хийж болно. Флюресценц детектортой шингэний хроматограф багаж ашиглах бол хандыг хуурай болтол ууршуулж, тодорхой эзэлхүүнтэй ацетонитрил уусгагчид уусгана. Шаардлагатай бол хандыг концентрацижуулахаас өмнө цэвэрлэнэ. Хандад шууд шинжилгээ хийхгүй үед уусгагч уурших, бодис задралд орохоос сэргийлж 6ºC-аас бага харанхуй орчинд нэг сар хүртэл хугацаагаар хадгалж болно.

Энэхүү хандлалтын аргууд EN 15549, EN 15890 стандарт аргаар лабораторын болон хөндлөнгийн баталгаажуулалт хийгдсэн.

Хандлалтын явагдсаны дараа уусмалд фильтрийн болон тоосонцрын жижиг хэсгүүд байвал хандыг зохих фильтр (уусгагчаар урьдчилан угаасан шилэн хөвөн фильтр) - ээр шүүх шаардлагатай. Шүүх явцад гарах алдагдлаас сэргийлж хэрэглэгдэж байгаа материалыг уусгагчаар хангалттай зайлна.

Нэрлэгийн хандлалт:

Фильтрийг жижиг хэсгүүдэд хуваан, хайчилна. Фильтрийн хэсгүүдийг нэрлэгийн аппаратын доод колбонд байрлуулна. 7 мл толуол нэмж, хандлалтыг нэг цаг явуулна. Хөргөсний дараа хандыг пастерын пипитка ашиглан хуруу шилэнд шилжүүлнэ. Хандлалтын колбыг ойролцоогоор 3 мл орчим толуолоор гурван удаа зайлж, зайлсан уусмалуудыг ханд дээр нэмнэ. Масс спектрофотометр детектортой хийн хроматограф багажаар шинжлэх тохиолдолд хандыг цэвэр азотын зөөлөн урсгалд ойролцоогоор 1 мл хүртэл концентрацижуулна. Флюресценц детектортой шингэний хроматограф багажаар

шинжлэх тохиолдолд хандыг хуурай болтол болгоомжтой ууршуулж, үлдэгдлийг 1 мл эзэлхүүнтэй ацетонитрил уусгагчид уусгана.

Сокслет хандлалт:

Уусгагчаар угаасан хямсаа ашиглан фильтрийг сокслетын аппаратад байршуулна. Фильтрийг 200 мл орчим толуолоор хамгийн багадаа 20 цаг хандлана. Сорьцонд шууд гэрэл тусах, аппаратыг дулаан байлгаж хандлагийн циклийн цагийг багасгах зорилгоор аппаратыг мөнгөлөг цаасаар бүрнэ. Уусгагч хөрсөний дараа аппаратыг салгана. Үлдэгдэл уусгагчийг бөөрөнхий ёроолтой колбонд хийн, хадгална. Масс спектрофотометр детектортой хийн хроматограф багажаар шинжлэх тохиолдолд хандыг цэвэр азотын зөөлөн урсгалд ойролцоогоор 1 мл хүртэл концентрацижуулна. Флюресценц детектортой шингэний хроматограф багажаар шинжлэх тохиолдолд хандыг хуурай болтол болгоомжтой ууршуулж, үлдэгдлийг 1 мл эзэлхүүнтэй ацетонитрил уусгагчид уусгана.

Богино долгионы хандлалт:

Хандлалтыг богино долгионы задаргааны зуухыг ашиглан явуулна. Хандлалтыг зохистой явуулахын тулд үйлдвэрлэгчээс гаргасан багажны зааврыг мөрдөж ажиллана. Фильтрийг тефлон (политетрафторэтилен - PTFE) саванд хийж, 15 мл уусгагч нэмнэ. Хандлалтын дараа, сорьцтой тефлон савыг онгойлгохоос өмнө өрөөний температур хүртэл хөргөнө. Масс спектрофотометр детектортой хийн хроматограф багажаар шинжлэх тохиолдолд хандыг цэвэр азотын зөөлөн урсгалд ойролцоогоор 1 мл хүртэл концентрацижуулна. Флюресценц детектортой шингэний хроматограф багажаар шинжлэх тохиолдолд хандыг хуурай болтол болгоомжтой ууршуулж, үлдэгдлийг 1 мл эзэлхүүнтэй ацетонитрил уусгагчид уусгана.

Хандлалтыг 400 В-д 20 минутын турш явуулна (8 сав).

Түргэсгэсэн уусгагчийн хандлалт:

:Хандлалтыг зохистой явуулахын тулд үйлдвэрлэгчээс гаргасан багажны зааврыг мөрдөж ажиллана. Уусгагчийн хэмжээг багасгахын тулд элс хэрэглэж болно. Фильтрийг хандлалтын камерт (extraction cell) байршуулж 120ºС, 140 бар даралтад 5 минутын турш хандлана. Хандлалтыг гурван удаа явуулна. Үлдэгдэл хандууд автоматаар нэмэгдэнэ. Масс спектрофотометр детектортой хийн хроматограф багажаар шинжлэх тохиолдолд хандыг цэвэр азотын зөөлөн урсгалд ойролцоогоор 1 мл хүртэл концентрацижуулна. Флюресценц детектортой шингэний хроматограф багажаар шинжлэх тохиолдолд хандыг хуурай болтол болгоомжтой ууршуулж, үлдэгдлийг 1 мл эзэлхүүнтэй ацетонитрил уусгагчид уусгана.

Ультрасоник хандлалт:

Фильтрийг жижиг хэсгүүдэд хуваан, хий алдахгүй таглаатай шил саван байршуулна. Фильтрийн хэсгүүдэд 5 мл уусгагч нэмж, таглана. 10ºС-д 15 минутын турш ультросоник баннд хандлана. Хандыг дээр дурьдсан аргачлалын дагуу шүүнэ. Фильтрийг үлдэгдлийг дахин хоёр удаа хандлана. Шүүсэн гурван хандыг нийлүүлнэ. Масс спектрофотометр

детектортой хийн хроматограф багажаар шинжлэх тохиолдолд хандыг цэвэр азотын зөөлөн урсгалд ойролцоогоор 1 мл хүртэл концентрацижуулна. Флюресценц детектортой шингэний хроматограф багажаар шинжлэх тохиолдолд хандыг хуурай болтол болгоомжтой ууршуулж, үлдэгдлийг 1 мл эзэлхүүнтэй ацетонитрил уусгагчид уусгана.

2.3. Тохирох уусгагчууд

Хүснэгт 1. Хандлалтанд тохиромжтой уусгагчуудын мэдээлэл

Хандлалтын арга	Уусгагч
Нэрлэгийн	толуол
Сосклетын	толуол, гексан/ацетон холимог 1:1, дихлорметан
Богино долгионы	гексан/ацетон холимог 1:1
Түргэсгэсэн уусгагчийн	толуол, дихлорметан, дихлорметан/гексан холимог 1:1
Ультросоник	дихлорметан, толуол

3. ТООСОНЦРЫН СОРЬЦЫН УСАН ХАНД БЭЛТГЭХ, УУСДАГ ИОНУУДЫН АГУУЛГЫГ ТОДОРХОЙЛОХ

Аргын үндэс: Сорьц дахь ионуудын тооны болон чанарын анализ хийх янз бүрийн аргууд байдаг. Эдгээрээс хамгийн түгээмэл ашиглагддаг төхөөрөмж бол ион хроматограф юм. Хроматографийн аргын үндэс нь хөдөлгөөнт болон хөдөлгөөнгүй гэсэн 2 фазын тусламжтайгаар хольц дахь бодисуудыг ялгахад оршдог. Сорьцыг төхөөрөмжид өгсний дараа хөөгч уусмалаар туугдан ион ялгах баганад очно. Ялгагч баганын цэнэглэгдсэн хөдөлгөөнгүй фазын үйлчлэлээр сорьц дахь ионууд цуваанд ордог. Эдгээр цуваанд орсон ионууд нь детекторoор бүртгэгдэхдээ хугацааны хувьд цуваа үүсгэсэн хроматограммуудыг харуулдаг. Хэмжилт эхлэхийн өмнө олон цэгт калибровк хийх ба системийн ажиллагааг шалгахын тулд дотоод стандарт ашиглана. Агаарын тоосонцрын массыг бүрдүүлэгч голлох ионууд нь усанд уусах шинж чанартай байдаг ба сорьцыг усан орчинд хандалж шинжилгээг гүйцэтгэдэг.

3.1. Багаж хэрэглэл, шил сав

- Ионы хроматографийн систем
- 50 мл-ийн хуруун шил
- Сэгсрэгч эсвэл ультра соникатор
- Нэг удаагийн 0.45мкм-ийн мембран шүүлтүүр, тариур
- 25 мл хэмжээст колбонууд

3.2. Урвалж бодис

- Метан сульфоны хүчил (катионы хөөх уусмал) х.ц
- Натрийн гидроксид (Анионы хөөх уусмал) х.ц
- 7 анионы холимог стандарт уусмал
- 6 катионы холимог стандарт уусмал
- Ионгүйжүүлсэн ус

3.3. Сорьц хандлах, шинжилгээ хийх.

50 мл-ийн хуруун шилэнд сорьц бүхий филтрээс тоосонцрын хэмжээнээс хамааруулан 2×2 см-ээс багагүй хэмжээтэй хэрчиж хийгээд 20 мл ионгүйжүүлсэн ус хийж 30 минут ультра соникатор багажинд хандална. Хэмжилт хийхийн өмнө сорьцын уусмалыг нэг удаагийн 0.45 мкм-ийн мембран шүүлтүүрээр шүүгээд ионы хроматографаар сорьцон дахь анион, катионы агууламжийг жиших муруй ашиглан тодорхойлно. 50 дээж тутамд нэг хоосон сорьц хандалж шинжилнэ.

3.4. Шинжилгээний дүнг тооцоолох:

Агаар дахь *i* ионы агууламж C_i-г дараахь томъёогоор олно.

$$C_i = \frac{C \times n \times 20}{V \times 1000}$$

Энд:

C_i - агаар дахь i ионы агууламж, мг/м^3

V - соруулсан агаарын эзлэхүүн, м^3

C - сорьцон дахь i ионы агууламж, мг/л

n- фильтрийн нийт талбай ба хандлалтанд авсан хэсгийн талбайн харьцаа

4. АГААРЫН ТООСОНЦРЫН СОРЬЦЫГ ХҮЧЛИЙН ХОЛИМГООР БИЧИЛ ДОЛГИОНЫ ЗУУХ АШИГЛАЖ ЗАДЛАХ, МЕТАЛЛЫН ШИНЖИЛГЭЭ ХИЙХ

Аргын зарчим: Богино долгионы зуух ашиглан тоосонцор бүхий кварцын шилэн фильтрээс органик бус бодисыг хүчилд уусгана. Сорьцыг ингэж уусмалд шилжүүлсний дараа ICP, ICP / MS, FAA, GFAA зэрэг багажаар металлуудын агуулгыг тодорхойлно.

Саад болох хүчин зүйлс:

Орчны агаарын кварцын шилэн шүүлтүүрийг тоосонцрын материалыг дотогшоо уртааш нь хагас нугалж, хамгаалалтын дугтуйнд хийж авах ёстой. Дугтуй бүхий дээжийг шинжилгээ хийх хүртэл 15-30°C-д хадгална.

Сорьцыг хадгалах хамгийн их хугацаа 180 хоног байна. Сорьцыг 180 хоногийн дотор шинжилнэ.

Агаарын тоосонцрын сорьцийг таслан авахдаа сорьц гэмтэх, бохирдохоос сэргийлэх ба сорьцийг бүрэн уусгах, жингийн алдагдалгүй байхад анхаарна.

4.1. Хэрэглэгдэх материал, урвалжууд:

Бичил долгионы зуух ба бусад материал

- Бичил долгионы систем. 600 ватт хүртэл чадлын, програмчлагдах тохируулгатай, цахилгааны тогтвортой, сайн эх үүсвэртэй байх.

  [Анхааруулга: Хүнсний болон гэр ахуйн хэрэглээний богино долгионы зуухыг дээж боловсруулахад ашиглаж БОЛОХГҮЙ. Зуухны хөндий нь зэврэлтэнд тэсвэртэй, агааржуулалт сайтай байх ёстой. Аюулгүй ажиллагааны хувьд бүх цахилгаан хэрэгслийг зэврэлтээс хамгаалсан байх ёстой.]

- PFA Teflon® дээж задлах сав. 120 psi хүртэлх даралтыг тэсвэрлэх чадвартай. 120 psi (60-120 мл багтаамжтай) -аас дээш даралттай үед даралтыг хянах сав
- Teflon® PFA задраагааны сав. (60-120 мл багтаамжтай), битүүмжлэл маш сайн байх.
- Эргэдэг тавиур. Зуухны доторх дээжийг жигд хөдөлгөх.
- Хэмжээст цилиндр. 50-100 мл багтаамжтай (боросиликат).
- Дээж хадгалах зориулалттай шил, полиэтилен эсвэл нэвчилтгүй бүрхүүлтэй полипропилен сав.
- Центрифугийн хоолой. 50 мл полипропилен хоолой, полипропилен эргэдэг таглаатай.
- Nylon эсвэл Teflon® 0.45 μм тариурын шүүлтүүр.
- Угааж бэлтгэсэн 15 мл полипропилен хоолой, полипропилен шураг таглаатай.
- Пипетка. 0.1 мл ба түүнээс дээш нарийвчлалтай, эсвэл автомат пипетк.
- Хамгаалалтын маск. Сорьц бүхий фильтрийг огтлох үед өмсөх.
- Хэмжээст тавиур. Фильтрийг огтлоход хэрэглэнэ.
- Пицца таслагч, нимгэн дугуй. Ирийг тогтмол цэвэрлэнэ (<1 мм зузаантай).

- Эргүүлэгтэй холигч (vortex mixer).
- Давсны хүчил. Анализын цэвэр буюу түүнээс дээш цэвэршилттэй.
- Азотын хүчил. Анализын цэвэр буюу түүнээс дээш цэвэршилттэй
- Ионгүйжүүлсэн ус (Milli Q буюу түүнтэй дүйцэхүйц)
- Хандлах уусмал (5.55% HNO_3 / 16.75% HCl). ~ 500 мл-ийн ионгүйжүүлсэн усан дээр 55.5 мл концентрацитай HNO_3, 167.5 мл концентрацитай HCl-ийг нэмж, ионгүйжүүлсэн усаар нэг литр хүртэл шингэлж бэлтгэнэ.

4.2. Ажлын явц:

Фильтр таслаж авах.

- Лавлагаа аргад заасны дагуу суурь ба зүсэгч ашиглаж 8 "x 10" фильтрээс 1 "x 8" туузан хэлбэртэй хайчилж авна. Лабораторийн бичил долгионы хандлах системийг ашиглан металлыг давсны/азотын хүчлийн уусмалаар уусгана. Хөргөсний дараа шингэнийг сайтар хольж, уусдаггүй материалыг зайлуулахын тулд тариурын шүүлтүүр ашиглан шүүнэ. Уусмалыг ICP, ICP/MS, FAA, GFAA-аар шинжлэнэ.
- Хэрэглэхийн өмнө шүүх хэрэгсэл, полисульфоны центрифугийн хоолой, таг болон бусад лабораторийн хэрэгжлүүдийг дээжийн бохирдуулахаас сэргийлэн хүчлээр угаана.
- Гялгар уутан (винил) бээлий ашиглан фильтрийг гэрнээс гаргаж хувуурит сууринд тавина.
- Дээжийг бохирдлоос урьдчилан сэргийлэхийн тулд суурь, бүрхүүл, зүсэх хутгыг цэвэр, хуурай Kimwipe®-ээр арчина.
- Хуваах 8 "x 10" кварцын шүүлтүүрийг гаргаж, дээж авсан талыг дээш харуулан шүүлтүүрийн сууринд болгоомжтой байрлуулна.
- Хайч эсвэл зүсэгч ашиглан 1 "x 8" хэмжээтэй тууз хэлбэртэй хайчилж авна.
- Бээлийтэй гараар баян хуурыг хэлбэрт нугалж эсвэл сайтар хуйлж, арилдаггүй харандаагаар тэмдэглэсэн, хүчлээр цэвэрлэсэн полисульфон® хоолойд хийнэ. Богино долгионы зууханд бар код, бусад материал бүхий шошго ашиглаж болохгүй.
- Шүүлтүүрийн суурь, хайя зэргийг хуурай Kimwipes® ашиглан сорьц хооронд цэвэрлэнэ. (Сорьцын харилцан бохирдлыг багасгахын тулд 50 сорьц тутамд бээлийг солих хэрэгтэй.)
- 20 дээж тутамд 1 давталттай дээж байна.
- Хоосон сорьцоор судалгаанд ашигласан фильтрийг хэрэглэнэ. Металл тодорхойлох зориулалттай фильтрийн тууз авахаас гадна мөн тодорхой концентрацитай металл нэмж шинжилж, аргыг шалгаж болно (spike).
- Хоосон сорьцыг 20 дээж тутамд 1 давтамжтай авах, эсвэл задаргаа хийх өдөр бүр хамгийн багадаа 1 хоосон дээж байхаар бэлтгэнэ.

PFA савыг цэвэрлэх арга

Задаргааны бүх савыг хэрэглэхээс өмнө хүчлээр цэвэрлэж, нэрмэл усаар зайлж угаана. Ингэхдээ:

- PFA сав бүрийг зориулалтын савангаар угааж, нэрмэл усаар зайлна.
- Сав бүрт 10 мл концентрацитай HNO_3 нэмж, таглаад богино долгионы зууханд хийнэ.
- Богино долгионы зуухыг зааврын дагуу 10 минутын турш 100% -ийн хүчээр халаана. Аливаа шинжилгээнд ашиглахын өмнө савыг заавал цэвэрлэж, нэрмэл усаар их хэмжээгээр зайлж угаана.

Орчны тоосонцрын фильтр сорьцыг бичил долгионы зууханд задлах

[**<u>Анхааруулга</u>:** Азотын хүчил, давсны хүчлийн уур хортой. Иймд татах шүүгээнд ажиллана. Эдгээр урвалжуудын уусмал бэлтгэхэд экзотерм урвал явагдаж, дулаан ялгарна. Удаанаар хутгана.]

6.2.5.1 Винил бээлий эсвэл хуванцар хямсаа ашиглан фильтрийн туузыг хэрчиж аваад, шошготой PFA хоолойд байрлуулна. Хуванцар хямсаа ашиглан фильтрийг PFA хоолойн доод хэсэгт дарж хүчилд бүрэн далд орохуйц болгоно.

[Анхааруулга: Хуурай фильтртэй ажиллах үед аюулгүй байдлыг хангах үүднээс маск, винил бээлий заавал хэрэглэнэ.

Маск нь шилэн хөвөнгийн хэлтэрхий, тоосонцор материалыг амьсгалахаар нэвтрэхээс сэргийлдэг. Бээлий нь арьсыг мөн материалаас хамгаалж, дээжийг арьснаас элдэв бохирдол орохоос хамгаалдаг. Хэрэв боломжтой бол ламинар шүүгээнд фильтрийг зүсэх, шилжүүлэх үйл ажиллагааг гүйцэтгэх хэрэгтэй.]

[Анхааруулга: Шүүлтүүрээс нэгээс илүү хэсэгчилсэн дээж тасалж авах хэрэгтэй бөгөөд түүвэр ба QC шинжилгээнд хангалттай хэмжээний эзэлхүүнтэй байх ёстой. Хоосон шүүлтүүрийн дээжийг мөн адил аргаар боловсруулж гарсан үр дүн дээжийн үр дүнгээс хасаж тооцно.]

6.2.5.2 Using a preset calibrated automatic dispensing pipette or Class A glass pipette, add 10.0 mL of the extraction solution to each of the centrifuge tubes. The acid should cover the strip completely. The sequence of adding the filter strip and acid to the centrifuge tube may be reversed, if more convenient, without affecting the results. Place the centrifuge tube in a Teflon® PFA vessel containing 31 mL of deionized water. Continue this process for a total of 12 samples to maximize microwave capacity.

6.2.5.3 Place the PFA vessel caps with the pressure release valves on the vessels hand-tight and tighten using the capping station to a constant torque of 12 ft-lb. Weigh and record the capped

vessel assembly to the nearest 0.01 g. Place the vessels in the microwave carousel. Connect each sample vessel to the overflow vessel using the Teflon® PFA connecting tubes (see Figure 3).

6.2.5.4 Place the carousel containing the 12 vessels onto the turntable of the microwave unit. Any vessels containing 10 mL of acid solution for analytical blank purposes are counted as sample vessels. Irradiate the sample vessels at 486 W (power output) for 23 min. (Based on the calibration of the microwave as previously described). If fewer than 12 samples are to be digested, adjust the microwave system by reducing the power so that equivalent digesting power is delivered to the smaller sample batch. Generally, each vessel represents approximately 5% power. Therefore, a reduction in W would be reduced by 30% if only 6 vessels are digested. This reduction is only approximate, and each microwave unit will produce a different level of power output.

6.2.5.5 At the end of the microwave program, allow the pressure to dissipate (venting may be utilized with caution), then remove the carousel containing the vessels and cool in tap water for 10 min. Weigh the capped vessels assembly to the nearest 0.01 g and compare to the initial weight to verify no loss of sample. The initial and final weights should compare within 0.1 g. If the initial and final weights do not agree within 0.01 g, the appropriate action must be taken which may include rejecting the digested sample. Using the capping station uncap the microwave vessels, remove the labeled centrifuge tubes containing samples and discard the water in the PFA vessels.

