ОРЧНЫ БОХИРДЛЫГ БУУРУУЛАХ ҮНДЭСНИЙ ХОРОО

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Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Umwelt Bundesamt

Recommendations for further development of air quality control planning and air quality monitoring in Ulaanbaatar

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Recommendations for further development of air quality control planning and air quality monitoring in Ulaanbaatar (Mongolia)

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Abstract

Together with the National Agency for Meteorology and Environmental Monitoring of Mongolia the German Environment Agency developed an advisory assistance project for the further development of air quality control planning and air quality monitoring in Ulaanbaatar. The overall objective of the project was to support national and municipal efforts to improve air quality, especially with regard to the particulate matter concentration in wintertime.

Based on the well-established network of measurement sites and existing inventories of emission sources, air quality control planning provides a diverse set of emission mitigation measures. The project aimed to further upgrade the abilities of air quality monitoring and air quality control planning in Ulaanbaatar to make prioritization of mitigation measures by emission source categories and spatial prioritization of target areas in Ulaanbaatar possible.

For that purpose, experts of administrations and institutions on national and municipal level were advised to enhance the analysis of existing data sets. In addition to existing monitoring programs, a modeling approach was developed in order to allow the Mongolian experts to estimate the source apportionment of air pollutant concentrations as well as the influence of meteorology and air flows on the pollutant dispersion. Considering the project outcomes several steps for further development are recommended.

Kurzbeschreibung

Zusammen mit der National Agency for Meteorology and Environmental Monitoring der Mongolei entwickelte das Umweltbundesamt ein Beratungshilfeprojekt zur Weiterentwicklung der Luftreinhalteplanung und des Monitorings der Luftqualität in Ulan Bator. Ziel des Projektes war es die nationalen und städtischen Anstrengungen zur Verbesserung der Luftqualität zu unterstützen, besonders hinsichtlich der winterlichen Feinstaubbelastung.

Auf der Grundlage eines gut aufgebauten Messnetzes und von Inventaren der Emissionsquellen bietet die Luftreinhalteplanung ein Set von Emissionsminderungsmaßnahmen. Das Projekt zielte darauf ab, die Fähigkeiten zum Luftqualitätsmonitoring und zur Luftreinhalteplanung in Ulan Bator zu verbessern und so die Priorisierung von Luftreinhaltemaßnahmen zu ermöglichen.

Dazu wurden Mitarbeitende der nationalen und städtischen Behörden und Einrichtungen beraten, die mit dem bestehenden Luftmessnetz erhobenen Daten zielgerichteter für die weitere Analyse aufzubereiten. Ergänzend zu bestehenden Monitoringprogrammen wurde ein Modellierungsansatz entwickelt, mit dem die mongolischen Fachleute die Anteile verschiedener Emissionsquellen an der Luftschadstoffkonzentration sowie den Einfluss von Meteorologie und Luftströmungen auf die Ausbreitung der Schadstoffe abschätzen können. Ausgehend von den Erkenntnissen des Projektes wurden Schritte zur Weiterentwicklung erarbeitet.

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List of abbreviations

AAAP	Agency Against Air Pollution of Ulaanbaatar
AAP	Advisory Assistance Program
AQI	Air Quality Index
AUSTAL2000	German regular dispersion model within a plant permission procedure
BaP	Benzo(a)pyrene
BaPeq	Benzo(a)pyrene toxicity equivalents
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit)
BTX	Benzene, Toluene and Xylenes
CLEM	Central Laboratory of Environment and Metrology
GIS	Geographical Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
HLNUG	Hessian Agency for the Environment and Geology, Germany
IARC	International Agency for Research on Cancer
JICA	Japan International Cooperation Agency
KOICA	Korea International Cooperation Agency
LIDAR	Light detection and ranging
NAMEM	National Agency for Meteorology and Environmental Monitoring
NUM	National University of Mongolia
NO_2	Nitrogen dioxide
PAH	Polycyclic Aromatic Hydrocarbons
PM10	Particulate Matter (diameter < 10 µm)
PM2.5	Particulate Matter (diameter < 2.5 µm)
SO_2	Sulphur dioxide
UB	Ulaanbaatar
UBA	German Environment Agency (Umweltbundesamt)
UNDP	United Nations Development Program
WMO	World Meteorological Organization