6.2.5.6 Using a calibrated automatic dispensing pipette or a Class A glass pipette, add 10 mL of

deionized distilled water to each centrifuge tube. Cap the centrifuge tube tightly and vortex (mix) the contents thoroughly for 2-3 minutes to complete extraction. Using a nylon or teflon syringe pull-up a volume of sample from the centrifuge tube, place Acrodisc filter on syringe and dispense into a prelabeled sterile 15 mL centrifuge tube. Continue until the centrifuge tube contains 10 mL of filtered digestate.

6.2.5.7 The final extraction volume is 20 mL based upon the above procedure. The final extraction solution concentration is 3% HNO3/8% HCl. The filtered sample is now ready for analysis. Store for subsequent analysis by one or more of the Inorganic Compendium methods.

Хавсралт 1.

Зураг 1: Десикатор

Зураг 2: Их эзэлхүүнт сорьц авагч авагч

Ашигласан материал

1. Агаарын чанарын хяналт шинжилгээний гарын авлага. БОАЖЯ 2018 он
2. U. S. Environmental Protection Agency, Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air (EPA/625/R-96/010a), 1999.
3. European committee for standardization, Technical Specification CEN/TS 16645, Ambient air - Method for the measurement of benz[a]anthracene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, dibenz[a,h]anthracene, indeno[1,2,3- cd]pyrene and benzo[ghi]perylene, 2014. English version
4. ISO international standard, ISO 16362, Ambient air — Determination of particle phase polycyclic aromatic hydrocarbons by high performance liquid chromatography, 2005.
5. U. S. Environmental Protection Agency, Compendium Method TO-13A, Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in Ambient Air Using Gas Chromatography/Mass Spectrometry (GC/MS), 1999.

Хавсралт 2. Агаарын чанарын судалгаанд түгээмэл ашиглагддаг фильтрүүдийн тодорхойлолт

Фильтрийн төрөл, үйлдвэрлэгч	**Фильтрийн хэмжээ**	**Физик шинж чанар**	**Химийн шинж чанар**	**Шинжилгээний аргууд [a]**
Цагаригт суурилуулсан тефлон мембран фильтр (Ringed Teflon membrane)	- 25 мм - 37 мм - 47 мм	- Фильтр тэгш гөлгөр гадаргатай. - Тоос барих үр ашиг өндөр. - Хайлах температур ~60°C. - Агаар нэвтрүүлэх эсэргүүцэл өндөр. - Сүвшилт 2 мкм - Статик цэнэг үүсдэг.	- Цэвэршилт өндөр. - Ямар нэг хий шингээдэггүй - Ус шингээх чанар бага.	Жингийн , IC, ICP/MS, ICP/OES
Тефлон мембран (Teflon Membrane)	- 47 мм	Зузаан полипропиленд суурилуулсан мембран фильтр - Цагаан тэгш гөлгөр гадаргатай. - Тоос барих үр ашиг өндөр. - Хайлах температур ~60°C. - Агаар нэвтрүүлэх эсэргүүцэл өндөр.	- Цэвэршилт өндөр. - Нүүрстөрөгч агуулсан материалаар хийсэн тул нүүрстөрөгчийн шинжилгээнд тохиромжгүй - Ямар нэг хий шингээдэггүй. - Ус шингээх чанар бага.	Жингийн, INAA, AAS, ICP/AES, ICP/MS, IC, AC
Нилон мембран фильтр, (Nylon membrane)	- 25 мм - 37 мм - 47 мм	Цэвэр нилон мембран - Цагаан тэгш гөлгөр гадаргатай - Сүвшилт 1 нм - Хайлах температур ~60°C. - Агаар нэвтрүүлэх эсэргүүцэл өндөр.	- HNO_3 дээжлэх чадвар сайн. - Ус шингээх чанар бага	IC, AC
Мөнгөлөг мембран фильтр (Silver membrane)	- 25 мм[b] - 37 мм[c]	Мөнгөний жижиг хэсгүүдээр жигд бүрж нийлэгжүүлсэн мембран - Цагаан саарал тэгш гөлгөр гадаргатай	- Химийн урвалжуудад идэвхгүй	Жингийн, XRD

		- Хайлах температур ~350°C. - Агаар нэвтрүүлэх эсэргүүцэл өндөр.	- Зарим органик уурыг шингээх чанартай. - Ус шингээх чанар бага	
Целлюлозын нитрат холимог эфир мембран фильтр (Cellulose esters membrane)	- 37 мм - 47 мм[d]	- Целлюлозын нитрат холимог эфир, целлюлозын ацетатын нимгэн мембран - Цагаан тэгш гөлгөр гадаргатай - Сүвшилт 0.025,0.05,0.1,0.22,0.30, 0.45,0.65,0.80, 1.2,3.0, 5.0, 8.0 мкм. - Хайлах температур ~70°C. - Агаар нэвтрүүлэх эсэргүүцэл өндөр.	- Бага зэрэг үнсний агуулгатай - Олон төрлийн органик уусгагчид уусдаг - Ус шингээх чанар бага	Жингийн, ОМ, ТЕМ, SEM, XRD t Biomedical applications
Поливинил хлорт мембран (Polyvinyl chloride membrane).	- 47 мм	- Целлюлозын нитратын нимгэн мембран - Цагаан тэгш гөлгөр гадаргатай - Сүвшилт: 0.2, 0.6, 0.8,2.0, 5.0 мкм - Хайлах температур ~50°C. - Агаар нэвтрүүлэх эсэргүүцэл өндөр.	- Зарим органик уусгагчид уусдаг - Ус шингээх чанар их	XRD
Поликарбонат мембран фильтр (Polycarbonate membrane)	- 47 мм[b]	- Нимгэн, гөлгөр поликарбонат гадаргуу нь капилляр сүвүүд нэвт гарсан - Тоосонцрыг хэмжээгээр нь ялгахад ашиглагддаг .	- Цэвэршилт өндөр. - Нүүрстөрөгч агуулсан материалаар хийсэн тул нүүрстөрөгчийн шинжилгээнд тохиромжгүй - Ус шингээх чанар бага	Жингийн, ОА, ОМ, SEM, XRF, PIXE

		- Зарим сүвшилт томтой фильтрийн хувьд тоосонцор барих үр ашиг бага, <70% - Цахилгаанждаг - Сүвшилт: 0.1,0.3,0.4,0.6, 1.0,2.0,3.0, 5.0, 8.0, 10.0, 12.0 мкм - Хайлах температур ~60°C. - Агаар нэвтрүүлэх эсэргүүцэл өндөр дунд зэрэг		
Кварц фильтр (Pure quartz-fiber)	- 25 mm - 37 mm - 47 mm - 20.3x25.4 cm	- Кварц материалаар хийгдсэн - Фильтрийн гадаргуу тэгш бус . - Тоос барих үр ашиг өндөр. - Хайлах температур >900°C. - Агаар нэвтрүүлэх эсэргүүцэл дунд зэрэг.	- Хөнгөн цагаан, цахиурын агууламж өндөр. - Органик уур шингээх шинж чанартай. - HNO_3, NO_2, SO_2 бага зэрэг шингээнэ - Ус шингээх чанар бага	ICP/AES, ICP/MS, IC, AC, T, TOR, TMO, TOT, OA
Холимог кварцтай мяндаслаг фильтр (Mixed quartz-fiber)	- 20.3 x 25.4 cm	5% борсиликат кварц фильтр - Цагаан тэгш гөлгөр гадаргатай - Тоос барих үр ашиг өндөр. - Хайлах температур ~500°C. - Дулааны нүүрстөрөгчийн шинжилгээнд хэрхэн нөлөөлдөг нь тодорхойгүй - Халах үед хэврэг болдогАгаар нэвтрүүлэх эсэргүүцэл муу	- Na, Al, Si болон зарим металлыг янз бүрийн хэмжээгээр агуулсан - Органик уурыг шингээх чанартай - HNO_3, NO_2, болон SO_2-г бага зэрэг шингээдэг, - Ус шингээх чанар бага	Жингийн, XRF, PIXE, AA, ICP/AES, ICP/MS for some metals, IC, AC, T, TOR, TMO, TOT

Целлюлоз-мяндаслаг фильтр (Cellulose fiber)	- 25 мм - 37 мм - 47 мм	- Цаасан фильтр. - Гэрэлтсэн тэгш гөлгөр гадаргатай. - Тоос барих үр ашиг муу <70% - High mechanical strength. - Шатах температур~150°C - Агаар нэвтрүүлэх эсэргүүцэл янз бүр	- Цэвэршилт өндөр. - Нүүрстөрөгч агуулсан материалаар хийсэн тул нүүрстөрөгчийн шинжилгээнд тохиромжгүй - Хий болон усны уур ихээр шингээдэг - Химийн урвалжаар дэвтээн HNO_3, SO_2, NH_3, NO_2 зэрэг хийнүүдийг шингээж авах боломтжой - Ус шингээх чанар их	Жингийн, XRF, PIXE, INAA, AAS, ICP/AES, ICP/MS, IC, AC
Тефлон бүрээстэй шилэн мяндаслаг фильтр (Teflon-coated glass-fiber)	- 37 мм - 47 мм	Тефлон бүрээстэй шилэн мяндаслаг фильтр - Тоос барих үр ашиг сайн - Хайлах температур ~500°C. - Агаар нэвтрүүлэх эсэргүүцэл бага	- Цэвэршилт сайн - HNO_3, NO_2, SO_2 хийнүүдийг шингээдэггүй - Ус шингээх чанар бага	Жингийн, IC, AC
Шилэн мяндаслаг (Glass fiber)	- 20.3 x 25.4 cm	- Борсиликатын шилэн мяндаслаг - Гэрэлтсэн тэгш гөлгөр гадаргатай - Тоос барих үр ашиг сайн - Хайлах температур ~500°C. - Агаар нэвтрүүлэх эсэргүүцэл бага	- Цэвэршилт муу - HNO_3, NO_2 SO_2, болон органик уур шингээдэг - Ус шингээх чанар бага	Жингийн, OA, XRF, PIXE, INAA, AAS, ICP/ AES, IC, AC

[a]AAS	Атом шингээлтийн спектрофотометр
AC	Автомат колориметр
IC	Ион хроматограф
ICP/AES	Индукцийн холбоост плазмат атом цацаруулалтын спектрофотометр

ICP/MS	Индукцийн холбоост плазмат масс спектрофотометр
INAA	Нейтроны хурдасгуурт шинжилгээ
OA	Оптик шингээлт эсвэл гэрэл нэвтрүүлэлтийн шинжилгээ (b_{abs})
OM	Оптик микроскоп
PIXE	Proton-Induced X-Ray Emissions
SEM	Scanning Electron Microscopy
T	Дулааны нүүрстөрөгчийн шинжилгээ
TEM	Электрон шилжилтийн микроскоп
TMO	Дулааны манган исэлдэлтийн нүүрстөрөгчийн анализатор
TOR	Дулаан болон оптик ойлтын нүүрстөрөгчийн анализатор
TOT	Дулаан болон оптик нэвтрүүлэлтийн нүүрстөрөгчийн анализатор
XRD	Дифракцын X-Ray
XRF	Флюоресценцийн X-Ray

Appendix 2. Abstract of domestic conference (paper title: Sources and chemical composition of atmospheric fine particulate matter in Ulaanbaatar, Mongolia)

"ХҮРЭЭЛЭН БУЙ ОРЧИН-2021" ҮНДЭСНИЙ ЭРДЭМ ШИНЖИЛГЭЭНИЙ II ХУРАЛ

Ханан илтгэл

УЛААНБААТАР ХОТЫН АГААРЫН НАРИЙН ШИРХЭГЛЭЛТ ТООСОНЦРЫН ХИМИЙН НАЙРЛАГА БА ЭХ ҮҮСВЭРИЙН СУДАЛГАА

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Хураангуй

Монгол Улсын нийслэл Улаанбаатар хот нь агаарын бохирдлын түвшнээр дэлхийд дээгүүрт тооцогддог. Агаарын чанарыг хянахдаа түгээмэл зургаан бохирдуулагчийн (хүхэрлэг хий-SO_2, азотын давхар исэл-NO_2, тоосонцор буюу PM10, PM2.5, нүүрстөрөгчийн дутуу исэл-CO, озон-O_3) агууламжийг хэмждэг. Тоосорцрын (PM10, PM2.5) агуулгаас гадна дотор нь агуулагдах химийн нэгдлүүдийг судалснаар хортой нөлөөллийг бүрэн үнэлэх, мөн төрөл бүрийн эх үүсвэрүүдийн оруулах хувь нэмрийг тодорхойлж, бохирдлыг бууруулах арга хэмжээ төлөвлөхөд ач холбогдолтой юм.

Энэхүү судалгааны ажлаар Улаанбаатар хотын гэр хороолол, хотын төв орчмоос 2017, 2020, 2021 онуудад нарийн ширхэглэгт тоосонцор (PM2.5)-ын дээжийг цуглуулан, гол ионууд (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, F^-, SO_4^{2-}, NO_3^-, NO_2^-)-ын агуулгыг ICS-3000 /Dionex Corp./ ион хроматограф багажаар тодорхойлж, улирлын өөрчлөлтийн судлав. Өвлийн улиралд сурьфат (SO_4^{2-}) ионы хэмжээ зуныхаас мэдэгдэхүйц их, харин хавар, зуны улиралд Ca, Mg-ийн агуулга бусад улирлаас өндөр байна. Улаанбаатар хотод түүхий нүүрсний хэрэглээг хориглож, сайжруулсан шахмал түлш хэрэглэж эхэлсэн үеэс агаарын нарийн ширхэглэлт тоосонцрын хлорид ионы агуулга нэмэгдсэн харин бусад ионы агуулга буурсан дүн ажиглагдаж байна.

Түлхүүр үг: *PM2.5, ионы найрлага, орчны агаар*

Appendix 3. Domestic paper (paper title: Chemical composition of atmospheric fine particulates (PM2.5) in Ulaanbaatar, Mongolia)

Улаанбаатар хотын агаар дахь нарийн ширхэглэгт тоосонцрын (PM2.5) химийн найрлага

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ABSTRACT

The determination of the chemical composition of particulate matter is important to predict the sources, formation, and effects of pollutants in the atmosphere. In 2019, the Mongolian government banned the use of raw coal in Ulaanbaatar and promoted the use of an improved briquette fuel. As a result, atmospheric PM was reduced by approximately 50%, and ambient air quality was improved. On the other hand, the atmospheric sulfur dioxide concentration was increased more than two times. However, the chemical composition of the particulate matter (PM) has still not been evaluated since 2019, when they started the use of briquette fuel. This study focuses on the seasonal variations of the chemical composition of PM2.5 using ninety-five daily PM2.5 samples that were collected in Ulaanbaatar between 2017 and 2021. Ion chromatography and a carbon analyzer were used to examine the major nine inorganic ions and organic/elemental carbon. In warm seasons, magnesium, sodium, calcium, and potassium ions are higher than they are in cold seasons and are possibly dominated by natural origins, while sulfate was dominant during the cold season. The carbonaceous composition, sulfate, nitrate, and ammonium accounted for the majority of fine particles in winter. Except for summer, sulfate ions predominated, possibly due to fuel combustion. Chloride ion concentrations were increased in the last two winters, 2020 and 2021, when compared to 2017.

Түлхүүр үгс: *нарийн ширхэглэгт тоосонцор, PM2.5, химийн найрлага, агаарын найрлага, хотын агаар*

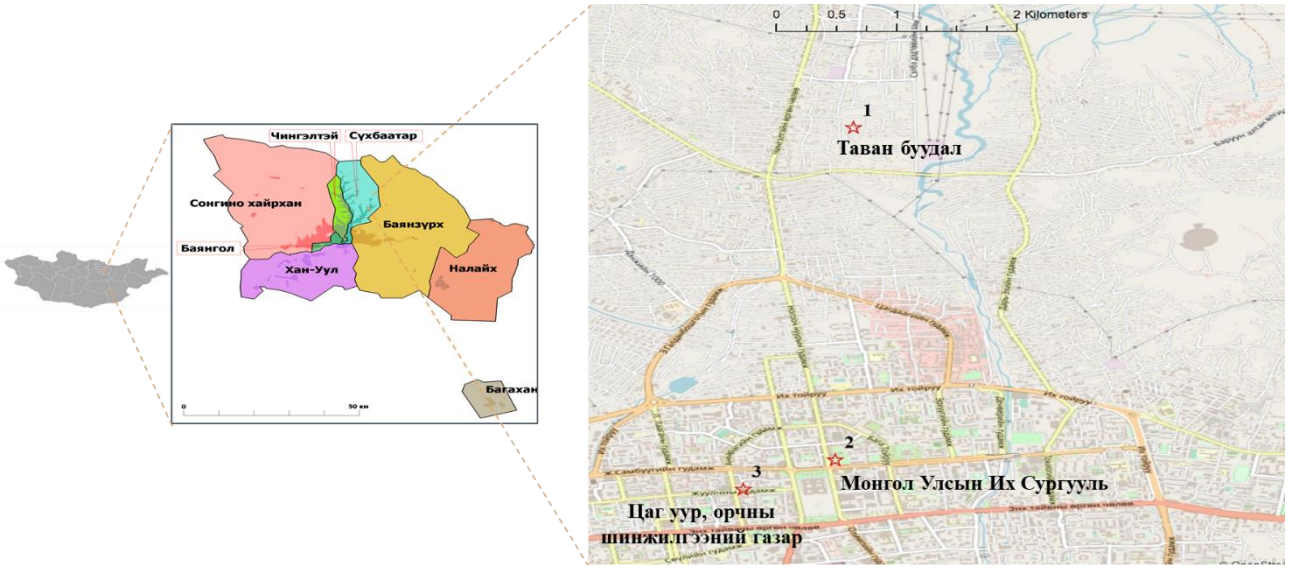
1. ОРШИЛ

Зөвхөн агаарын бохирдлын нөлөөнөөс болж жил бүр Азид 1.5 сая хүн нас бардаг гэсэн тооцоог дэлхийн эрүүл мэндийн байгууллага, дэлхийн банк болон бусад олон улсын байгууллагууд гаргасан байдаг [1], [2]. Улаанбаатар хот нь Туул голын сав газарт уулсаар хүрээлэгдэн оршдог тул салхины хурд багатай байдаг. Манай улсын хүн амын 46% нь Улаанбаатар хотод оршин суудаг бөгөөд хотжилт, үйлдвэржилт, газарзүйн тогтоц зэргээс шалтгаалан агаарын бохирдол удаан хугацаанд хотын дээр тогтон хуримтлагддаг онцлогтой [3], [4]. 10 микрон ба түүнээс бага диаметртэй (≤ PM10) тоосонцор нь хүний уушги руу ордог бол 2.5 микрон ба түүнээс бага диаметр бүхий (≤ PM2.5) тоосонцор нь цусанд нэвчиж хордуулах шинж чанартай байдаг [5]. Монгол улсын агаарын чанарын хяналтын үндэсний сүлжээгээр PM10 болон PM2.5 тоосонцрын массын агууламжийг хэмждэг [6]. Агаарын бохирдол ба түүний хор нөлөөг зөвхөн тоосонцрын агууламжаар нь шууд илэрхийлэх нь ихээхэн учир дутагдалтай юм. Харин өөр өөр хэмжээст тоосонцруудын (PM2.5, PM10, PM1 зэрэг) химийн найрлагыг судлан агаарын бохирдлын хор нөлөөлөл болон эх үүсвэрийн тухай нарийвчлан тогтоох боломжтой [7], [8]. Сүүлийн үед олон улсад PM2.5 -аас гадна PM1 (1 микрон диаметр)-ийг ч судалж байгаа бол PM1 тоосонцрын талаарх судалгаа манай улсад дутагдалтай байна [9], [10]. Улаанбаатар хотын тоосонцрын эх үүсвэрийн судалгааныудаас харахад цахилгаан станцууд, ахуйн зуухнууд, замын тоосжилт, автомашины утаа зэрэг эх үүсвэрүүд давамгайлдаг гэж тогтоосон [4], [11]. 2019 оны сүүл үеэс Монгол улсын засгийн газрын шийдвэрээр Улаанбаатар хотод сайжруулсан шахмал түлшийг ахуйн хэрэглээнд нэвтрүүлснээр агаар дахь тоосонцрын агуулгыг ойролцоогоор 50% бууруулсан [6]. Сайжруулсан шахмал түлш нь чийгийн агуулга багатай, илчлэг өндөртэй учраас агаарын бохирдол буурч, үзэгдэх орчин сайжирч байгаа гэжээ [12]. Монгол улсын агаарын тоосонцрын химийн найрлагыг судалсан хэд хэдэн судалгаа хийгдсэн байдаг ч 2019 оноос хойш хийгдсэн агаарын тоосонцрын химийн найрлагын судалгаа байхгүй байна. Энэхүү судалгааны ажлаар PM2.5 тоосонцрын дээжийг 2020 онд гэр хорооллын бүсээс, 2017 болон 2021 онд хотын төвийн бүсээс цуглуулан химийн найрлагыг судаллаа. PM2.5 тоосонцрын массын агууламжийг хотын агаарын чанарын харуулын мэдээнээс авч ашигласан. Судалгааны үр дүнг өмнөх судалгаануудын үр дүнтэй харьцуулан хэлэлцүүлсэн болно.

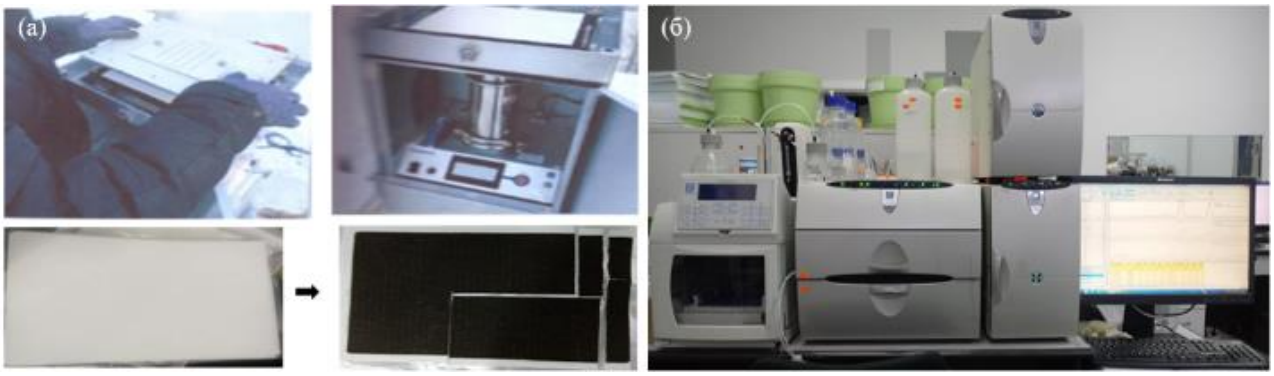
2. СУДАЛГААНЫ АРГАЗҮЙ

2.1. Дээж цуглуулалт

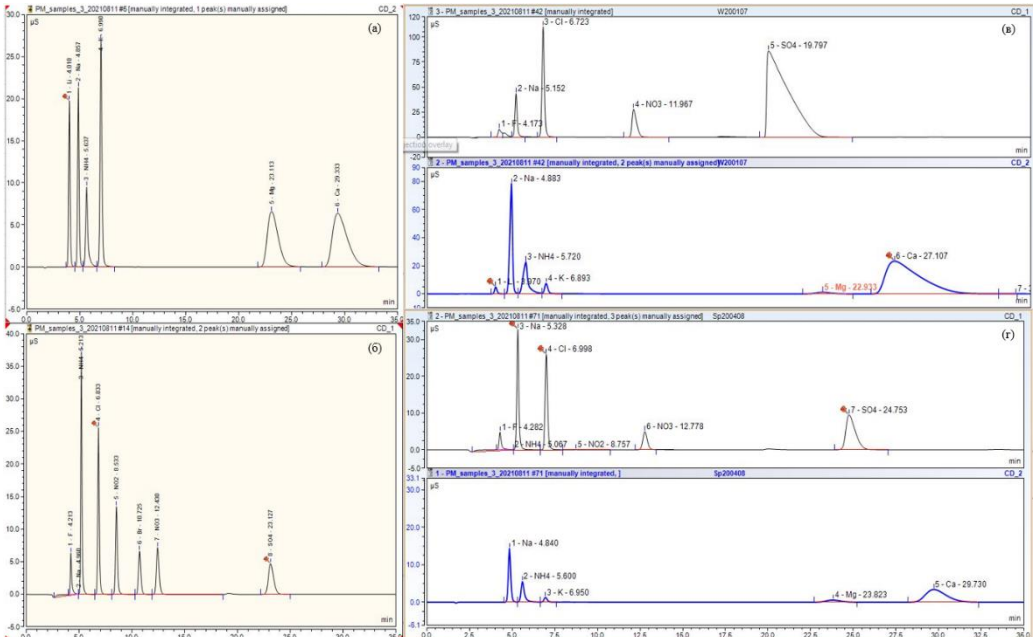
2017 онд 12, 2020 онд 68, 2021 онд 15, нийт 95 ширхэг агаарын нарийн ширхэглэгт тоосонцрын дээжийг 24 цагийн хугацаанд цуглуулан авсан. 2017 онд 16.7 л/мин хурдтай бага эзэлхүүнт дээж авагчаар (Partisol 2025, Thermo Fisher Scientific Inc.) Цаг Уур Орчны Шинжилгээний Газар (ЦУОШГ) (47.9207665N, 106.9106782E), 2020 болон 2021 оны онд 1 $м^3$/мин хурдтай их эзэлхүүнт дээж авагчаар (TH-1000C, Wuhan Tianhong Instruments Co. Ltd) хотын төвөөс хойш 4.3 км зайд гэр хорооллын бүс болох Сүхбаатар дүүргийн 13-р хороонд байрлах 248-р цэцэрлэг (47.9539654N, 106.9177139E), Монгол Улсын Их Сургууль (МУИС) (47.9230352N, 106.9167062E)-ийн дээвэр дээрээс (~8 м өндөр) цуглуулсан (Зураг 1). PM2.5-ын дээжийг 450°C -д 6 цаг урьдчилан шатааж бэлтгэсэн 47-мм (бага эзлэхүүнт дээжлэгчийн хувьд) ба 8×10 инч (их эзлэхүүнт дээжлэгчийн хувьд) хэмжээтэй кварцан фильтр (Merck Millipore Ltd.) хэрэглэн авч мөнгөлөг цаасанд баглан, -20°C -д



Зураг 1. PM2.5 тоосонцрын дээж цуглуулсан байршлын зураг



Зураг 3. (а) TH-1000C өндөр багтаамжид агаарын сорьц авагчийн дотоод бүтэц болон дээж бүхий фильтр, түүнийг хуваасан байдал, (б) Dionex ICS-3000 ион хроматограф



Зураг 2. Дээжийн хроматограмууд. (а) катионы стандарт, (б) анионы стандарт, (в) өвлийн дээж, (г) хаврын дээжний хроматограм.

анализ хийх хүртэл хадгалсан . Зураг 2а -д агаарын тоосонцрын дээж авч байгаа байдал ба их эзлэхүүнт дээж авагчийн дотоод бүтцийг харуулав.

1.1. Химийн шинжилгээ

Усанд уусамтгай ионы шинжилгээг хийхдээ дээж бүхий фильтрээс 2 × 10 см хэмжээтэйгээр таслан авч, 10 мл ионгүйжүүлсэн усанд 30 минут ультрасоник аппаратанд хандалж, 0.45 мкм сүвэрхэгийн хэмжээтэй тариурын фильтр ашиглан шүүсэн [12]. Шүүгдэст агуулагдах F^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+ зэрэг ионуудыг МУИС-ын Хүрээлэн буй орчны хими, геохимийн лабораторид IonPac TM AS23 (4 × 250 mm, Dionex) анионы, IonPac TM CS12A (4 × 250 mm, Dionex) катионы анализын багана бүхий Dionex ICS-3000 загварын ион хроматограф багажаар (Зураг 2б) анионд 10 мкМ NaOH, катионд 10 мкМ MSA (метан сульфоны хүчил) тус тус хөөгч уусмал болгон хэрэглэж тодорхойлсон [13].

Dionex ICS-3000 ион хроматограф багажаар F^-, Cl^-, Br^-, NO_2^-, NO_3^-, SO_4^{2-}, Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+ гэх 12 ионыг тодорхойлох боломжтой ч сорьцод Br^-, NO_2^-, Li^+ ионууд илрээгүй болно. Зарим дээжийн хроматограмыг Зураг 3 -т харуулав.

Ионы шинжилгээний явцыг олон улсын стандарт загварын SLRS-5 (голын ус), Burtap05 (ундны ус) дээжүүдээр шалган баталгаажуулахад [14], [15] стандарт дээжүүдийн баталгаат утгатай ±10% алдааны утгатай тохирч байв (*Хүснэгт 1, Хүснэгт 2*).

Ион хроматограф багажийн үр дүн нь усан ханд дахь агууламж (мг/л) бөгөөд үүнийг агаар дахь агууламжид (мкг/м^3) шилжүүлэхэд (1) томъёог хэрэглэсэн [16].

Хүснэгт 1. SLRS -5 стандарт загварын дээжийн ионы шинжилгээний үр дүн

Ион	Хэмжсэн утга, мг/л	Баталгаат утга, мг/л
F^-	0.35 ± 0.03	
Cl^-	5.12 ± 0.22	
SO_4^{2-}	4.75 ± 0.18	
Na^+	4.69 ± 0.04	5.38 ± 0.10
K^+	0.80 ± 0.07	0.839 ± 0.036
Mg^{2+}	2.39 ± 0.08	2.54 ± 0.16
Ca^{2+}	9.98 ± 0.56	10.5 ± 400

Хүснэгт 2. Burtap05 стандарт загварын дээжийн ионы шинжилгээний үр дүн

Ион	Хэмжсэн утга, мг/л	Баталгаат утга, мг/л
F^-	0.46 ± 0.05	0.55 ± 0.08
Cl^-	28.7 ± 0.72	29.5 ± 1.6
NO_3^-	2.27 ± 0.16	
SO_4^{2-}	42.2 ± 1.5	42.0 ± 2.2
Na^+	20.4 ± 0.5	18.8 ± 1.3
K^+	1.74 ± 0.1	
Mg^{2+}	8.50 ± 0.26	8.92 ± 0.63
Ca^{2+}	33.5 ± 0.14	36.0 ± 2.1
NH_4^+		

$$\frac{(C \times V_e \times \frac{S_a}{S_f})}{V_{air}} \quad (1)$$

C – уусмал дахь ионы агууламж, мг/л

V_e - хандалсан усны эзэлхүүн, мл

S_a - таслан авсан фильтрын хэмжээ, $см^2$

S_f – нийт фильтрын хэмжээ, $см^2$

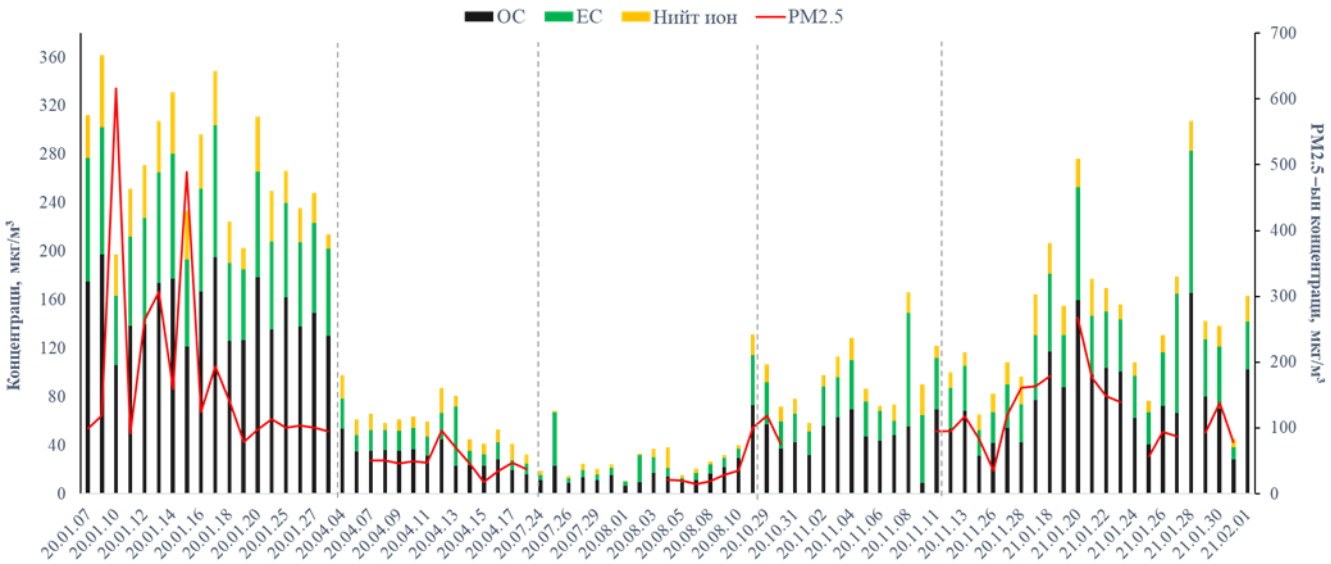
V_{air} –нийт сорсон агаарын эзэлхүүн, $м^3$

Эх сорьцоос 12.5 × 20 см хэмжээтэйгээр таслан авч органик нүүрстөрөгч (OC), элемент нүүрстөрөгчийн (EC) агууламжийг Бээжингийн Багшийн Их Сургуульд DRI 2001A carbon analyzer загварын багажаар тодорхойлуулсан [13].

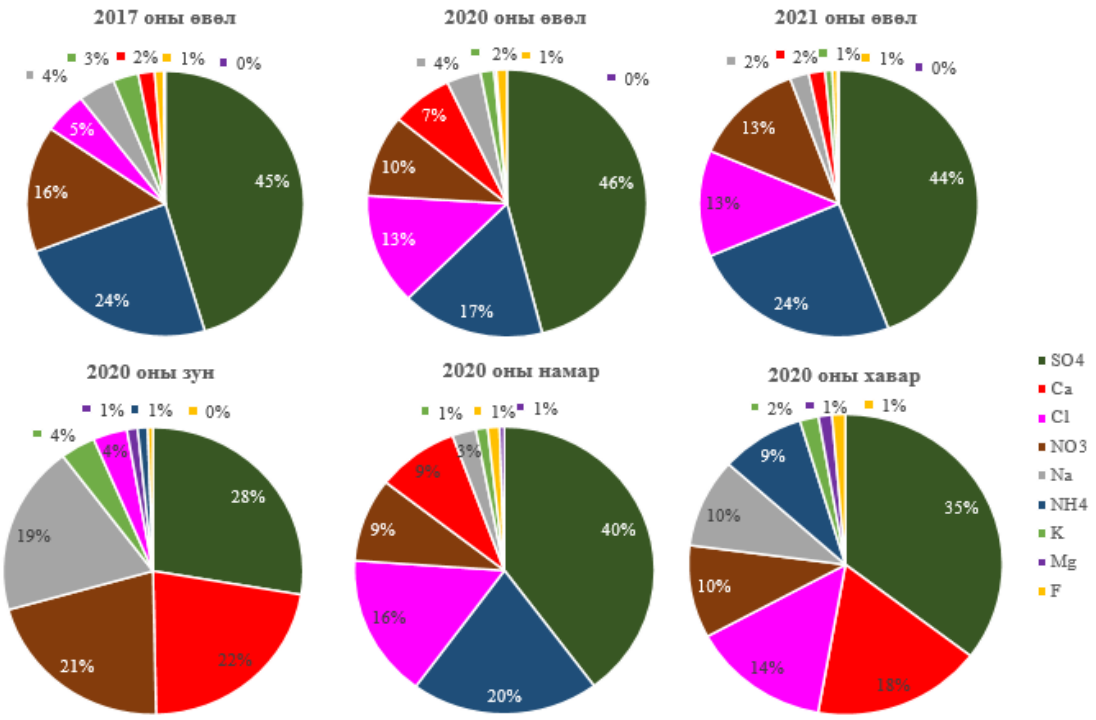
3. СУДАЛГААНЫ ҮР ДҮН, ХЭЛЭЛЦҮҮЛЭГ

Агаарын чанарын хяналтын суурин харуулын PM2.5 тоосонцрын хэмжилтийн дүн, тоосонцрын химийн найрлагыг нэгтгэн Зураг 4 -т үзүүлэв. 2017 оны EC, OC ба PM2.5-ын зарим өдрийн хэмжилт тасалдсан болно.

Агаарын PM2.5 тоосонцрын агууламж өвөл > намар > хавар > зун гэсэн дарааллаар буурч байна. Сайжруулсан түлш хэрэглэж эхэлсэнтэй холбоотойгоор 2020, 2021 оны өвлийн саруудад 2017 онтой харьцуулахад PM2.5 тоосонцрын массын агууламж буурсан. Сорьц авсан нийт хугацаан дахь органик (OC), органик бус (EC) нүүрстөрөгчийн агууламж нь нийт ионуудтай харьцуулахад 4-8 дахин их байгаа ба 2020 болон 2021 оны өвөл тус бүр 81.1 мкг/$м^3$, 152 мкг/$м^3$ байснаас 53.9 мкг/$м^3$, 90.4 мкг/$м^3$ болж буурсан. OC, EC нь агаарт байх нүүрстөрөгчийн агууламж өндөртэй тоосонцрыг илэрхийлдэг бөгөөд нүүрсний шаталттай голчлон холбоотой байдаг [17], [18]. Агаарын PM2.5 -ын агууламж 2020 оны өвөл 182 мкг/$м^3$, 2021 оны өвөл



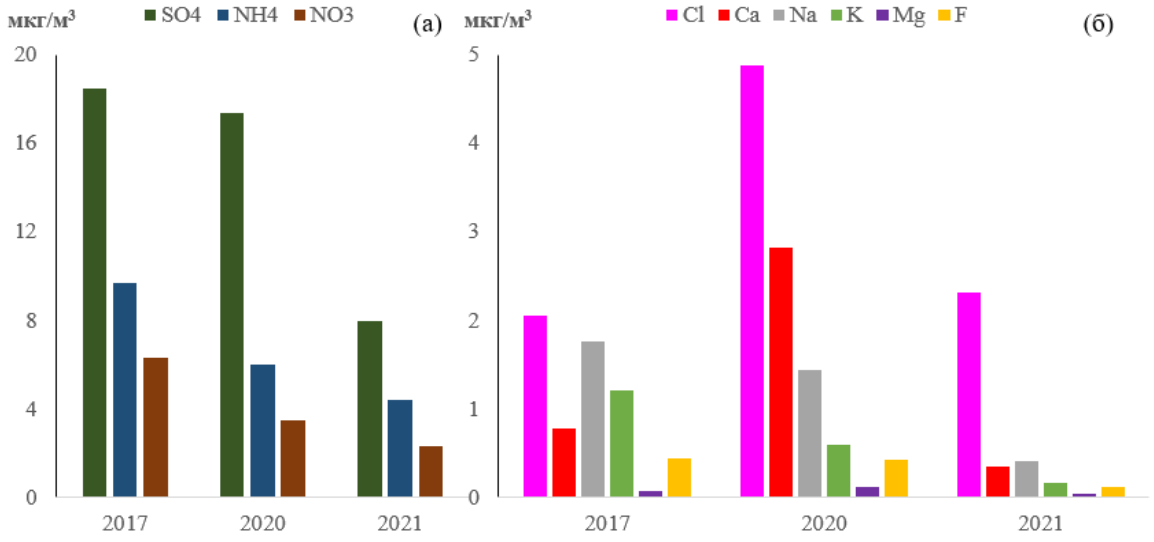
Зураг 4. Сорьц авсан хугацаан дахь PM2.5 тоосонцорын химийн найрлага.



Зураг 5. Сорьц авсан хугацаан дахь PM2.5 тоосонцрын нийт ионы найрлага

нь 133 мкг/м^3 болж буурсан хэдий ч Монгол улсын агаарын чанарын стандартад заасан зөвшөөрөгдөх дээд хэмжээнээс (24 цагийн дундаж 50 мкг/м^3) болон Дэлхийн эрүүл мэндийн байгууллагын зөвлөмжид заасан утгаас (24 цагийн дундаж 25 мкг/м^3) хэтэрсэн хэвээр байна [6], [19].

Улирал тус бүрийн хувьд агаарын нарийн ширхэглэлт тоосонцрын нийт ионы харьцааг Зураг 5 -д дугуй диаграмаар үзүүлэв. Сорьц авсан зуны саруудад PM2.5 тоосонцрын нийт ионы 90% орчмыг сульфат (28%), кальци (22%), нитрат (21%), натри (19%) зэрэг ионууд, үлдсэн 10% орчмыг аммони, хлорид, фторид, кали, магни ионууд бүрдүүлж байна. Өвлийн саруудад 80% орчмыг сульфат (~45%), аммони (~22%), нитрат (~13%) зэрэг ионууд, 20% орчмыг бусад ионууд эзэлж байна. Харин хаврын саруудад 65% орчмыг сульфат (35%), кальци (18%), хлорид (14%) ионууд, натри, аммони, нитрат ионууд нь тус бүр ~10%, кали, магни, фторид ионууд тус бүр ~1% байна. Намрын саруудад 76% орчмыг сульфат (40%), аммони (20%), хлорид (16%) эзэлж, кальци, нитрат нь тус бүр 9%, натри 3%, фторид, кали, магни тус бүр 1% байна. Ерөнхийдөө агаарын PM2.5 -ын ионы найрлагад сульфат ион 2020 оны зунаас бусад бүх улиралд хамгийн өндөр байна. Сульфатын ялгарал нь төрөл бүрийн шаталтын процесс (нүүрс



Зураг 6. Нийт ионуудын өвлийн улирал дахь дундаж агууламж. PM2.5 дахь агуулга нь (а) 0-20 мкг/м^3, (б) 0-5 мкг/м^3 агууламжтай.

болон биомасс), тамхины утаатай холбоотой байдаг [7], [20]. Нийт ионд эзлэх хувиар аммони ион хүйтний улиралд (өвөл, намар) 20-22%, хавар 9%, зун 1%, хлорид ион 2017 оны өвөл болон 2020 оны зун 4-5%, бусад улиралд 13-16% болж өссөн, кальци хүйтний улиралд 2-9%, дулааны улиралд (хавар, зун) 20-22%, натри нь зөвхөн зун 19%, нитрат бүх улиралд (зунаас бусад) 9-16%, зун 21% болж өссөн. Кали, магни, фторид ионууд хэмжилт хийгдсэн бүх хугацаанд 0-3% байв (Зураг 5). Хлорид ионы агууламж өндөр үед агаарын тоосонцорт NH_4Cl нэгдэл үүсдэг [21].