1 Air quality situation in Ulaanbaatar

In recent years the number of inhabitants of the Mongolian capital Ulaanbaatar continued to grow. Almost half of the country's population is now living here. The continuous growth of the city is on the one hand accompanied by an increasing demand for thermal heat supply, electricity and water and on the other hand challenging the city's systems of sewerage and solid waste disposal and treatment. Especially the increasingly emerging Ger-settlements up the hill slopes around Ulaanbaatar represent a challenging issue not only for urban planning. Not least an increasing number of vehicles and traffic congestions contribute to a serious air quality issue and an alarming burden of air pollution related diseases.

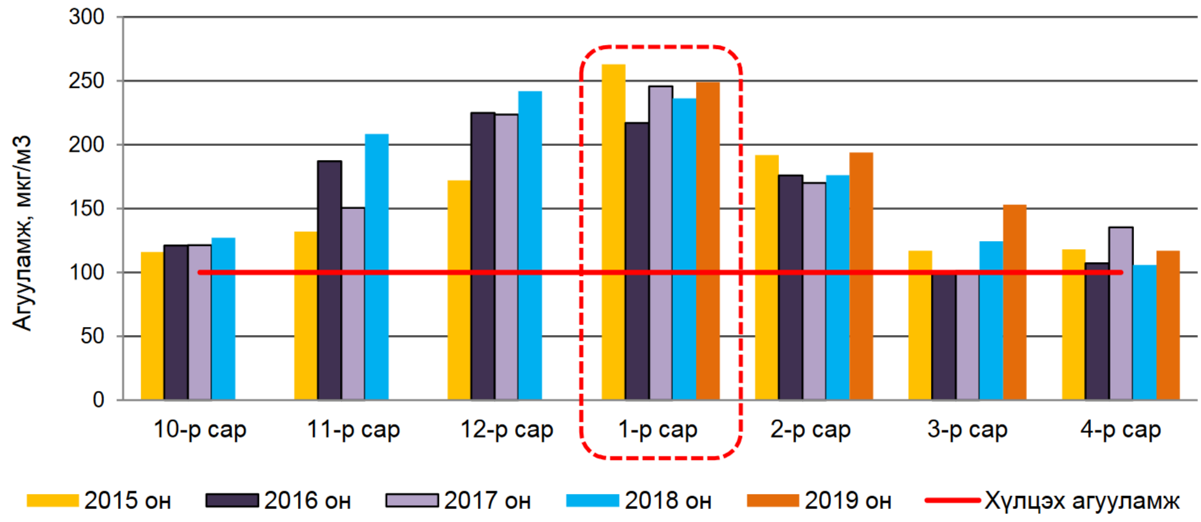
Ulaanbaatar faces pronounced continental climate conditions with short, warm summers and long and cold winters. In addition, the temperature differences between day and night and between summer and winter are among the highest of the world. Moreover, Ulaanbaatar is the coldest capital of the world. Monthly average temperatures in winter drop down to -25 °C and the daily minima frequently fall below -30 °C.

Therefore, reliable and cost- and energy-efficient heating appears a major concern. Because of extensive coal deposits in Mongolia, coal mining plays an important role for the country's economy. An overwhelming share of Ulaanbaatar's demand for thermal heat and electricity is therefore supplied from coal combustion in large combustion plants up to residential coal combustion in stoves. Especially in winter time atmospheric temperature inversions cause dramatic high loads of air pollution in the lower atmosphere – the so-called smog. This is the reason why Ulaanbaatar is not only the coldest capital of the world, but also highest concentrations of Particulate Matter (PM) are measured here.

A lot of international support is taking place to clean the air under the challenging circumstances in urban development, e. g.:

- Integrated Urban Development Program, GIZ (2006-2012)
- Air Quality Monitoring in Ulaanbaatar, GIZ (2008-2011)
- Air Monitoring and Health Impact Baseline, World Bank (2008-2009)
- Reduce Air Pollution by Improving Heating Culture, KOICA (2008-2009)
- Capacity Development Project for Air Pollution Control in Ulaanbaatar City, JICA (Phase 1: 2010-2011, Phase 2: 2012-2017, Phase 3: 2018-2020)
- Air pollution in Mongolia: Opportunities for further actions, UNDP (2019)

However, measured concentrations of air pollutants in Ulaanbaatar are in winter time still exceeding the harmless range of values concerning human health (Figure 1.1). Unfortunately, improvements in source-specific emission factors are most often overcompensated by increasing activities especially regarding combustion and traffic. Finally, effective emission mitigation measures are still urgently needed. The integration of air quality findings in in an air quality management system addressing urban planning and development processes seems to be one of the most promising elements.



Зураг 2. Хүйтний улирлын PM10 тоосонцрын
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Figure 1.1: Averages over several air quality stations, monthly mean PM_{10} values of 2019 compared to previous years (October to April)[1]

[1] Reference: http://agaar.mn/files/article/738/UB%20hotiin%20hvitnii%20ulirliin%202015-2019.%201-4,%2010-12-r%20sar%20(all).pdf, access: 16/09/2019

2 Objectives of the advisory assistance on "Further development of air quality control planning and air quality monitoring in Ulaanbaatar"

The overall objective of the advisory assistance project was to support national and municipal efforts to improve air quality in Ulaanbaatar, especially with respect to particulate matter pollution in winter. Based on the well-established network of measurement sites and existing inventories of emission sources, air quality planning provides a diverse set of emission mitigation measures. Though air pollution is on top of the political agenda, there are other fields of political, economic and public interest also determining the development of Ulaanbaatar.

The project aimed to further upgrade the abilities of air quality monitoring and air quality control planning in Ulaanbaatar to make prioritization of emission mitigation measures due to their air pollution reduction efficiency possible. The proven steps of air quality control planning (see Figure 2.1) have to be fitted to Ulaanbaatar's specific situation. The workflow starting with an assessment based on measurements and modeling tools which are applied in the requested area aims to identify mitigation measures to build up an integrated Air Quality Plan or Program.