Нийт ионуудын 2017, 2020, 2021 оны өвлийн улирлын дундаж агууламжийг Зураг 6 -д үзүүлэв. Сульфат, нитрат, аммони ионууд 2.31-18.5 мкг/м^3, бусад ионууд нь 0.03-4.88 мкг/м^3 агууламжтай байна. Кальци болон хлорид 2017 онд 0.78 мкг/м^3, 2.05 мкг/м^3 байснаа 2020 оны 2.81 мкг/м^3, 4.38 мкг/м^3 болон өсч, 2021 оны өвөл 0.34 мкг/м^3, 2.31 мкг/м^3 агууламжтай болон буурсан байна. Бусад ионууд 2017 оноос 2021 онд жигд буурсан байна. Улаанбаатар хотын агаарын PM2.5 тоосонцрын химийн найрлагыг судалсан өмнөх судалгааны үр дүнгүүдийг энэ судалгааны дүнтэй харьцуулан Хүснэгт 3-д үзүүлэв. OC -ийн агууламж нь 2008-2009 оныхтой харьцуулахад 2017-2018 онд ~2 дахин их, 2019-2020 онд ~6.3 дахин их, 2020-2021 онд ~3.8 дахин их байна. EC -ийн агууламж нь 2008-2009 оныхтой харьцуулахад 2017-2018 онд ~50 дахин бага, 2019-2020 онд ~1.07 дахин бага, 2020-2021 онд 1.6 дахин бага болсон байна. Нитратын ион бага зэрэг их, бусад органик бус ионуудын агууламж 2008-2009 оныхтой харьцуулахад 2017-2018 онд 1.2-8.9 дахин бага, 2019-2020 онд тун ойролцоо агууламжтай, 2020-2021 онд 1.02-22.6 дахин бага байна. Бидний 2017-2018 оны үр дүн Nirmalkar et al., (2020) судалгааны үр дүнтэй адил цаг хугацаанд ойролцоо байрлалд хийгдсэн ба үр дүнгүүд мөн ихээхэн ойролцоо гарсан байна.

Цаашид орчны агаар дахь янз бүрийн хэмжээст тоосорцрын химийн найрлагын нарийвчилсан судалгааг хийх хэрэгтэй ба ингэснээр тэдгээрийн эх үүсвэр, нөлөөллийг тодорхойлох боломжтой юм.

5. ДҮГНЭЛТ

Улаанбаатар хотын агаарын PM2.5 тоосонцорт химийн шинжилгээ хийж, улирлаар нь харьцуулан судаллаа. Сорьц авсан нийт хугацаанд агаарын PM2.5 тоосонцорт хүйтний улиралд сульфат, аммони, нитрат ионууд, дулааны улиралд сульфат, кальци, нитрат, натри ионууд зонхилж байна. Агаарын PM2.5-ын сорьц авсан 2017, 2020, 2021 онуудын өвлийн улирлын үр дүнг харьцуулахад агаарын PM2.5 тоосонцрын массын агууламж, органик ба органик бус нүүрстөрөгчийн агууламж, нийт ионы агууламж нь 2017 оноос 2021 онд ион тус бүрийн хувьд 1.4 - 8.1 дахин буурсан байна. Энэ нь сайжруулсан шахмал түлшийг ахуйн хэрэглээнд нэвтрүүлж, түүхий нүүрсний хэрэглээг хорьсонтой холбоотой гэж үзэж болох юм. Уусамтгай ионуудаас зөвхөн хлорид ион 2017 онтой харьцуулахад 2021 онд өссөн байгаа бөгөөд энэ нь сайжруулсан шахмал түлшний шаталтаас гарах хлорид ионы ялгарал нь түүхий нүүрсний шаталттай харьцуулахад өндөр байж болохыг харуулж байна.

ТАЛАРХАЛ

Энэхүү судалгааны ажил нь Глобал өөрчлөлтийн судалгааны Ази Номхон далайн орнуудын сүлжээ байгууллагын санхүүжилттэй (PN: CRECS-01MY) төсөл болон Уур Амьсгалын Ногоон Сангийн санхүүжилтээр БОАЖЯ, НҮБ-ын Байгаль орчны хөтөлбөр хамтран хэрэгжүүлж буй “Уур амьсгалын өөрчлөлтөд дасан зохицох төлөвлөлтийн процессыг боловсронгуй болгох Үндэсний чадавхыг бэхжүүлэх (NAP)” төслийн судалгааны тэтгэлгээр хийгдсэн болно.

АШИГЛАСАН МАТЕРИАЛ

[1] Д.Төмөрсүх, “Азийн зарим орны усны болон агаарын бохирдол,” *ШУА.Геоэкологийн хүрээлэнгийн бүтээл*, vol. 6, 2006.

[2] НҮБ-ын Хүүхдийн сан, “Агаарын бохирдол, эрүүл мэндийн чиглэлээрх эрдэм шинжилгээ, судалгааны ажлын төлөв байдлын судалгаа.,” 2019.

[3] Sarath Guttikunda, “Urban Air Pollution Analysis in Ulaanbaatar, Mongolia,” 2008.

[4] T.-O. Soyol-Erdene, G. Ganbat, and B. Baldorj, “Urban air quality studies in Mongolia: pollution characteristics and future research needs,” *Aerosol Air Quality*, vol. 21, no. 12, 2021, doi: https://doi.org/10.4209/aaqr.210163.

[5] Дашням.Б, “Улаанбаатар хотын нарийн ширхэглэгт тоосонцрын олон цагирагт ароматик нүүрсустөрөгчийн хавдрын эрсдлийн үнэлгээ,” 2020.

[6] ЭЗМНС, “Агаар, орчны бохирдлыг бууруулах үндэсний хөтөлбөр,” 2017. https://legalinfo.mn/mn/detail/12588/2/207779 (accessed Dec. 03, 2021).

[7] F. Dominici, Y. Wang, A. W. Correia, M. Ezzati, C. A. Pope, and D. W.

Dockery, “Chemical Composition of Fine Particulate Matter and Life Expectancy: In 95 US Counties between 2002 and 2007,” *Epidemiology*, vol. 26, no. 4, pp. 556–564, Jul. 2015, doi: 10.1097/EDE.0000000000000297.

[8] M. Nakao, K. Yamauchi, Y. Ishihara, H. Omori, D. Ichinnorov, and B. Solongo, “Effects of air pollution and seasons on health-related quality of life of Mongolian adults living in Ulaanbaatar: Cross-sectional studies,” *BMC Public Health*, vol. 17, no. 1, Jun. 2017, doi: 10.1186/s12889-017-4507-1.

[9] A. Chakraborty and T. Gupta, “Chemical characterization and source apportionment of submicron (PM 1) aerosol in Kanpur Region, India,” *Aerosol and Air Quality Research*, vol. 10, no. 5, pp. 433–445, Oct. 2010, doi: 10.4209/aaqr.2009.11.0071.

[10] Q. Yu *et al.*, “Characteristics and secondary formation of water-soluble organic acids in PM 1 , PM 2.5 and PM 10 in Beijing during haze episodes,” *Science of the Total Environment*, vol. 669, pp. 175–184, Jun. 2019, doi: 10.1016/j.scitotenv.2019.03.131.

[11] G. Gunchin *et al.*, “Three-year long source apportionment study of airborne particles in ulaanbaatar using X-ray fluorescence and positive matrix factorization,” *Aerosol and Air Quality Research*, vol. 19, no. 5, pp. 1056–1067, May 2019, doi: 10.4209/aaqr.2018.09.0351.

[12] МХЕГ, “Мэргэжлийн Хяналтын Ерөнхий Газар,” 2019. http://home.inspection.gov.mn/news/295/single/1975 (accessed Dec. 03, 2021).

[13] L. Wei *et al.*, “Stable sulfur isotope ratios and chemical compositions of fine aerosols (PM2.5) in Beijing, China,” *Science of the Total Environment*, vol. 633, pp. 1156–1164, Aug. 2018, doi: 10.1016/j.scitotenv.2018.03.153.

[14] A. Heimburger, M. Tharaud, F. Monna, R. Losno, K. Desboeufs, and E. B. Nguyen, “SLRS-5 Elemental Concentrations of Thirty-Three Uncertified Elements Deduced from SLRS-5/SLRS-4 Ratios,” *Geostandards and Geoanalytical Research*, vol. 37, no. 1, pp. 77–85, Mar. 2013, doi: 10.1111/j.1751-908X.2012.00185.x.

[15] National Research Council Canada, “Certified reference materials,” 2018.

[16] Y. Wu *et al.*, “Seasonal variations, source apportionment, and health risk assessment of heavy metals in pm2.5 in Ningbo, China,” *Aerosol and Air Quality Research*, vol. 19, no. 9, pp. 2083–2092, Sep. 2019, doi: 10.4209/aaqr.2018.12.0452.

[17] B. Khan, M. D. Hays, C. Geron, and J. Jetter, “Differences in the OC/EC ratios that characterize ambient and source aerosols due to thermal-optical analysis,” *Aerosol Science and Technology*, vol. 46, no. 2, pp. 127–137, Feb. 2012, doi: 10.1080/02786826.2011.609194.

[18] J. Nirmalkar, T. Batmunkh, and J. Jung, “An optimized tracer-based approach for estimating organic carbon emissions from biomass burning in Ulaanbaatar, Mongolia,” *Atmospheric Chemistry and Physics*, vol. 20, no. 5, pp. 3231–3247, Mar. 2020, doi: 10.5194/acp-20-3231-2020.

[19] WHO, “WHO global air quality guidelines,” 2021.

[20] L. D. Hill *et al.*, “Health assessment of future PM2.5 exposures from indoor, outdoor, and secondhand tobacco smoke concentrations under alternative policy

pathways in Ulaanbaatar, Mongolia," *PLoS ONE*, vol. 12, no. 10, Oct. 2017, doi: 10.1371/journal.pone.0186834.

[21] Y. L. Sun *et al.*, "Long-term real-time measurements of aerosol particle composition in Beijing, China: seasonal variations, meteorological effects, and source analysis," *Atmospheric Chemistry and Physics*, vol. 15, no. 17, pp. 10149–10165, Sep. 2015, doi: 10.5194/acp-15-10149-2015.

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REVIEW
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Urban Air Quality Studies in Mongolia: Pollution Characteristics and Future Research Needs

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ABSTRACT

For the last decades, Mongolia has seen an extensive escalation in population growth, urbanization, and industrialization, together with great increase in mining and usage of vehicles. As a result, a substantial increase has taken place in the types and number of emission sources of air pollutants, especially in urban areas. During the cold season, air pollution level in Ulaanbaatar, the capital of Mongolia, is frequently ranked as the highest in the world. However, due to the lack of air quality management, the country is suffering from a deterioration of air quality.

Despite the worse air pollution situation, due to insufficient research capacity of the country, to date, research works on characteristics of air pollution have mainly been based on current capability and/or collaboration with foreign institutes. The research gap in this area necessitates numerous investigations, which could have great importance in developing mitigating strategies and minimizing the adverse impact of air pollution on local and regional scales. This paper reviews previously available studies and reports in international scientific journals on air quality in Mongolia. Based on the existing research works, future needs of studies on ambient air pollution in Mongolia are suggested.

Keywords: Air pollution, Literature overview, Ulaanbaatar, Mongolia, Further research recommendations

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1 INTRODUCTION

Asian countries have experienced substantial growth in development and urbanization coupled with increases in energy use and transportation in recent decades (Moran and Kanemoto, 2016; Bilgili *et al.*, 2017; Li *et al.*, 2017). A considerable increase has occurred in the number and types of emission sources of air pollutants in Asia (Moran and Kanemoto, 2016; Li *et al.*, 2017). As a result, air pollution has emerged as a significant threat to the environment, quality of life, and health of the inhabitants in Asia, especially in developing countries where emission control system and strategies are not usually well established (Liu *et al.*, 2016; Moran and Kanemoto, 2016). Mongolia is one of the most rapidly developing countries in the world. As an East Asian country located between China and Russia, it is known for pristine environments with largely empty grassland, cold winters, and nomadic traditional culture. After the transition from a socialist system during the Soviet Union to democratic system in the beginning of the 1990s, urbanization, population growth, industrialization, and transportation development accelerated and created various environmental stresses in both urban and rural areas in the country (Warburton *et al.*, 2013; Pfeiffer *et al.*, 2015; Fan *et al.*, 2016; Batsaikhan *et al.*, 2018). Especially in recent years, Mongolia has become known for one of the world's worst air in the winter months (Davy *et al.*,

2011; Cousins, 2019). The most polluted air in Mongolia is found in the capital city of Ulaanbaatar, where 46% of the country's population resides (NSOM, 2021). Furthermore, other cities in rural areas of the country are also facing a high degree of air pollution up to and exceeding the World Health Organization (WHO) and permissible levels of national guidelines (MET, 2019). The defining characteristic of air pollution in Mongolia—as in many countries—is the high concentration of particulate matter (PM) (Davy *et al.*, 2011; Nishikawa *et al.*, 2011; Guttikunda *et al.*, 2013; Hasenkopf *et al.*, 2016). It has been considered that air pollution represents a major threat to public health in Ulaanbaatar, the capital city of Mongolia (Allen *et al.*, 2013).

In the last two decades, with worsening air quality in Ulaanbaatar, interest in addressing air pollution has been increased. A number of research works has been performed on the assessment of the ambient air quality by evaluating criteria (Luvsan *et al.*, 2012; Huang *et al.*, 2013) and trace (Byambaa *et al.*, 2019; Nirmalkar *et al.*, 2020) pollutants in Mongolia, chemical (Jung *et al.*, 2010; Davy *et al.*, 2011; Nishikawa *et al.*, 2011; Batmunkh *et al.*, 2013; Amgalan *et al.*, 2016) and physical characteristics (Jung *et al.*, 2011; Oyungerel *et al.*, 2012; Hasenkopf *et al.*, 2016) of atmospheric particulate matter, source apportionment of certain atmospheric pollutants (Davy *et al.*, 2011; Nishikawa *et al.*, 2011; Amgalan *et al.*, 2016) and other climatic and socioeconomic factors impacting urban air quality (Luvsan *et al.*, 2012; Ganbat *et al.*, 2013; Huang *et al.*, 2013; Ganbat and Baik, 2016). To date, there have been no systematic reviews of published studies on air pollution in Mongolia. In an effort to fill this gap in the literature, we aim to provide a systematic literature review of air pollution in Mongolia focusing on the source apportionment, physical and chemical characteristics of air pollutants, and identify areas for future research. The review is limited to articles and reports in the English language peer-reviewed scientific literature. Studies of health impacts including exposure and clinical symptoms resulting from indoor and outdoor air pollution are not discussed.

Section 2 introduces the study area and its climate, which constitutes the important factor affecting air pollution. Some characteristics of the air quality monitoring network are also described in Section 2. Section 3 presents an overview of air pollution studies in Mongolia and particularly in Ulaanbaatar. The paper recommends the directions for further research. Conclusions are given in Section 4.

2 STUDY AREA

Mongolia is a landlocked country in the East Asian region positioned between 41°40′ to 52°15′N and 87°44′ to 119°54′E (Fig. 1). Mongolia has a marked continental climate with a broadly latitudinal rainfall distribution, causing a steep climatic gradient from semi-arid conditions in the north, with a mean annual precipitation of up to nearly 400 mm, to arid conditions in the south, with only 100 mm (Wesche and Treiber, 2012). The climate supports three main rangeland types: meadow steppe or forest steppe in the north, true steppe in the center and desert steppe in the south. The highest temperatures can reach 45°C in the Gobi region, which is in the southern part of the country and covered by sandy desert. Very cold and dry winters occur in the Central Northern and Northwestern mountain regions in Mongolia, with decreases in temperature to –45°C (Wesche and Treiber, 2012). This cold weather is attributed to the Siberian high-pressure system, which extends southeastward across the Eurasian continent in winter. Wintertime Siberian high-pressure system is also responsible for both weak winds that prevent air from mixing near the surface and clear skies, causing the formation of temperature inversion. This condition plays a significant role in winter air pollution (Ganbat and Baik, 2016).

Mongolia is the least densely populated country in the world, with a total population of only 3.36 million in an area of 1.56 million square kilometers, and is the 18th largest country worldwide (NSOM, 2021). The administrative division of Mongolia consists of twenty-one provinces and a capital city. Mongolia's population has undergone rapid urbanization since the mid-1990s, and this shift has had a major impact on the capital city, Ulaanbaatar, which is now home to 1.57 million people, equaling 45.4% of the nation's total population (NSOM, 2021). In addition to the capital city, each province has a city as its center, where the most populated areas within the provinces have a population of 10.7–103.7 thousands (NSOM, 2021). Two main industrial cities, Erdenet (#23 and #24 in Table 1 and Fig. 1) and Darkhan (#7 in Table 1 and Fig. 1), which are the centers

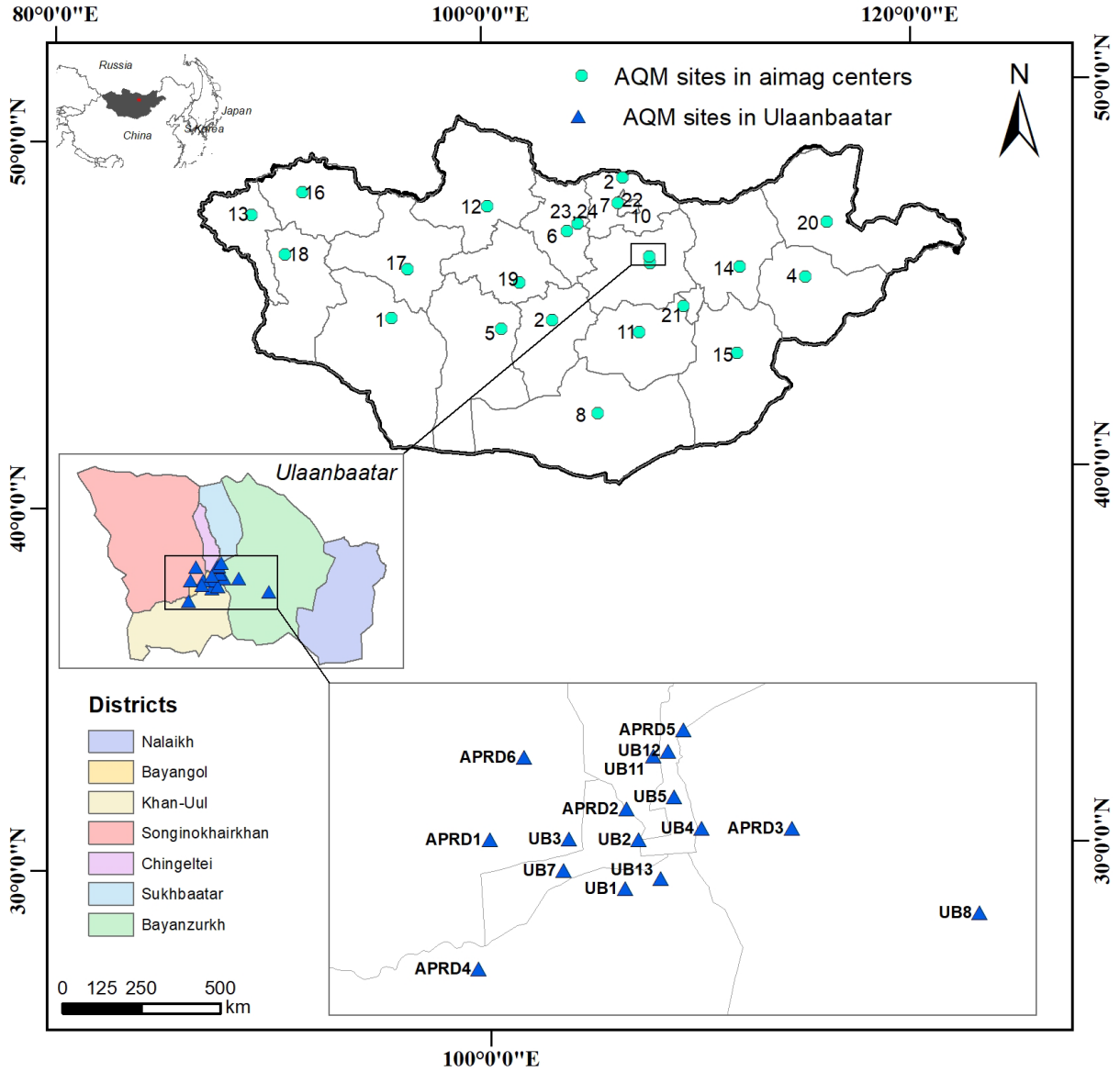

Fig. 1. Mongolia's geographic administrative boundaries and air quality monitoring sites in province centers and Ulaanbaatar. Site identifications are mentioned in Table 1.

of Orkhon and Darkhan-Uul provinces, respectively, are the most populated and industrial hub regions outside the Ulaanbaatar. The populations living in cities, both centers of provinces and the capital, have increased dramatically in recent decades (Warburton *et al.*, 2013). The urban population occupied 57% (1.226 million) of the total population of 2.153 million in 1990, and as of 2020, it had increased by a factor of two, reaching 69% (2.316 million) of the total population of the country (NSOM, 2021).

Ambient air pollution is the main environmental issue in the cities of Mongolia. Because of its high population and air pollution emission rate coupled with geographical and climatic conditions, air pollution is the most serious in Ulaanbaatar (Cousins, 2019). Other cities (the centers of the provinces including major industrial cities—Darkhan and Erdenet) have also been experiencing a high degree of ambient air pollution in recent years, especially during the winter season (MET, 2019).