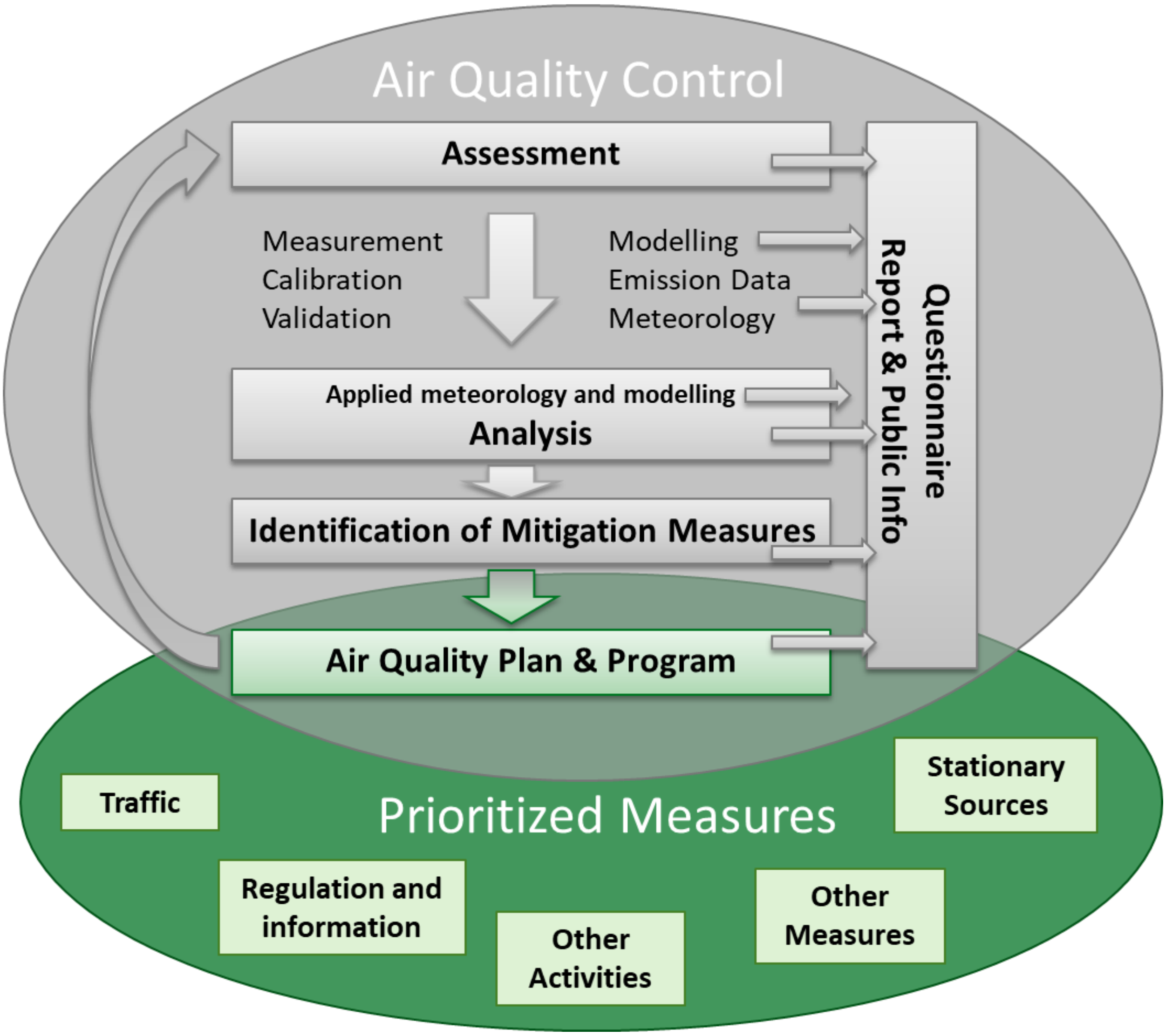

Figure 2.1: Systematic approach for integrated air quality control management, Lohmeyer 2019

All these steps of the workflow should be combined by broad public information and participation. Not only define the climatic and meteorological conditions the scope of action for clean air policy in Ulaanbaatar, but also the needs of a growing metropolis and its population. The initial situation has to be carefully analyzed, to find the key spots for further development of air quality planning and monitoring to improve the interaction and implementation of scientific findings in the field of air quality within urban and national policy. The impact of all measures should be checked again by iterative assessment according to the workflow.

Following the results of the above-mentioned projects as well as the experiences from cities in other parts of the world facing similar topographic conditions, the possibility of prioritization of emission mitigation measures was presumed. Examples of mitigations measures include stationary sources, traffic network, regulations and other measures like fuel improvement and urban planning and should be discussed with all stakeholders, public and politicians (see Figure 2.2).