Through the air quality (AQ) monitoring network, which constitutes of the National Agency for Meteorology and Environmental Monitoring (NAMEM) and the Air Pollution Reduction Department of Ulaanbaatar city (APRD), a total of 42 sites are operating across the country (Fig. 1). At the site, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matters (PM_{10} and $PM_{2.5}$) are monitored

Table 1. List of the air quality monitoring sites with measured parameters in Mongolia.

Site name (ID)	Measuring parameters						
	WP	SO_2	NO_x	CO	O_3	$PM_{2.5}$	PM_{10}
Ulaanbaatar city							
Uildver (UB1)	o	o	o	o	o	-	o
Baruun 4 zam (UB2)	o	o	o	o	-	o	o
1-r horoolol (UB3)	o	o	o	o	o	o	o
Zuun 4 zam (UB4)	o	o	o	o	o	o	o
Zuun ail (UB5)	o	o	o	o	o	-	o
Mongol gazar (UB7)	o	o	o	o	-	-	o
Urgakh naran (UB8)	o	o	o	o	o	-	o
Selbe 5 buudal (UB12)	-	o	o	-	-	o	o
Hailaast (UB11)	-	o	o	-	-	-	o
Bogdkhaanii ordon museum (UB13)	-	o	o	o	-	o	o
Tolgoit (APRD1)	o	o	o	o	o	o	-
MNB (APRD2)	o	o	o	o	o	o	-
Amgalan (APRD3)	o	o	o	o	o	o	-
Nisekh (APRD4)	o	o	o	o	o	o	o
Dambadarjaa (APRD5)	-	○	○	○	-	○	○
Bayankhoshuu (APRD6)	o	o	-	-	-	o	o
Other cities (province centers)							
1-Altai	△	o	o	-	-	-	-
2-Arvaikheer	△	o	o	-	-	-	-
3-Baganuur	△	o	o	-	-	-	-
4-Baruun-Urt	△	o	o	-	-	-	-
5-Bayankhongor	△	o	o	-	-	-	o
6-Bulgan	△	o	o	-	-	-	-
7-Darkhan-1	△	o	o	-	-	-	o
8-Dalanzadgad	△	o	o	-	-	-	-
9-Zuunmod	△	o	o	-	-	-	-
10-Zuunkharaa	△	o	o	-	-	-	-
11-Mandalgobi	△	o	o	-	-	-	-
12-Murun	△	o	o	-	-	-	o
13-Ulgii	△	o	o	-	-	-	-
14-Undurkhaan	△	o	o	-	-	-	-
15-Sainshand	△	o	o	-	-	-	-
16-Ulaangom	△	o	o	-	-	-	-
17-Uliastai	△	o	o	-	-	-	-
18-Khovd	△	o	o	-	-	-	-
19-Tsetserleg	△	o	o	-	-	-	-
20-Choibalsan	△	o	o	-	-	-	-
21-Choir	△	o	o	-	-	-	-
22-Shariin gol	△	o	o	-	-	-	-
23-Erdenet-1	△	o	o	-	-	-	o
24-Erdenet-2	△	o	o	-	-	-	
25-Sukhbaatar	△	o	o	-	-	-	-

WP: weather parameters; o Measure; - Not measure; △ Measure at local weather station.

regularly. Only a few sites in Ulaanbaatar measure ozone (O_3) and carbon monoxide (CO) concentrations. The numbers of measuring parameters vary between the sites. The AQ monitoring sites of Mongolia with the measured parameters is listed in Table 1. Sixteen air quality monitoring sites are operated in Ulaanbaatar and located in—industrial (UB1 and UB7), residential (UB4, UB5 and UB13), ger area (UB3, UB11, UB12, APRD1, APRD2, APRD3, APRD4, APRD5, and APRD6), roadside (UB2), and remote areas (UB8). The current national air quality standard (MNS 4585:2016)

designating the maximum permissible levels of pollutants in ambient air was last amended in 2016. The pollutant levels in the national standard are high in comparison with those in the WHO guidelines (UNDP, 2019). For example, the national standard for 24-hour $PM_{2.5}$ is 50 μg m^{-3}, while the WHO standard is 25 μg m^{-3} (Table 2.2 from UNDP (2019)). The air quality index is used to report the air quality situation to the public and has been revised and implemented in 2018 based on the effects of air pollutant concentrations on human health (MET, 2018).

3 RESULTS AND DISCUSSION

3.1 Pollutant Sources

For decision-makers, accurate and up-to-date knowledge of the source apportionment is essential in developing an optimal air quality management program. There is a lack of studies focusing on the source apportionment of air pollution and emission inventory except for Ulaanbaatar. Several published reports and studies on the air pollution sources in Ulaanbaatar are available. For the first time, Guttikunda (2008) presented the sources of particulate matter emissions for 2006. A local source predominates over the long-range transport (Nishikawa *et al.*, 2011). The PM emitters were reported to be from power plants (36%), followed by household stoves (25%) and heat-only boilers (17%). At the ground level in the city, it was calculated that stoves and HOBs (heat-only boilers) contribute the most to air pollution. The largest source of PM_{10} is household stoves and HOBs, which were indicated at ground level in the city (Guttikunda, 2008). It was mentioned that the PM source from vehicles is less important than that from power plants, stoves, and boilers, however, is increasing rapidly than the other sectors (Guttikunda, 2008).

The PM pollution source from combustion processes in stoves is also found to be significant (87%) from the analysis done in 2008–2009 (Lodoysamba and Pemberton-Pigott, 2011). The different averaging period and spatial location showed different contributions; for example, the difference between the contributions from combustion sources for $PM_{2.5}$ for 1-year and 5-year is ~35%, and locations near ger (Mongolian traditional felt tent) areas showed the highest contributions from combustion.

The emission inventory has been updated and reported within the Capacity Development Project for Air pollution control supported by the Japan International Cooperation Agency (JICA, 2017). The source contributions of individual PM, sulfate, and nitrate in Ulaanbaatar were identified. The pollution source contributions are likely to show spatial variations; for example, power plants in southern Ulaanbaatar show the largest contribution to PM_{10} emission sources, along with stoves, dust from roads and vehicle exhaust gas, while roads tend to show greater source contributions, followed by stoves in another part of Ulaanbaatar. Contributions from different sources may also depend on the emission height, e.g., stack height is 150–250 m for power plants, ~10–40 m for HOBs and ~3–6 m only for households' stoves.

3.2 Air Quality Studies in Small and Industrial Cities

In this section, ambient air quality studies in the central towns of the twenty-one provinces of Mongolia are considered. Within the framework of the National Environmental Monitoring System, criteria pollutants are monitored (Table 1) at the air quality (AQ) monitoring sites. Due to scattered sites of the national network, small and industrial cities have difficulty in getting detailed information on air quality. Nevertheless, according to the observation results, the main pollutants that show comparably higher concentrations and risks for human health overall in Mongolia are SO_2, NO_2, and PM, while CO and O_3 are below the national standard levels.

3.2.1 Gaseous pollutants

Fig. 2 shows the comparison of monthly mean concentrations for December of SO_2 and NO_2 for 2013–2015 and 2017–2019 periods measured at the AQ monitoring sites in non-capital locations. December month is chosen because it is the second coldest and polluted month of the year in the region. The concentrations of air pollutants vary across the country which are likely to be associated with various factors, such as pollutant sources, geographical and climate conditions, and socioeconomic factors. The mean SO_2 concentrations for December varied in the range of

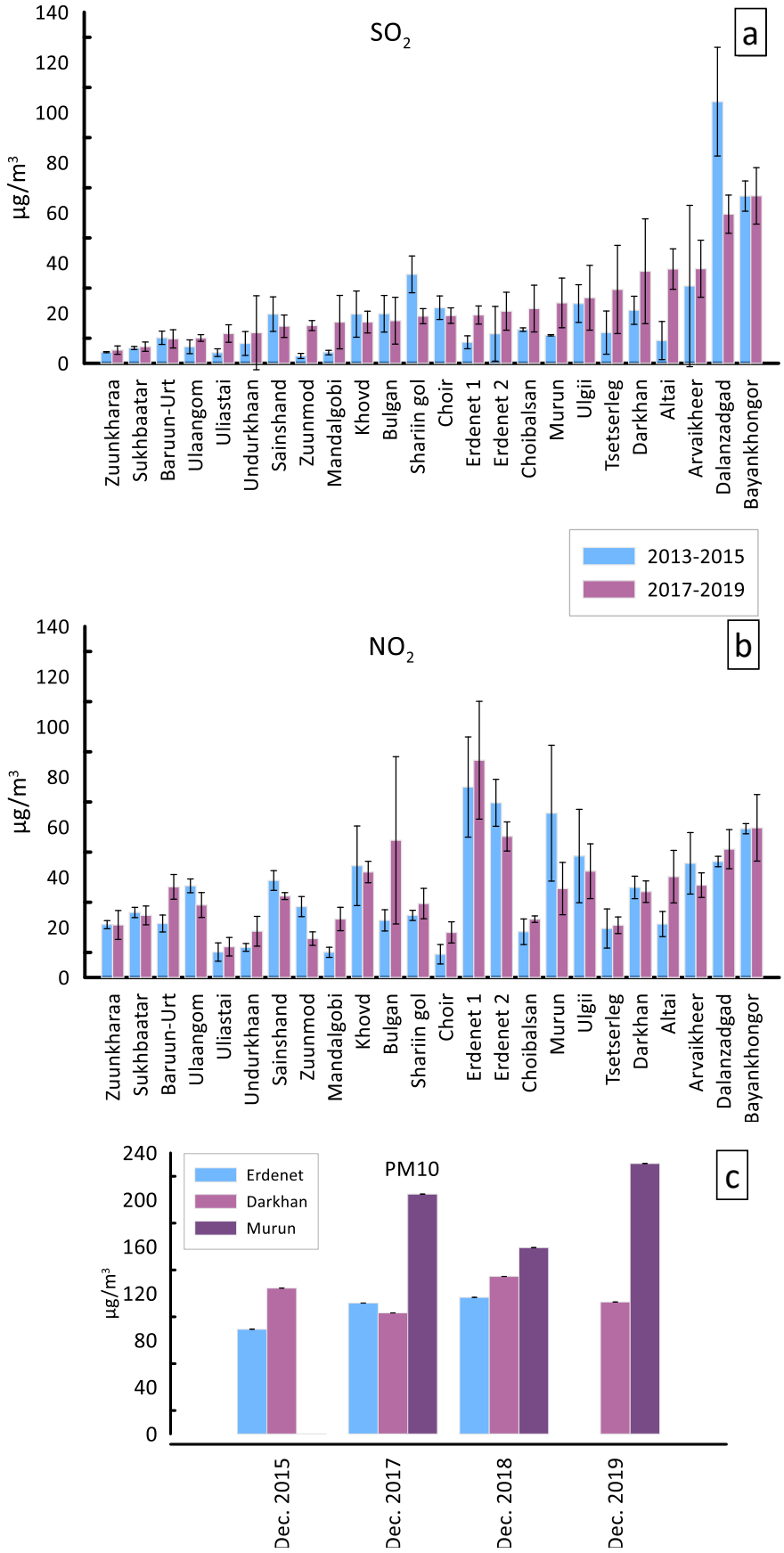

Fig. 2. Monthly mean concentrations for December of (a) SO_2, (b) NO_2, and (c) PM_{10} at the air quality monitoring sites.

2.2–117 μg m^{-3} (not shown here) at the AQ monitoring sites and exceeded the permissible level (50 μg m^{-3}, the daily mean) in Bayankhongor (#5 in Fig. 1 and Table 1) and Dalanzadgad (#8 in Fig. 1 and Table 1) in 2018 (Fig. 2(a)). The mean NO_2 concentrations for December of each year at the AQ monitoring sites varied in the range of 6.4–112 μg m^{-3} (not shown here). In Bayankhongor and Erdenet, high levels of NO_2 were observed, exceeding the national permissible level (50 μg m^{-3}, daily mean) (Fig. 2(b)). Air quality monitoring sites in Bayankhongor and Erdenet are located on roadside and the numbers of automobiles in the cities are dramatically increased in recent years. According to the National Statistical Office of Mongolia, the numbers of automobiles are increased by factor of ~1.8 in Orkhon province (96% of population lives in the Erdenet city) for the last eight years (NSOM, 2020). During the period from 2017 to 2019, the mean concentration of SO_2 for December clearly increased for the most sites in comparison with period from 2013 through 2015 (Fig. 2(a)). Luvsan *et al.* (2012) discussed regular monitoring data of SO_2 from 10 AQ monitoring sites in cities (Khovd, Ulaangom, Murun, Tsetserleg, Arvaikheer, Mandalgobi, Darkhan, Sukhbaatar, Erdenet, and Choibalsan) and four AQ monitoring sites (UB1 to UB4) of Ulaanbaatar for the period 1996–2009 to determine the source area of sulfur dioxide in Mongolia. Clear seasonal variations in SO_2 associated with heating demand in harsh winter and increased emissions from urbanization and industrialization were seen and the annual mean concentrations of SO_2 are likely to rise with increasing population and industrial development (Luvsan *et al.*, 2012). Moreover, the steel industry, mining, and/or other industrial activities can be major contributors to air pollution in Darkhan, Erdenet, and Sukhbaatar (Luvsan *et al.*, 2012).

3.2.2 Particulate matter

As mentioned, particulate matter is the most common polluting parameter in Mongolia due to emissions from incomplete coal combustion in households and soil resuspended dust. Fig. 2(c) shows December mean concentration of PM_{10} at three local sites—Erdenet, Darkhan, and Murun for the period of 2015–2019. As shown in Fig. 2(c), the PM_{10} concentration exceeds the national permissible level at the sites (100 μg m^{-3}, daily mean), with monthly average concentrations ranging between 89 μg m^{-3} (in Erdenet in 2015) and 230 μg m^{-3} (in Murun in 2019) in winter. Bolor-Erdene *et al.* (2011) conducted an analysis of PM_{10} and $PM_{2.5}$ mass concentrations and their elemental compositions in ambient air in the cities of Erdenet and Ulaanbaatar, but detailed information about the sampling period and concentration for the Erdenet cities was not provided (Bolor-Erdene *et al.*, 2011).

3.2.3 Trends of air quality in small cities

According to a report from the Ministry of Environment and Tourism (MET, 2020), the air quality in many cities of Mongolia is getting worse each year. Variations in the yearly mean concentrations of SO_2 at three sites (Bayankhongor, Darkhan, and Arvaikheer, Fig. 2(a)) illustrate a dramatic increase of 50–90% for the 2009–2011 period. In addition to the continuous increase in the pollution level of ambient air in many small and industrial cities of Mongolia, detailed research works on both criteria and trace pollutants—spatial and temporal variations, risk assessment, source characteristics, and socioeconomic, geographical, and climatic condition impacts were not yet systematically investigated or published in international scientific journals. Only two works (Bolor-Erdene *et al.*, 2011; Luvsan *et al.*, 2012) considered a few air pollution parameters outside of the capital city Ulaanbaatar. Both studies noticed clear seasonal variations in pollution levels in ambient air at all investigated sites, with the greatest variations occurring from December to February. The major sources are household and heat power stations' fuel burning for heating, which impacts the seasonal frequency of these air pollutants in Mongolia (Luvsan *et al.*, 2012). Moreover, mining waste dump can have a significant contribution to ambient PM pollution in Erdenet city (Bolor-Erdene *et al.*, 2011). Air pollution from SO_2 in small cities of Mongolia is becoming worse as urbanization (Luvsan *et al.*, 2012) and energy use increase.

3.3 Air Quality Studies in Ulaanbaatar City

Ulaanbaatar, Mongolia, is known as one of the most severely polluted cities in the world (Cousins, 2019). Ulaanbaatar's air pollution has become of increasing concern in recent two decades. Table 2 summarizes international publications focusing ambient air pollution and related

Table 2. Compilation of published studies on ambient air quality in Mongolia.

Study	Study area (number of sites)	Focus	Considered pollutants and data collection	Study period
Guttikunda *et al.* (2013)	UB	• General discussion of PM pollution	• Emission inventory of PM, SO_2, NO_x, CO_2 for 2010; forward trajectory modeling to estimate PM concentration	2010
Amarsaikhan *et al.* (2014)	UB	• General discussions of air pollution	• Recall of previously reported studies	Recall studies covering 2007–2013
Lodoysamba and Pemberton-Pigott (2011)	UB	• Emission inventory	• PM measurement • Multi-element analysis using the ion beam method • Source apportionment	2008–2009
Ganbat and Baik (2016)	UB	• Weather and topographic condition	• Meteorological condition analysis • Numerical weather modeling	2013
Wang *et al.* (2018)	UB	• Impact of meteorological condition on air pollution	• Analysis of meteorological, air quality (PM), ground based LIDAR, and radiosonde data	2008–2016
Wang *et al.* (2017)	UB	• Impact of meteorological condition on air particulate pollution	• Analysis of meteorological and LIDAR data	2010
Prikaz *et al.* (2018)	UB (1)	• Source area of SO_2 by HYPSLIT model	• NO_x, NO, NO_2, O_3, CO, PM_{10}, $PM_{2.5}$, PM_1 from National monitoring network	Over 2017
Luvsan *et al.* (2012)	UB (4) Provinces (10)	• Influence of sources and meteorological conditions on SO_2 pollution by multiple regression models	• SO_2 data from National monitoring network	Multiyear (1996–2009)
Bolor-Erdene *et al.* (2011)	UB (1) Erdenet (1)	• Mass concentration • Elemental composition of $PM_{2.5}$ and $PM_{2.5\text{-}10}$	• $PM_{10\text{-}2.5}$, $PM_{2.5}$ sampling • Elemental analyses by XRF	No information provided
Huang *et al.* (2013)	UB (38)	• Source contributions for SO_2 and NO_2 using land use regression model	• SO_2, NO_2 by 2 weeks passive sampling, analyses	Three different seasons (Sep. 2011–Mar. 2012)
Amgalan *et al.* (2016)	UB (2)	• Elemental composition, • Source contributions PMF model	• Sampling of $PM_{0\text{-}2.2}$, $PM_{2.2\text{-}10}$ • Elemental analyses by XRF	Over 1 year (Sep. 2012–Aug. 2013)
Batmunkh *et al.* (2013)	UB (1)	• Chemical characteristics of atmospheric aerosol during winter	• $PM_{2.5}$ sampling • mass concentration chemical analyses for ions, metals, OC, EC	One season (Jan. 2008–Feb. 2008)
Byambaa *et al.* (2019)	UB (5)	• Source contribution prediction of PAHs in ambient TSP • Health risk assessment based on concentrations	• 15 priority PAHs	1-week sampling at three seasons (Jan. 2017, Mar. 2017, Sep. 2017)
Hasenkopf *et al.* (2016)	UB (1)	• Elemental composition of $PM_{2.5}$ • Physical characterization of $PM_{2.5}$	• $PM_{2.5}$ mass concentration • Elemental analyses • Determination of particle size, shape, and ice nucleation	Nine months (Jun. 2012–Feb. 2013)

Table 2. (*continued*).

Study	Study area (number of sites)	Focus	Considered pollutants and data collection	Study period
Davy *et al.* (2011)	UB (1)	• PM mass concentration • Elemental composition, source contributions by PMF model	• $PM_{10-2.5}$, $PM_{2.5}$ sampling • Elemental analyses by XRF	Multiyear (Oct. 2004–Apr. 2008)
Gunchin *et al.* (2019)	UB	• PM mass concentration • Elemental composition, source contributions by PMF model	• $PM_{10-2.5}$, $PM_{2.5}$, sampling • Elemental analyses by XRF	Multiyear (Jan. 2014–Jan. 2017)
Nishikawa *et al.* (2011)	UB (1)	• Two seasons chemical composition of PM_{10} • Monitoring $PM_{2.5}$ and PM_{10}	• PM_{10} sampling and analyses for ions, elements, OC, EC, C isotope composition in OC • $PM_{2.5}$, SO_2, PM_{10}	• PM_{10} sampling: 1-week each season (Jan. 2008; Jun. 2008) • $PM_{2.5}$, SO_2, PM_{10}-Over a year (Jun. 2009–May 2010)
Oyungerel *et al.* (2013)	UB (12)	• Particle sizes and their distributions of roadside aerosols	• Particles in snow samples	January 2011 (total accumulated snow)
Jung *et al.* (2010)	UB (1)	• Composition of water-soluble organic acids in atmospheric fine PM during winter haze period	• $PM_{2.5}$ sampling • Analyses of 40 water soluble organic acids	Dec. 2007
Jung *et al.* (2011)	UB (1)	• Hydrophobic property of water-soluble organic rich aerosols	• Determination of shape and hydrophobic property of $PM_{2.5}$ samples	Dec. 2007
Lee *et al.* (2018)	UB (2)	• Comparison size and chemical composition of < 2.5 μm of road dust in Ulaanbaatar and in Gwangju, Korea.	• Size and chemical composition of < 2.5 μm dust; metals, ions, carbonaceous compounds	Jan. 2016
Morino *et al.* (2008)	UB (2)	• VOC concentration in ambient air	• 12 VOC in ambient air	No information provided
Ganbat *et al.* (2020)	UB (12)	• Improvement in air quality	• Reduction of $PM_{2.5}$ and PM_{10} concentrations	Multiyear (2014–2020)
Batbold *et al.* (2021)	UB (57)	• Source apportionment of heavy metals from ground surface	• Determination of heavy metal source from settled dust samples	Jan. 2020
Nirmalkar *et al.* (2020)		• Biomass burning contribution OC in $PM_{2.5}$	• $PM_{2.5}$ sampling and analyses of biomass burning markers (levoglugocsan/mannosan), EC, OC, water soluble ions • Data analyses for contribution of biomass burning and non-biomass burning sources in OC	Jan.–Feb. and Apr.–May 2017
Gunchin *et al.* (2021)	UB (1)	• Chemical speciation of Zn and Cr in PM	• PM sampling and analysis by XANES	Jun. 2016–Jan. 2017
Yamamoto *et al.* (2020)	UB (1)	• Chemical characteristics of suspended PM and sources contributions	• PM analyses for OC, metals, ions, n-alkanes and PAHs	Jan. 2014–Apr. 2015

topics mentioned above in Mongolia. Almost all studies conducted on the Ulaanbaatar's air pollution (Table 2), while only two works considered the air pollution in other cities (Bolor-Erdene *et al.*, 2011; Luvsan *et al.*, 2012). To date, ambient air quality and its related topics including chemical composition for both critical and trace (emergent) pollutants, toxicity, physical properties, source characteristics and apportionment, and distribution have been insufficiently studied (see also Fig. 1 of Hasenkopf *et al.*, 2016) (Hasenkopf *et al.*, 2016).

3.3.1 Impacts of climate and topographic conditions

Geographical and weather conditions are important factors affecting air pollution in Ulaanbaatar (Guttikunda *et al.*, 2013). Considering how weather conditions affect air pollution may help understand the essence of air pollution and is important for appropriate reduction measures. Studies attempting to explain the weather and geographical impacts on air pollution in Ulaanbaatar have applied different methods. The city of Ulaanbaatar is located in the valley of Tuul River and surrounded by high mountains (Amarsaikhan *et al.*, 2014). Due to complex topography, the pollutant dispersion is complex in Ulaanbaatar. The valleys, for example the Selbegol valley located to the north of the city, play an important role in transporting the pollutants over/toward the city (Lorentz *et al.*, 2019). In summertime, when the fair condition for the development of local winds is met, urban breeze circulation, mountain/valley winds are well developed (Ganbat and Baik, 2015). Well-developed winds and deep convective boundary layers are capable to transporting pollutants far away from their emission sources. Weather conditions and air circulations on a local scale in summertime (Ganbat and Baik, 2015, 2016) are very different from those in wintertime. In winter, weak local winds are developed in a stable boundary layer (Ganbat and Baik, 2016) where the motion is suppressed resulting in trapped pollutants in the shallow boundary layer. With extreme climate, Ulaanbaatar is the coldest capital of the world; the average temperature of January is –33°C, but the temperatures can drop below –40°C (Pillarisetti *et al.*, 2019). Temperature inversions are frequently observed in mountainous urban areas and can cause severe air pollution problems, especially in wintertime (Luvsan *et al.*, 2012).

During winter periods, the effects of temperature inversion are enhanced because of lower mixing layer heights (Whiteman *et al.*, 1999). Air pollutants emitted from various sources tend to be concentrated within the valley area under the temperature inversion condition, and a layer of cooler air is trapped near the ground by a layer of warmer air above that prevents any dispersion of pollutants (Baumbach and Vogt, 2003). The low wind speed within the atmospheric boundary layer accompanied by the temperature inversion condition due to the Siberian high-pressure system contributes to the increase in air pollutants in winter in Mongolia (Wang *et al.*, 2018; Lorentz *et al.*, 2019). Ganbat and Baik (2016) conducted a numerical modeling experiment to investigate wintertime weather conditions that are favorable for bad air quality in Ulaanbaatar. It was revealed that the air is very stable and windless within the temperature inversion layer, which leads to the stagnation of air pollutants. Spatial and temporal variations of temperature inversion in Ulaanbaatar for the chosen case are clearly presented in the numerical modeling study (Ganbat and Baik, 2016). The numerical study reveals that the temperature inversion is strong and deep in the valleys compared to that over the mountains and mountain slopes. The temperature inversion weakens in the daytime as surface heats.

Wang *et al.* (2018) employed statistical methods using meteorological and air quality observations, LIDAR, and radiosonde data (Wang *et al.*, 2017; Wang *et al.*, 2018). They elucidated the formation and breakup timing of the temperature inversion layer capping the urban area of Ulaanbaatar. A stable atmosphere persists throughout winter (Fig. 6(c) in Wang *et al.* (2018)) and becomes thicker and stronger from September to January. A relatively shallow mixing layer ($<$ 300 m), where the wind is weak and vertical convection is suppressed, allows the air pollutants to stagnate within it. Using observational data for the period 2008–2016, the authors presented a significant positive correlation (R = 0.595) between the temperature inversion intensity and $PM_{2.5}$ concentration in Ulaanbaatar (Wang *et al.*, 2017, 2018).

Statistical analysis of meteorological impacts on SO_2 concentration at 14 different sites in Mongolia was conducted by Luvsan *et al.* (2012). Linear regression model confirmed that SO_2 levels are negatively correlated with wind speed and temperature in Ulaanbaatar and SO_2 pollution has worsened since 2000s because of social impacts including urbanization and industrialization.

The authors mentioned the importance of wind directions in the increase in SO_2 levels due to coal consumption emissions in ger areas. SO_2 levels tend to be higher with winds from N–NNW (north–north northwest) than those from N–ENE (north–east northeast) (Luvsan *et al.*, 2012). Considering the studies on relationship between air pollutant concentrations and several meteorological conditions are insufficient, more sophisticated numerical modeling approach should be applied to understand the complex mechanisms.

3.3.2 Particulate matter

3.3.2.1 Mass concentration

The concentration of inhalable particulate matter (PM_{10} and $PM_{2.5}$) in Ulaanbaatar is the highest in the country, making Ulaanbaatar city one of the most polluted cities in the world for several years (Guttikunda *et al.*, 2013; Cousins, 2019). Due to incomplete combustion in traditional low-efficiency stoves in ger area of Ulaanbaatar, high-concentration particulate matter is emitted from stacks of those stoves. These emissions (from 25% (Guttikunda, 2008) to 87% (Lodoysamba and Pemberton-Pigott, 2011)) result in extremely high concentrations of particulate matter in the urban atmosphere.

Fig. 3 shows the daily mean PM_{10}, $PM_{2.5}$, SO_2, and NO_2 concentrations for 2014–2021 averaged over the AQ monitoring sites in Ulaanbaatar. Prominent seasonal variations are clearly seen having the greatest concentration in cold seasons due to high pollutant emissions resulting from fuel consumption and weather condition with temperature inversion (discussed in Section 3.3.1). The $PM_{2.5}$ concentration is greatest in winter exceeding many times the national permissible level (50 μg m^{-3}) while it is likely to be below/near the permissible level most of the time during warm, non-heating seasons. Ganbat *et al.* (2020) reported the daily (hourly) maximum PM_{10} and $PM_{2.5}$ concentrations of 833.6 (2505) μg m^{-3} and 511.4 (1413) μg m^{-3} for the period, respectively (Ganbat *et al.*, 2020).

Many studies indicated that emissions from coal burning in ger area are the main reason for Ulaanbaatar's pollution problem (Guttikunda *et al.*, 2013; Lodoysamba and Pemberton-Pigott, 2011; JICA, 2017). Over the last decade, a variety of efforts have been made to reduce emissions from polluting sources, special attention has been paid to reduce emissions from ger areas because of coal combustion. A city-wide substitution of raw coal with upgraded briquette coal has been effective in reducing particulate matter pollution and largely reduced the $PM_{2.5}$ and PM_{10} concentrations in winter. In the past two winters, the air quality was improved in Ulaanbaatar to some extent which was first documented in Ganbat *et al.* (2020). For winter 2019–2020, the daily mean concentrations of $PM_{2.5}$ and PM_{10} during the heating season were reduced by 36% and 40% compared to the heating seasons in 2014–2018, respectively. The improvement was mainly by the city-wide substitution of raw coal with upgraded briquette fuel since 15 May 2019 according to Governmental resolution No. 62 adopted in 2018. Despite the progress in reductions in PM concentrations, the PM concentrations are still well above the WHO guideline values and the national standard levels.

3.3.2.2 Chemical composition

a) Elemental composition

Various organic and inorganic toxic substances can be present on particulate matter emitted from coal combustion as soot and ash particles. The elemental compositions of fine particulate matter in Ulaanbaatar ambient air were previously investigated in several locations by separating two different sizes of fine (aerodynamic diameter less than 2.5 μm) and coarse (between 2.5 and 10 μm) fractions (Davy *et al.*, 2011; Amgalan *et al.*, 2016; Hasenkopf *et al.*, 2016; Gunchin *et al.*, 2019). The main discussions were conducted on the source contributions of atmospheric particulate matter in the atmosphere based on seasonal variation and PMF (positive matrix factorization) analyses. Based on an investigation of a multiseasonal long period between 2004 and 2008 (Davy *et al.*, 2011), the combustion sources, such as coal combustion, biomass burning, and motor vehicles, dominated the fine fraction of particulate matter in Ulaanbaatar, primarily from local emission sources, but forest fires in the north can be a significant contributor to biomass burning concentrations over time. Crustal dust sources were the primary contributors to the coarse particle fraction ($PM_{2.5\text{-}10}$). For the study period, at the site of city center (National University of Mongolia), the distributions of source contribution of the coarse particulate matter ($PM_{2.5\text{-}10}$)

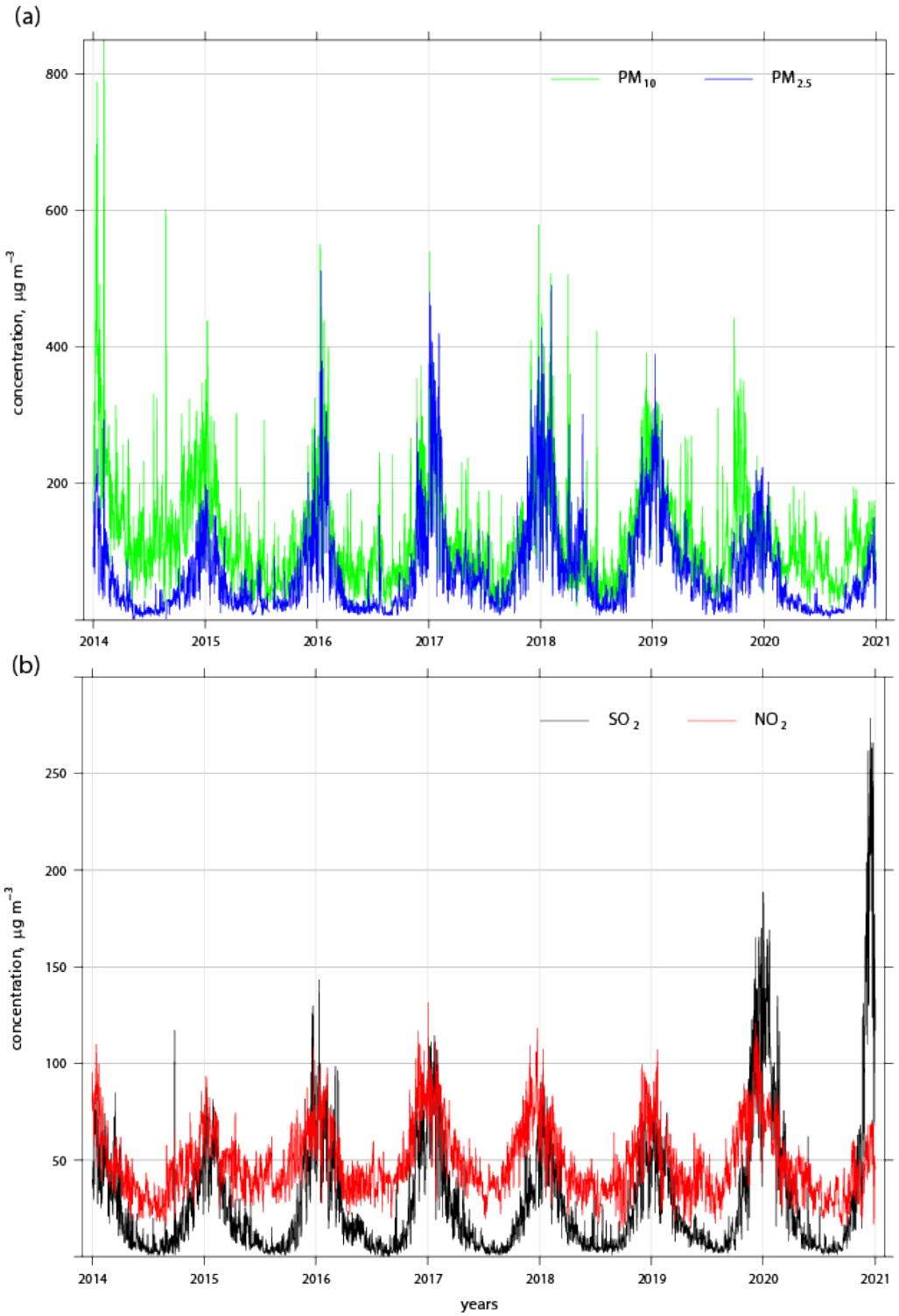

Fig. 3. Daily mean concentrations of (a) PM_{10}, $PM_{2.5}$ and (b) SO_2, NO_2 for 2014–2021 averaged over the AQ monitoring sites in Ulaanbaatar.

were in the order: soil > road dust > combustion, while of the fine particulate matter ($PM_{2.5}$), more categories were separated and in the order: combustion > soil > road dust > motor vehicles > biomass burning. There was also an unknown source grouped with high Zn loading for fine aerosols (Davy *et al.*, 2011). In addition, the results of different studies on source contributions for particulate matter can differ depending on time and locations of the studies. In an investigation by Amgalan *et al.* (2016) using the same techniques as Davy *et al.* (2011), source contribution of

$PM_{2.5}$ were observed at two suburban ger areas of the city over the period of Sep 2012–Aug 2013. In the ger area, the source contribution of $PM_{2.5}$ aerosols were determined in the following order: combustion > road dust > motor vehicles > soil. At another site located in the eastern part of the city, the contribution of $PM_{2.5}$ changed to the following order: soil > combustion > motor vehicle > road dust (Amgalan *et al.*, 2016).

While numerous studies of approaches on elemental composition and organic compounds (described in the next section) in PM have been carried out, the only study was recently conducted on chemical speciation of zinc (Zn) and chromium (Cr) in aerosols. Gunchin *et al.* (2021) introduced a chemical speciation analysis of two elements in fine ($PM_{2.5}$) and coarse ($PM_{2.5\text{-}10}$) particulate matters based on the results of X-Ray Absorption Near-edge Structure Spectroscopy measurements. According to the results, chromium (Cr) was dominant in the form of tri-valent chromium sulfate ($Cr_2(SO_4)_3$) and chromium oxide (Cr_2O_3) for both $PM_{2.5}$ and $PM_{2.5\text{-}10}$ fractions. Relative abundances of those forms were varied between the samples, but no direct relation was observed with Cr and S concentrations in aerosol. Two abundant speciation of Zn—sulfate ($ZnSO_4$) and silicate (Zn_2SiO_4) were identified for both fine and coarse PM fractions. Zn oxalate (ZnC_2O_4) was determined in fine particles, while Zn chloride ($ZnCl_2$) in the coarse particles and the relative abundances of the species of Cr and Zn were also had no direct relation with the concentrations of Zn, S, Si, and Cl. The authors concluded that Cr and Zn were mainly originated from anthropogenic sources—combustion and resuspension of dust particles due to traffic (Gunchin *et al.*, 2021).

b) Combined approaches for chemical composition and sources

The chemical compositions of atmospheric fine aerosols ($PM_{2.5}$) in Ulaanbaatar city including water-soluble organic acids (Jung *et al.*, 2010) and ionic, elemental, and carbonaceous compounds (organic and black carbon) were investigated during winter haze events (Jung *et al.*, 2010; Nishikawa *et al.*, 2011; Batmunkh *et al.*, 2013) and compared with those of the warm season (Nishikawa *et al.*, 2011). According to these earlier studies performed decade ago, ionic, metallic, and carbonaceous compositions of particulate matter in Ulaanbaatar ($PM_{2.5}$ and PM_{10}) are attributed mostly to coal combustion products in the winter (heating) period (Nishikawa *et al.*, 2011; Batmunkh *et al.*, 2013). Carbon components (OC and EC) are dominant in PM_{10} for both heating (47%) and non-heating (33%) seasons in Ulaanbaatar air (Nishikawa *et al.*, 2011). Concentrations of OC (EC) were ranged between 45.4 μg m^{-3} and 119 μg m^{-3} (18.7 μg m^{-3} and 30 μg m^{-3}) in heating season and between 10.1–27.3 μg m^{-3} (4.31-8.28 μg m^{-3}) in non-heating season (Nishikawa *et al.*, 2011). During the same year in winter (2008), the organic mass carbon content in $PM_{2.5}$ counted 62.7%, and the content of ammonium sulfate followed, with a 12.6% contribution (Batmunkh *et al.*, 2013). Elemental concentration and their ratios are clearly distinguished for different sampling periods due to their dominant sources, e.g., coal combustion in heating season, while soil dust resuspension in non-heating season. The research by Jung *et al.* (2010) firstly reported the dicarboxylic acids, ketocarboxylic acids, and α-dicarbonyls, and as well as soluble inorganic ions of $PM_{2.5}$. The most part of aerosols were composed from emissions from local sources and as well as weather/geographical condition is a key factor of occurrence of haze events. Distributions of dicarboxylic acids and related compounds were determined to have a predominance of terephthalic acid followed by oxalic, succinic, glyoxylic, and phthalic acids (Table 3), which indicated a significant contribution from the uncontrolled burning of plastic materials in home stoves for heating and waste incineration during the cold winter (Jung *et al.*, 2010).

Recently, Nirmalkar *et al.* (2020) conducted research on estimation of organic carbon emissions from biomass burning in Ulaanbaatar based on organic carbon (OC) and elemental carbon (EC), anhydrosugars (levoglucosan, mannosan, and galactosan), and water-soluble ionic composition. Biomass and coal burning and followed by soil dust and secondary aerosols formation were the major sources of $PM_{2.5}$. Similar to previous findings, in winter and spring, the OC was found to be a major component in $PM_{2.5}$ constituting 64% and 56%, respectively, and 68% and 63% of the OC were emitted from biomass burning, respectively. The indicator compounds such as levoglucosan/mannosan and levoglucosan/K^+ ratios revealed that the softwood burning aerosols in Ulaanbaatar is a major source of organic carbon in $PM_{2.5}$. Multivariate correlation analysis identified that non-biomass burning organic carbon is dominantly produced by coal burning and followed by vehicle and vegetative emissions (Nirmalkar *et al.*, 2020).

Table 3. Concentrations of dicarboxylic acids and related compounds in $PM_{2.5}$ of Ulaanbaatar (Jung *et al.*, 2020).

Compounds	Concentration, ng m^{-3}	Percentage in total organic acids, %
Terephthalic acid	130 ± 51	19
Oxalic acid	107 ± 28	15
Succinic acid	63 ± 20	9
Glyoxylic acid	55 ± 18	8
Phthalic acid	54 ± 27	8

Soil dust contributions existed with almost the same contributions in two seasons, heating (January) and non-heating (June) (Nishikawa *et al.*, 2011). The meteorological conditions were determined to be the most impactful factor on the particulate matter concentration level in Ulaanbaatar (Jung *et al.*, 2010; Batmunkh *et al.*, 2013). During high-speed windy days with low atmospheric pressure (LP), the PM concentrations were lower by a factor of two or three than those on high-pressure days with a comparably stable stagnant atmosphere (Batmunkh *et al.*, 2013). Most of the air pollutants were directly emitted from local sources such as heat and power plants, home stoves, and automobiles during the winter season (Jung *et al.*, 2010).

c) Organic pollutants

Since the main producer of atmospheric pollution in the city is coal combustion (Guttikunda *et al.*, 2013; JICA, 2017), trace amounts of organic toxic compounds that are emitted by incomplete combustion (i.e., various types of PAHs) (Bari *et al.*, 2010; Sarigiannis *et al.*, 2015) are expected to be present at high concentrations in the air of Ulaanbaatar. However, very few research studies have been performed and published internationally on this topic. Total suspended particles (TSPs) collected from five different locations of the city for the heating and non-heating period of 2017 were investigated by Byambaa *et al.* (2019). The total PAH concentrations (15 priority PAHs) ranged between 131 and 773 ng m^{-3} in winter, 22.2 and 530.6 ng m^{-3} in spring, and 1.4 and 54.6 ng m^{-3} in autumn and showed a high risk for inhabitants, with the PAH levels exceeding the World Health Organization guidelines in winter (Byambaa *et al.*, 2019). In addition, a significantly higher concentration of 16 priority PAHs in inhalable particulate matter ($PM_{2.5}$) in the ambient air of the ger area in Ulaanbaatar was observed during the transition period between the heating and non-heating periods (Feb–Apr 2019) (Lorentz *et al.*, 2019). The risk level of PAHs bound to PM_{10} was calculated to be extremely high (with a benzo[a]pyrene equivalent factor of 32 ± 17) and similar to that in the most polluted industrial city, Tianjin in China (29.7 ± 15.1 recalculated) (Jin *et al.*, 2018). Further detailed investigations on PAHs for fine atmospheric PM including size and molecular distributions as well as different source contributions and impacting parameters are urgently needed in Ulaanbaatar city to provide guidance to people to avoid exposure to such highly toxic carcinogenic compounds. It can also be noted that in addition to evaluation of the pollution level in ambient air, atmospheric transfer mechanisms, which depend on the climatic factors in the city air, as well as environmental fate and transfer through the geochemical cycle in certain conditions of the country can be important research topics.

d) Dust deposition

Lee *et al.* (2018) investigated size and chemical composition of a fine fraction (< 2.5 μm) of road dust collected from two locations in Ulaanbaatar and compared with those in Gwangju, South Korea. The authors found greater fractions of ultrafine fine (~30 nm) particles in UB road dust with comparably higher concentrations of As, SO_4^{2-}, and Cl^- and is indicated significant impact of residential coal/biomass burning. In a recent study, application of chemical methods of atmospheric dry deposited dust is used to determine the sources for the seven potentially toxic metals (As, Co, Cr, Cu, Ni, Pb, and Zn) in heating season based on settled dust analyses sampled at 57 sites in Ulaanbaatar (Batbold *et al.*, 2021). The results showed that the metals composition in settled dust are attributed to coal combustion, vehicle exhaust emission, and soil particles. Southern part of the city is enriched with comparably high concentrations of As, Zn, Cu, and Cr when compared to other parts of the city and are mainly attributed to coal combustion sources.

3.3.3 Physical properties

The size distribution of the nanosized fraction of ambient air particulate matter along the roadside was investigated by Oyungerel *et al.* (2012). Snow samples collected from twelve locations of the city were used for particle size and size distribution analysis by photon cross-correlation spectroscopy. The particle mean diameters were found to be from 1.1 to 2.5 μm, ranging between 74 nm and 4.0 μm. Ultrafine particles or nanoparticles (0.02% volume percent) were found in the range of 74–100 nm, while 83.73% fine particles ($PM_{2.5}$) were found in the range of 100 nm–2.4 μm, and 16.25% coarse particles (PM_{10}) were found in the range of 2.4–4.0 μm. Aerosols along the road had a high content of $PM_{2.5}$ particles (Oyungerel *et al.*, 2012). Hasenkopf *et al.* (2016) studied the particle sizes, shapes, and ice-nucleating properties of particulate matter collected during different seasons. As a result, all particles are in the inhalable range, with almost all particles smaller than 2.5 mm, composed of minerals, soot, and sulfate-organic compounds. The particle concentration and sulfur content of particles increase in winter with lower ice nucleation activity (Hasenkopf *et al.*, 2016). Moreover, the hygroscopic property of water-soluble organic-enriched aerosols in Ulaanbaatar during the winter of 2007 was investigated by Jung *et al.* (2011). The authors found that hygroscopic growth of water-soluble organic matter (WSOM) in at RH 85% (g(85%)) is ranged between 1.11 and 1.35 (avg. 1.23 ± 0.10), which are comparable to those of the biomass burning aerosols (Jung *et al.*, 2011).

3.3.4 Other pollutants

a) Sulfur dioxide (SO_2)

As expected, in Mongolia, SO_2 pollution in winter is more serious than that in the other three seasons. According to the observational data from 1996-2009 at the AQ monitoring sites in Ulaanbaatar (UB1, UB2, UB3, and UB4, see Table 1), the daily mean concentrations of SO_2 were 27.3 ± 24.7 μg m^{-3} and increased dramatically during the study period (Luvsan *et al.*, 2012). The observed results are attributed to the use of raw coal in ger area for heat production over the years, where this coal without a washing pretreatment contains a significant amount of sulfur (Prikaz *et al.*, 2018). The main SO_2 emitters in Ulaanbaatar are combustion sources such as ger stoves, traffic and power plants. All seasonal fluctuations in SO_2 emissions are shown to be due to the increase in fuel consumption requirements in cold weather conditions (Luvsan *et al.*, 2012). Prikaz *et al.* (2018) investigated source areas of SO_2 in Ulaanbaatar based on whole-year data of air pollutants (NO_x, NO, NO_2, O_3, CO, PM_{10}, $PM_{2.5}$, and PM_1) measured at the APRD3 site (Fig. 1) and using HYSPLIT backward trajectory analyses (Prikaz *et al.*, 2018). According to the results, in 2017, the annual average concentration of SO_2 at the site was 32.43 μg m^{-3} and the hourly maximum concentration reached 233.2 μg m^{-3} in January. Back trajectory analyses showed that 78.8% of the total trajectories in Ulaanbaatar came from an area inside Mongolia.

Fig. 3(b) shows a noticeable variation of SO_2 with seasons and worsened SO_2 pollution in recent years in Ulaanbaatar city. The seasonal variation of SO_2 is similar to that of particulate matter showing a significantly higher concentration in winter than in summer. Compared with that in winters before 2018/2019, SO_2 increased by 41% in the following two winters, which has already elicited concerns. However, no study to date has yet elaborated and reported the recent increase in SO_2 concentration in Ulaanbaatar. Sulfur content in briquette fuel is ~0.9% (MNIA, 2019) and is not exceeding the National Standard (MNS 5679:2019, < 1.0% S), however, is approximately two times higher than that in Baganuur coal (0.42% S) (JICA, 2013), previously used as the main fuel of residences of Ulaanbaatar's ger area before the substitution to briquette in 2019. Thus, further investigation is needed by combining of fuel's characteristics (e.g., caloric values, compositions, and ash contents), emissions to propose adequate measures to reduce SO_2 pollution in Ulaanbaatar.

As shown in Table 2, the source apportionment studies for the SO_2 level and sulfur compounds in the particulate matter have not been sufficiently conducted in Mongolia. Spatial distributions of SO_2 and source characteristics across Ulaanbaatar were investigated by Huang *et al.* (2013). The authors collected multiseasonal passive samples from 38 locations in 2011–2012 and evaluated the impact of land use patterns on SO_2 and NO_2 distributions by multiple regression models. The SO_2 concentrations were 121.9 μg m^{-3} in the cold season and 46.62 μg m^{-3} in the moderate season (units were converted from ppb in original). Ger area sites showed significantly

higher SO_2 concentrations than non-ger area sites (60.09 μg m^{-3} and 32.78 μg m^{-3}, respectively). These results also supported that the main source of atmospheric SO_2 in the winter season is coal combustion in ger areas (Huang *et al.*, 2013).

On the other hand, when considering the recent increase in vehicle and fuel consumption accordingly in the city due to an increasing population and number of vehicles, a high contribution from fuel combustion to the urban atmosphere is expected. This expectation is supported by the analytical results of fuels used in Mongolia. According to the Tables 1 and 2 of Bayasgalan *et al.* (2018), there are extremely high concentrations of sulfur in gasoline (117–400 ppm S) and diesel (1,135–1,165 ppm S) used in Mongolia, exceeding the Euro 4 standard (50 ppm S) by 2–8 times and 22–23 times, respectively (Bayasgalan *et al.*, 2018). So far, there have been no reported contributions of SO_2 from other sources related to industrial activities within the Ulaanbaatar city. Thus, detailed studies on the source contributions of SO_2 and sulfur compounds in the atmospheric particulate matter would have been one of the urgently needed research topics.

b) Nitrogen dioxide (NO_2)

As described in the previous sections, in addition to coal combustion, automobile emissions play a significant role in air pollution in cities (Davy *et al.*, 2011; Amgalan *et al.*, 2016). For the last ten years, the number of vehicles has increased in Ulaanbaatar by a factor of 4.5 and has reached ~540,000 (Bayasgalan and Matsumoto, 2017; NSOM, 2021). Approximately 72% of all vehicles were aged more than 10 years, and most of them were second-hand (Bayasgalan and Matsumoto, 2017). In connection with automobile emissions, NO_2 concentrations detected at roadside sites of NAMEM were in the range of 41–65 μg m^{-3} and exceeded national air quality guidelines for 97% of all measured days in 2014 (Bayasgalan and Matsumoto, 2017). The only study (Huang *et al.*, 2013) reported the seasonal variation in ambient NO_2 pollution, its spatial distribution, and the contributions of different sources in Ulaanbaatar. As described above, through two weeks of passive sampling at 38 locations in the warm, cold, and moderate seasons of 2011–2012, ionic analyses of the samples, and multiple regression models, ambient NO_2 pollution was explained by several land-use variables. As a result, the NO_2 concentrations at traffic road-side sites in the warm and moderate seasons (24.16 μg m^{-3} and 38.51 μg m^{-3}, respectively, units were converted from ppb in original) were significantly higher than those at urban sites (14.3 μg m^{-3} and 27.06 μg m^{-3}). Otherwise, during the cold season, significantly higher concentrations of NO_2 were observed, with an average of 66.9 ±19.9 μg m^{-3} for all sites without a clear distinction between land use types (Huang *et al.*, 2013). Primarily, NO released into the air from the automobiles, and is converted to NO_2 in the atmosphere with the presence of oxidants (e.g., ozone). The conversion rate is increased in warm and moderate season when level of ozone concentration is higher. Thus, further evaluation for the variations of NO, NO_2 and ozone is needed to distinguish sources contributions for NO_x (NO and NO_2) over the year.

c) Volatile organic compounds

Volatile organic compounds (VOCs) are one group of components of air pollution comprising a complex mix of hundreds of carbon-containing gases. If VOCs occur in high concentrations in ambient air, exceeding permissible levels, then exposure can cause health risks (Han *et al.*, 2017; Barabad *et al.*, 2018; Kumar *et al.*, 2018). On the other hand, VOCs are the main precursors that form secondary air pollutants such as ozone through photochemical reactions in the atmosphere especially on hot and sunny days (Han *et al.*, 2017; Kumar *et al.*, 2018). The assessment of VOCs is not included in air quality network monitoring in Mongolia. Regarding the lack of analytical capacity, there have been almost no attempts made to identify, quantify, and characterize VOCs in urban or rural areas in Mongolia. Much earlier, Morimo *et al.* (2008) detected several VOCs in urban air and reported the results in conference proceedings, but no information about sampling sites or the duration of the study was provided. Significantly elevated concentrations of VOCs were detected in Ulaanbaatar air. The concentrations of 1,3-butadiene, chloroform, and benzene in the ambient air of Ulaanbaatar were much higher than those in the Japan Environmental Standards (Morimo *et al.*, 2008). More recently, the spatial distribution of VOCs at six sampling sites was determined within the framework of a collaborative project between German and Mongolia (Lorentz *et al.*, 2019). Three main VOCs, BTX (benzene, toluene, xylene), were detected by passive sampling in four weeks. Similar to those in other Asian cities, the VOC levels measured

in urban areas in Mongolia appear to be affected by automobile exhaust. The VOC concentrations near high traffic density were higher than those measured at other locations. Urban VOC emissions often represent a complex mix of traffic, industry, solvents, waste burning, and other sources (Barabad *et al.*, 2018).

d) Ozone (O_3)

Tropospheric ozone is a main secondary pollutant formed by photochemical reactions between oxides of nitrogen (NO_x) and volatile organic compounds (VOC). The precursors, NO_x and VOC, are primarily emitted by a various source in urban area including cars, power plants, industrial boilers, refineries, chemical plants, and other sources and chemically react in the presence of sunlight to produce ozone. Typically, ozone concentration is increased to unhealthy levels on hot sunny days in urban environments. Very scarce literature is available on ozone pollution in Ulaanbaatar. Dugerjav *et al.* (2013) analyzed ambient O_3 concentration for four measuring sites of Ulaanbaatar and indicated that the daily averaged O_3 were higher in summer season and were exceeded the national air quality permissible level (8-hour mean) at UB01 site and UB08 on some days (Dugerjav *et al.*, 2013). Dorligjav *et al.* (2014) studied temporal variation of ground level ozone over Ulaanbaatar by using surface observation, radiosonde, and air mass back trajectory analyses during 2014. The authors noted that there is a linear relationship between the ozone and sunshine duration. The ozone concentration also showed a logarithmic relationship with water vapor and a hyperbolic relationship with CO and NO_x (Dorligjav *et al.*, 2014). Based on the measurements at three AQ monitoring sites for 2020 (Fig. 4), O_3 level in Ulaanbaatar is not serious and is well below the permissible level (100 μg m^{-3}, 8-hour mean) for whole year in comparison to many other cities in the world, where the O_3 pollution is a serious problem. Higher level of O_3 concentration is possibly related to the high traffic emission density on weekdays.

4 FUTURE RESEARCH NEEDS

In reviewing the current state of knowledge for urban air quality studies and overviewing the urban air quality in Mongolia, we found a growing interest in reporting fundamental studies of concentrations and physical and chemical characteristics of air pollutants in Ulaanbaatar. The

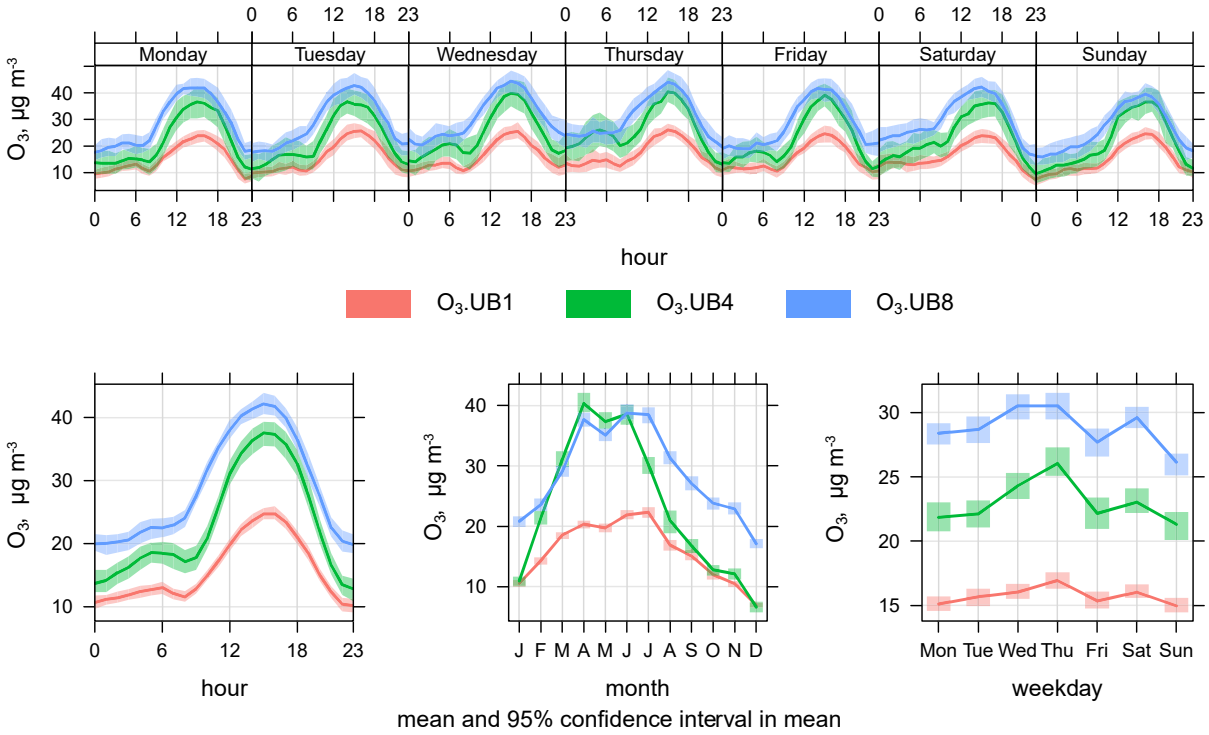

Fig. 4. Diurnal, weekly, and annual variations of ozone in Ulaanbaatar for 2020.

frame of related scientific studies is still inadequate. Therefore, our review paper suggests several directions for future research.

To the authors' knowledge, there is no extensive scientific study reporting up-to-date emission inventory and its application in numerical modeling for scenario analysis. In addition, a better understanding of the air pollution sources and their chemical composition, stable and radiogenic isotopes and other tracer to identify source contributions and relevant studies coupled with modeling investigations are helpful for decision-makers to address the scope for policy interventions and take measures on controlling the pollutant emissions. Improvement in investigations on the source contributions of SO_2 and sulfur compounds in the atmospheric particulate matter should be feasible.

Further studies on air quality issues in other industrial cities/provinces such as Darkhan and Erdenet are recommended to systematically extend the current knowledge. The establishment of air quality monitoring sites and improvement in air quality investigations need continued emphasis to provide guidance in optimizing control measures.

Studies on size distribution using cascade impactors have not been reported, and size distribution in real-time size and composition distribution measurements are also not conducted up to date. Measurements and studies on VOC and organic trace gases are still limited in Mongolia. Further improvement on the investigation of the emission and formation of organic compounds are needed. Since there is a lack of control and management system on the usage and emission of hazardous volatile compounds in Mongolia (Barabad *et al.*, 2018; Bayasgalan *et al.*, 2018), further investigations through long-term and multiple-point observations are strongly needed to evaluate major sources, risks to inhabitants, and possible contributions to the regional atmosphere. Future research should aim to investigate the PAHs for fine atmospheric PM in details to provide a guidance to people to avoid exposure to toxic carcinogenic compounds.

Since the introduction of briquette fuel in Ulaanbaatar, current scientific knowledge on emission inventory and source apportionment is still limited; thus, further studies should address these uncertainties. Beyond knowledge in sources, a better understanding of the vertical structure of air pollution and the relationship with weather condition in Ulaanbaatar is important to explain air pollution more in-depth. In line with the necessity of society to prevent air pollution, further research area should be expanded into the comprehensive numerical modeling and dynamical forecast of air quality in cities of Mongolia. The efforts on air quality modeling techniques of computational fluid dynamics, urban air pollution and climate integrated modeling will greatly improve understanding of air pollution behavior and its environmental impacts and enable to run future scenarios. Apart from modeling activities, measurements of different parameters in different areas, especially in obviously high polluted areas, should be extended and intensified.

Study on contributions of human activities on pollutant characteristics and behavior, such as traffic related air pollution, is suggested to be conducted. Furthermore, since the surrounding environment of the monitoring sites affect the measurement, further identification of the influencing factors on measurement sites is necessary. Since the dust storm event, the biggest source of coarse particles in non-heating season, is frequent in Mongolia, the detailed investigations to differentiate the natural and anthropogenic sources of particulate matter should be conducted.

Finally, little is known regarding the impacts of air pollution on ecosystem and urban greening. A worthwhile future endeavor would include environmental impacts of air pollution and a next step is to identify environmental risks associated with long-term air pollution in Ulaanbaatar and other urban areas in Mongolia.

5 CONCLUSIONS

In this paper, we present a systematic review of the studies that have investigated air pollution in Mongolia, mainly focusing on air pollution studies in Ulaanbaatar since there is a lack of comprehensive studies on air pollution in other cities. As extremely high pollution appears and becomes a major concern in Mongolia, a significant body of research has addressed the problem.

Based on this systematic review of existing research works, particulate pollution is the most severe, and it is a primary pollutant in cities of Mongolia. Studies have been adequately reported the sources and composition of particulate matter in Ulaanbaatar. Most studies focused on mass

concentration and the chemistry (ions, metals, EC/OC) of the TSP, PM_{10} and $PM_{2.5}$ components, however, frequent updates are essential. It is already known that an increase in NO_2 is closely associated with an increase in the number of vehicles. Sulfur dioxide (SO_2) emission is mainly associated with coal combustion and partly with transport activities. Compared to a growing number of air quality studies in Ulaanbaatar, the air quality studies in other provinces are still limited. The findings on the urban air quality studies in Mongolia informs several directions for future research.

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REFERENCES

Allen, R.W., Gombojav, E., Barkhasragchaa, B., Byambaa, T., Lkhasuren, O., Amram, O., Takaro, T.K., Janes, C.R. (2013). An assessment of air pollution and its attributable mortality in Ulaanbaatar, Mongolia. Air Qual. Atmos. Health 6, 137–150. https://doi.org/10.1007/s11869-011-0154-3

Amarsaikhan, D., Battsengel, V., Nergui, B., Ganzorig, M., Bolor, G. (2014). A study on air pollution in Ulaanbaatar city, Mongolia. J. Geosci. Environ. Prot. 2, 123–128. https://doi.org/10.4236/gep.2014.22017

Amgalan, N., Narantsetseg, T., Shagjjamva, D. (2016). Valuations of elemental concentrations of particle matter in Ulaanbaatar, Mongolia. Open J. Air Pollut. 5, 160–169. https://doi.org/10.4236/ojap.2016.54012

Barabad, M.L.M., Jung, W., Versoza, M.E., Kim, M., Ko, S., Park, D., Lee, K. (2018). Emission characteristics of particulate matter, volatile organic compounds, and trace elements from the combustion of coals in Mongolia. Int. J. Environ. Res. Public Health 15, 1706. https://doi.org/10.3390/ijerph15081706

Bari, M.A., Baumbach, G., Kuch, B., Scheffknecht, G. (2010). Particle-phase concentrations of polycyclic aromatic hydrocarbons in ambient air of rural residential areas in southern Germany. Air Qual. Atmos. Health 3, 103–116. https://doi.org/10.1007/s11869-009-0057-8

Batbold, C., Chonokhuu, S., Buuveijargal, K., Gankhuyag, K. (2021). Source apportionment and spatial distribution of heavy metals in atmospheric settled dust of Ulaanbaatar, Mongolia. Environ. Sci. Pollut. Res. 28, 45474–45485. https://doi.org/10.1007/s11356-021-13861-2

Batmunkh, T., Kim, Y.J., Jung, J.S., Park, K., Tumendemberel, B. (2013). Chemical characteristics of fine particulate matters measured during severe winter haze events in Ulaanbaatar, Mongolia. J. Air Waste Manage. Assoc. 63, 659–670. https://doi.org/10.1080/10962247.2013.776997

Batsaikhan, N., Lee, J., Nemer, B., Woo, N. (2018). Water resources sustainability of Ulaanbaatar City, Mongolia. Water 10, 750. https://doi.org/10.3390/w10060750

Baumbach, G., Vogt, U. (2003). Influence of inversion layers on the distribution of air pollutants in urban areas. Water Air Soil Pollut. 3, 65–76. https://doi.org/10.1023/A:1026098305581

Bayasgalan, B., Matsumoto, T. (2017). Estimation and prediction of road traffic emissions in Ulaanbaatar. J. JSCE 73, I_183–I_190. https://doi.org/10.2208/jscejer.73.I_183

Bayasgalan, B., Matsumoto, T., Altangerel, O. (2018). On-board measurement and emission prediction from vehicle engines using ordinary fuel and fuel additives in Mongolia. J. JSCE 6, 118–126. https://doi.org/10.2208/journalofjsce.6.1_118

Bilgili, F., Koçak, E., Bulut, Ü., Kuloğlu, A. (2017). The impact of urbanization on energy intensity: Panel data evidence considering cross-sectional dependence and heterogeneity. Energy 133, 242–256. https://doi.org/10.1016/j.energy.2017.05.121

Bolor-Erdene, D., Ganbaatar, D., Shagjjamba, D., Tugjsuren, N. (2011). The study on Ambient Air Quality in the some cities of Mongolia, Proceedings of 2011 6th International Forum on Strategic Technology. IEEE, pp. 495–498.

Byambaa, B., Yang, L., Matsuki, A., Nagato, E.G., Gankhuyag, K., Chuluunpurev, B., Banzragch, L., Chonokhuu, S., Tang, N., Hayakawa, K. (2019). Sources and characteristics of polycyclic aromatic hydrocarbons in ambient total suspended particles in Ulaanbaatar City, Mongolia. Int. J. Environ. Res. Public Health 16, 442. https://doi.org/10.3390/ijerph16030442

Cousins, S. (2019). Air pollution in Mongolia. World Health Organization. Bull. World Health Organ. 97, 79–80. https://doi.org/10.2471/BLT.19.020219

Davy, P.K., Gunchin, G., Markwitz, A., Trompetter, W.J., Barry, B.J., Shagjjamba, D., Lodoysamba, S. (2011). Air particulate matter pollution in Ulaanbaatar, Mongolia: Determination of composition, source contributions and source locations. Atmos. Pollut. Res. 2, 126–137. https://doi.org/10.5094/APR.2011.017

Dorligjav, S., Sumiya, E., Purevjav, G. (2014). Influence of photochemistry and meteorology on seasonal variation of surface ozone. National Agency for the Meteorology and Environmental Monitoring, Mongolia.

Dugerjav, O., Sato, K., Ohizumi, T. (2013). Long range transport of air pollutants (trace gases) related with meteorological process in Asia (subregion). EANET Research Fellowship Program 2013.

Fan, P., Chen, J., John, R. (2016). Urbanization and environmental change during the economic transition on the Mongolian Plateau: Hohhot and Ulaanbaatar. Environ. Res. 144, 96–112. https://doi.org/10.1016/j.envres.2015.09.020

Ganbat, G., Han, J.Y., Ryu, Y.H., Baik, J.J. (2013). Characteristics of the urban heat island in a high-altitude metropolitan city, Ulaanbaatar, Mongolia. Asia Pac. J. Atmos. Sci. 49, 535–541. https://doi.org/10.1007/s13143-013-0047-5

Ganbat, G., Baik, J.J. (2015). Local circulations in and around the Ulaanbaatar, Mongolia, metropolitan area. Meteorol. Atmos. Phys. 127, 393–406. https://doi.org/10.1007/s00703-015-0374-4

Ganbat, G., Baik, J.J. (2016). Wintertime winds in and around the Ulaanbaatar metropolitan area in the presence of a temperature inversion. Asia Pac. J. Atmos. Sci. 52, 309–325. https://doi.org/10.1007/s13143-016-0007-y

Ganbat, G., Soyol-Erdene, T.O., Jadamba, B. (2020). Recent improvement in particulate matter (PM) pollution in Ulaanbaatar, Mongolia. Aerosol Air Qual. Res. 20, 2280–2288. https://doi.org/10.4209/aaqr.2020.04.0170

Gunchin, G., Manousakas, M., Osan, J., Karydas, A.G., Eleftheriadis, K., Lodoysamba, S., Shagjjamba, D., Migliori, A., Padilla-Alvarez, R., Streli, C. (2019). Three-year long source apportionment study of airborne particles in Ulaanbaatar using X-ray fluorescence and positive matrix factorization. Aerosol Air Qual. Res. 19, 1056–1067. https://doi.org/10.4209/aaqr.2018.09.0351

Gunchin, G., Osan, J., Migliori, A., Shagjjamba, D., Streli, C. (2021). Chromium and zinc speciation in airborne particulate matter collected in Ulaanbaatar, Mongolia, by X-ray absorption near-edge structure spectroscopy. Aerosol Air Qual. Res. 21, 210018. https://doi.org/10.4209/aaqr.210018

Guttikunda, S.K. (2008). Urban air pollution analysis for Ulaanbaatar, Mongolia. TheWorld Bank, Washington, DC.

Guttikunda, S.K., Lodoysamba, S., Bulgansaikhan, B., Dashdondog, B. (2013). Particulate pollution in Ulaanbaatar, Mongolia. Air Qual. Atmos. Health 6, 589–601. https://doi.org/10.1007/s11869-013-0198-7

Han, D., Wang, Z., Cheng, J., Wang, Q., Chen, X., Wang, H. (2017). Volatile organic compounds (VOCs) during non-haze and haze days in Shanghai: Characterization and secondary organic aerosol (SOA) formation. Environ. Sci. Pollut. Res. 24, 18619–18629. https://doi.org/10.1007/s11356-017-9433-3

Hasenkopf, C.A., Veghte, D.P., Schill, G.P., Lodoysamba, S., Freedman, M.A., Tolbert, M.A. (2016). Ice nucleation, shape, and composition of aerosol particles in one of the most polluted cities in the world: Ulaanbaatar, Mongolia. Atmos. Environ. 139, 222–229. https://doi.org/10.1016/j.atmosenv.2016.05.037

Huang, Y.K., Luvsan, M.E., Gombojav, E., Ochir, C., Bulgan, J., Chan, C.C. (2013). Land use patterns and SO_2 and NO_2 pollution in Ulaanbaatar, Mongolia. Environ. Res. 124, 1–6. https://doi.org/10.1016/j.envres.2013.02.006

JICA (2013). Capacity Development Project for Air Pollution Control in Ulaanbaatar City Phase 3 in Mongolia. Japan International Cooperation Agency (JICA), Ulaanbaatar, Mongolia.

JICA (2017). Capacity Development Project for Air Pollution Control in Ulaanbaatar City Phase 2 in Mongolia. Japan International Cooperation Agency (JICA), Ulaanbaatar, Mongolia.

Jin, T., Han, M., Han, K., Fu, X., Xu, L., Xu, X. (2018). Health risk of ambient PM_{10}-bound PAHs at bus stops in spring and autumn in Tianjin, China. Aerosol Air Qual. Res 18, 1828-1838. https://doi.org/10.4209/aaqr.2017.11.0461

Jung, J., Tsatsral, B., Kim, Y.J., Kawamura, K. (2010). Organic and inorganic aerosol compositions in Ulaanbaatar, Mongolia, during the cold winter of 2007 to 2008: Dicarboxylic acids, ketocarboxylic acids, and α-dicarbonyls. J. Geophys. Res. 115, D22203. https://doi.org/10.1029/2010JD014339

Jung, J., Kim, Y.J., Aggarwal, S.G., Kawamura, K. (2011). Hygroscopic property of water-soluble organic-enriched aerosols in Ulaanbaatar, Mongolia during the cold winter of 2007. Atmos. Environ. 45, 2722–2729. https://doi.org/10.1016/j.atmosenv.2011.02.055

Kumar, A., Singh, D., Kumar, K., Singh, B.B., Jain, V.K. (2018). Distribution of VOCs in urban and rural atmospheres of subtropical India: Temporal variation, source attribution, ratios, OFP and risk assessment. Sci. Total Environ. 613, 492–501. https://doi.org/10.1016/j.scitotenv.2017.09.096

Lee, K.Y., Batmunkh, T., Joo, H.S., Park, K. (2018). Comparison of the physical and chemical characteristics of fine road dust at different urban sites. J. Air Waste Manage. Assoc. 68, 812-823. https://doi.org/10.1080/10962247.2018.1443855

Li, M., Zhang, Q., Kurokawa, J.-i., Woo, J.H., He, K., Lu, Z., Ohara, T., Song, Y., Streets, D.G., Carmichael, G.R. (2017). MIX: A mosaic Asian anthropogenic emission inventory under the international collaboration framework of the MICS-Asia and HTAP. Atmos. Chem. Phys. 17, 935–963. https://doi.org/10.5194/acp-17-935-2017

Liu, J., Mauzerall, D.L., Chen, Q., Zhang, Q., Song, Y., Peng, W., Klimont, Z., Qiu, X., Zhang, S., Hu, M. (2016). Air pollutant emissions from Chinese households: A major and underappreciated ambient pollution source. PNAS 113, 7756–7761. https://doi.org/10.1073/pnas.1604537113

Lodoysamba, S., Pemberton-Pigott, C. (2011). Mitigation of Ulaanbaatar city's air pollution-from source aportionment to ultra-low emission lignite burning stoves. Proceedings of International conference Towards Sustainable Energy, Solutions for the Developing World, Domestic Use of Energy, 2011.

Lorentz, H., Müller, W.J., Baumbach, G., Vogt, U., Eisold, A. (2019). Further development of air quality control planning and air quality monitoring in Ulaanbaatar (Mongolia). German Environmental Agency.

Luvsan, M.E., Shie, R.H., Purevdorj, T., Badarch, L., Baldorj, B., Chan, C.C. (2012). The influence of emission sources and meteorological conditions on SO_2 pollution in Mongolia. Atmos. Environ. 61, 542–549. https://doi.org/10.1016/j.atmosenv.2012.07.044

MET (2018). Pocedure of announce Air Quality Index (AQI). http://agaar.mn/article-view/692

MET (2019). Yearly report of environmental situation of Mongolia-2017-2018 (in Mongolian). Ministry of Environment and Tourism of Mongolia.

MET (2020). Webpage of air quality announcement (agaar.mn). agaar.mn (accessed February 2020).

MNIA (2019). Web page of National Inspection Agency of Mongolia. http://home.inspection.gov.mn/news/295/single/1975 (accessed September 2021).

Moran, D., Kanemoto, K. (2016). Tracing global supply chains to air pollution hotspots. Environ. Res. Lett. 11, 094017. https://doi.org/10.1088/1748-9326/11/9/094017

Morimo, R., Hamada, E., Munkhbaatar, P., Dash, I., Shimotsu, Y., Iwakiri, Y., Kawasoe, M. (2008). Measurement of air quality of Ulaanbaatar City, Mongolia, 2008 Third International Forum on Strategic Technologies, pp. 656–657.

Nirmalkar, J., Batmunkh, T., Jung, J. (2020). An optimized tracer-based approach for estimating organic carbon emissions from biomass burning in Ulaanbaatar, Mongolia. Atmos. Chem. Phys. 20, 3231–3247. https://doi.org/10.5194/acp-20-3231-2020

Nishikawa, M., Matsui, I., Batdorj, D., Jugder, D., Mori, I., Shimizu, A., Sugimoto, N., Takahashi, K. (2011). Chemical composition of urban airborne particulate matter in Ulaanbaatar. Atmos. Environ. 45, 5710–5715. https://doi.org/10.1016/j.atmosenv.2011.07.029

NSOM (2021). Web page of National Statistical Office of Mongolia. (accessed June 2021).

Oyungerel, G., Batdemberel, G., Chadraabal, S., Munkhbaatar, P., Altantsog, P. (2012). A study of nanoparticle sizes and their distributions aerosols along the road in Ulaanbaatar city, 2012 7th International Forum on Strategic Technology (IFOST), pp. 1–3.

Pfeiffer, M., Batbayar, G., Hofmann, J., Siegfried, K., Karthe, D., Hahn-Tomer, S. (2015). Investigating arsenic (As) occurrence and sources in ground, surface, waste and drinking water in northern Mongolia. Environ. Earth Sci. 73, 649–662. https://doi.org/10.1007/s12665-013-3029-0

Pillarisetti, A., Ma, R., Buyan, M., Nanzad, B., Argo, Y., Yang, X., Smith, K.R. (2019). Advanced household heat pumps for air pollution control: A pilot field study in Ulaanbaatar, the coldest capital city in the world. Environ. Res. 176, 108381. https://doi.org/10.1016/j.envres.2019.03.019

Prikaz, M., Fang, C., Dash, S., Wang, J. (2018). Origin and background estimation of sulfur dioxide in Ulaanbaatar, 2017. Environments 5, 136. https://doi.org/10.3390/environments5120136

Sarigiannis, D.A., Karakitsios, S.P., Zikopoulos, D., Nikolaki, S., Kermenidou, M. (2015). Lung cancer risk from PAHs emitted from biomass combustion. Environ. Res. 137, 147–156. https://doi.org/10.1016/j.envres.2014.12.009

UNDP (2019). Air pollution in Mongolia: Opportunities for further actions. United Nations Development Program.

Wang, M., Kai, K., Jin, Y., Sugimoto, N., Dashdondog, B. (2017). Air particulate pollution in Ulaanbaatar, Mongolia: Variation in atmospheric conditions from autumn to winter. SOLA 13, 90–95. https://doi.org/10.2151/sola.2017-017

Wang, M., Kai, K., Sugimoto, N., Enkhmaa, S. (2018). Meteorological factors affecting winter particulate air pollution in Ulaanbaatar from 2008 to 2016. Asian J. Atmos. Environ. 12, 244–254. https://doi.org/10.5572/ajae.2018.12.3.244

Warburton, D., Gilliland, F., Dashdendev, B. (2013). Environmental pollution in Mongolia: Effects across the lifespan. Environ. Res. 124, 65. https://doi.org/10.1016/j.envres.2013.04.002

Wesche, K., Treiber, J. (2012). Abiotic and biotic determinants of steppe productivity and performance–A view from Central Asia, Eurasian steppes. Ecological problems and livelihoods in a changing world. Springer, pp. 3–43. https://doi.org/10.1007/978-94-007-3886-7_1

Whiteman, C.D., Bian, X., Zhong, S. (1999). Wintertime evolution of the temperature inversion in the Colorado Plateau Basin. J. Appl. Meteorol. 38, 1103–1117. https://doi.org/10.1175/1520-0450(1999)038<1103:WEOTTI>2.0.CO;2

Yamamoto, K., Suzuki, Y., Oyunjargal, G., Fukuda, H., Oidov, M., Hasegawa, H. (2020). Inorganic and organic chemical characteristics and sources of suspended particulate matters in Ulaanbaatar, Mongolia. Geochem. J. 54, 267–276. https://doi.org/10.2343/geochemj.2.0579

Formation mechanism and source apportionment of nitrate in $PM_{2.5}$ in Ulaanbaatar and Beijing: comparing results between Bayesian Isotopic Mixing Model and Positive Matrix Factorization Model

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ABSTRCT: Nitrate as a primary component of secondary inorganic aerosol is relevant to many atmospheric chemistry reactions. $PM_{2.5}$ samples were collected in two capital cities Ulaanbaatar in four seasons and Beijing only in winter due to

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cleaner days in other seasons for learning the sources and formation mechanism of nitrate aerosols profoundly. We measured the $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$ isotopic characteristics of nitrate so that we can trace the sources and quantify the relative contributions of each formation pathway to nitrate in two cities using Bayesian Isotopic Mixing Model (MixSIAR). The peak mean concentration of NO_3^- showed in winter with 3.79 ± 1.4 μg m^{-3} in Ulaanbaatar, which was lower than Beijing with 7.11±7.4 μg m^{-3}. $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$ both showed significant seasonal variation trend with higher values in cold seasons and lower values in warm seasons, the former may be associated with the sources of nitrate, the latter with formation pathways. The whole $\delta^{15}N\text{-}NO_3^-$ varied within a narrower range in Ulaanbaatar from -9.67‰ to +21.92‰ compared with Beijing from +1.56‰ to +35.49‰. According to the $\delta^{18}O\text{-}NO_3^-$, •OH+$NO_2$ was main mechanism in Ulaanbaatar with 88.82%, 76.96%, 66.64%, 61.23% in summer, spring, autumn and winter, while the contribution of N_2O_5 + H_2O and •OH+NO_2 was nearly equal with 48.22% and 46.78%, respectively in Beijing, which implies that N_2O_5 + H_2O is more dominate when high NO_3^- concentration occurred. The result from MixSIAR analyzed four sources' contributions. Vehicles was a crucial source in both cities, and we furtherly quantified the contributions of it as fuel types like gasoline and diesel in Ulaanbaatar, additional LPG in Beijing. Coal combustion would rather be important than Beijing in Ulaanbaatar in winter. The results from PMF mainly classified the nitrate into secondary formation and could not trace the direct sources, but it is not constrained by sources. While the sources

information is limited and MixSIAR model may arise weak evidences while the number of sources is more than the number of tracers plus one. It therefor is vital to combine these two models to learn the sources of nitrate.

KEYWORDS: nitrate aerosols, formation mechanism, source apportionment, Beijing, Ulaanbaatar, MixSIAR, PMF

SYNOPSIS: The estimate of formation mechanism of nitrate aerosols and comparison of source apportionment results from Bayesian Isotopic Mixing Model and PMF in Ulaanbaatar and Beijing

Abstract Art

INTRODUCTION

Nitrate acting as the dominant sink for NO_X ($NO+NO_2$) is more and more important with the remarkably elevating in the concentration and deposition fluxes of nitrogen oxide and its ramifications around the world [1-5]. Particulate nitrate is associated with a lot of atmospheric environment problems. The photolysis of NO_3^- can influence the atmospheric oxidation capacity, like in polar atmosphere, the marine and continental boundary layer [6-9]. Inorganic nitrate in aqueous phase is conductive to the photooxidation of organic compounds and then accelerate the production of brown

Carbon Research

Modeling of wintertime regional formation of secondary organic aerosols around Beijing: sensitivity analysis and anthropogenic contributions

--Manuscript Draft--

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Abstract:	Modeling of secondary organic aerosol (SOA) has remained a big challenge due to the various precursors and complex processes involved. In this study, the WRF-CAMx model was used to predict the ambient SOA concentrations in urban Beijing as well as the North China Plain (NCP) during a polluted period in winter. Both the volatility basis set (VBS) approach and the two product approach (SOAP) were used for SOA simulation. Although the modeled SOA was underpredicted compared with the SOA estimated by the OC/EC method, the VBS scheme produced higher SOA than the traditional two-product scheme. According to the sensitivity tests with the VBS scheme, the emissions of volatile organic compounds (VOC) and intermediate volatility organic compounds (IVOC) as well as the oxidant levels were the key factors that affected SOA prediction. In comparison, the predicted SOA was less affected by primary organic aerosol (POA) emission and chemical aging during the winter time. The potential contributions from different anthropogenic sources and source areas were also identified using the brute-force method. Over 80% of SOA in urban Beijing resulted from regional transport of SOA or its precursors from the surrounding areas during the polluted period. Residential emission in the North China Plain appeared as the dominant source of SOA in urban Beijing from the perspective of regional contribution.
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Appendix 7. Abstract of international conference

111 Seasonal Variations of Aerosol Composition and Sources of $PM_{2.5}$ in the Ulaanbaatar, MONGOLIA

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In this study, we used inductively coupled plasma mass spectrometry (ICP-OES) to evaluate the $PM_{2.5}$ bound elemental composition.

The average concentration of $PM_{2.5}$ was highest in winter (92.56 μgm^{-3}) and in summer (13.64 μgm^{-3}), with a greater abundance of sulfate in winter (155.63 μgm^{-3}) and (6.84 μgm^{-3}) in summer. In the $PM_{2.5}$ samples, high concentrations of ambient elements were observed for Ca, Al, K, Zn, and Pb. The concentrations of toxic heavy metals such as Pb was 1.4 higher than the Mongolian National Standard (MNS 4585:2016, which is 1 $\mu g/m^3$). In conclusion, the seasonal variation of the elements' concentrations mostly depended on consumption, such as coal and wood consumption (W/S > 1). Crustal matter elements depended on dusting and vacuuming activities (W/S < 1).

For detecting potential emission mitigation measures and for impact assessment of implemented air pollution reduction measures further components should be measured that are typical for specific emission sources. Especially the pollution load in some Ger-districts, which are not yet equipped with automatic monitoring stations, should be further investigated.

References

[1] Davy PK, Gunchin G, Markwitz A, et al. Air particulate matter pollution in Ulaanbaatar, Mongolia: determination of composition, source contributions and source locations. *Atmos Pollut Res* 2011; 2: 126-137.

[2] Amgalan N, Narantsetseg T, Shagjjamba D. Valuations of Elemental Concentrations of Particle Matter in Ulaanbaatar, Mongolia. *Open J Air Pollut* 2016; 05: 160-169.