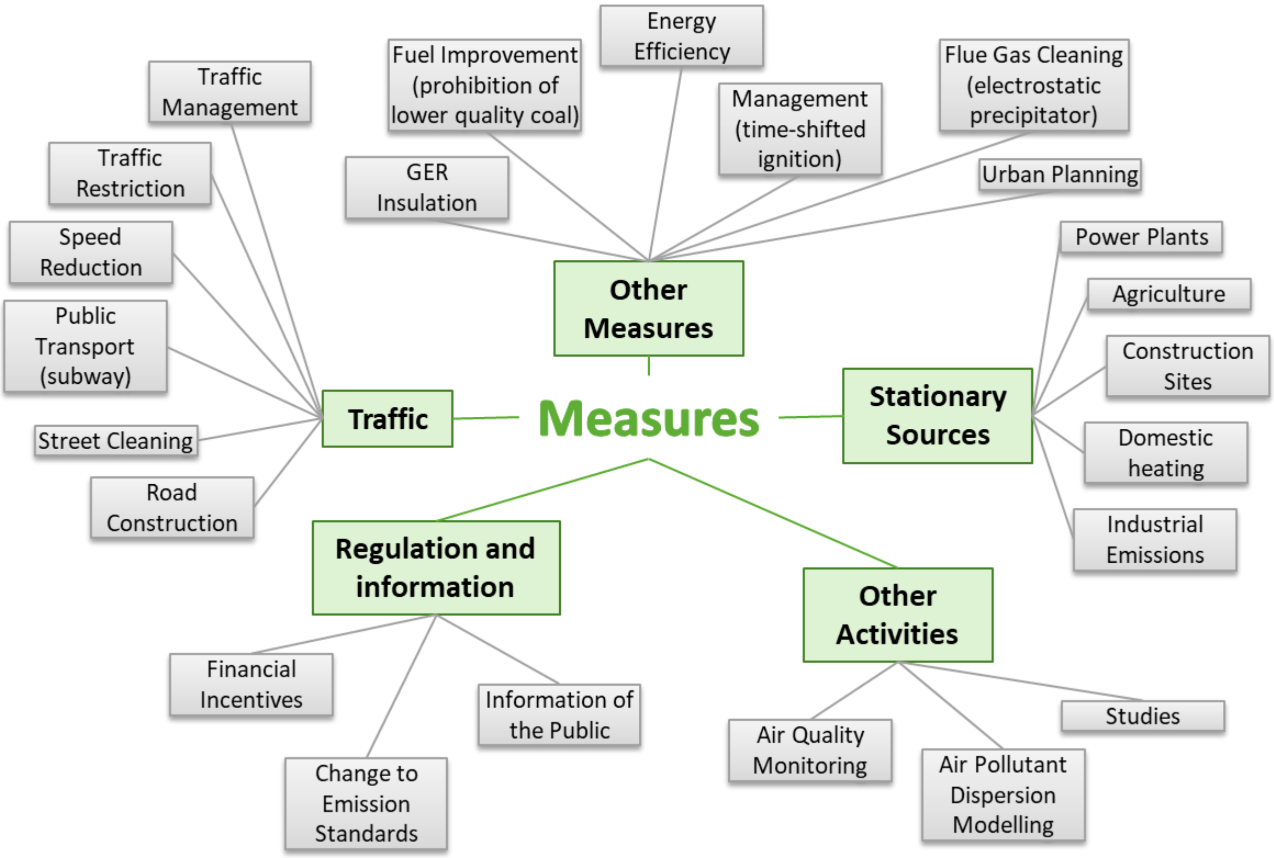

Figure 2.2: Examples of mitigation measures which could be part of air quality plan or program, Lohmeyer 2019

The key questions of the project are, if there are districts in the urban and suburban area of Ulaanbaatar whose emissions are contributing to high concentrations of air pollutants above average and what further extension of air quality measurements and modeling is needed for purposeful further improvement of the situation.

To contribute to answering this question, the task of a group of German clean air experts was to support the relevant Mongolian national and municipal authorities and institutions (chiefly in Ulaanbaatar, especially the National Agency for Meteorology and Environmental Monitoring (NAMEM) and the Air Pollution Reduction Department of Ulaanbaatar (AAAP)) to identify and monitor the spatial and temporal air pollution distribution for further development of air quality monitoring. Main tasks to support prioritization of mitigation measures for further development of air quality control planning (see Figure 2.2) are:

- analyzing measured time series of air quality and meteorological data by statistic program system "R",
- optimization of the existing air quality measuring network and data management in Ulaanbaatar,
- additional measurements of meteorological and air quality parameters,
- modeling of meteorological situation (cold air drainage flow) applying METEOKART GIS[2]
- analyzing emission inventory and
- modeling dispersion of air pollutants and air pollution concentrations applying the local dispersion model AUSTAL2000 (developed by the German Environment Agency[3]).

[2] more information: http://www.lohmeyer.de/en/content/research-development/software-development/meteokart-gis
[3] https://www.umweltbundesamt.de/en/topics/air/air-quality-control-in-europe

3 Results of the advisory assistance on "Further development of air quality control planning and air quality monitoring in Ulaanbaatar"

There is a well-equipped network of measurement sites in Ulaanbaatar and the surroundings operated partly by NAMEM and AAAP. Measurement data is collected and provided online (http://agaar.mn/index). Some additional measurement sites are operated by several institutions.

To assure consistency within the time series of measurements at each station and comparability between the stations and with international measurements a lot of steady and recurring work has to be done. Regularly calibration of the measuring equipment is essential and needs continuous investment, e. g. in calibration gases and wear parts of the instruments. The Central Laboratory (CLEM) therefore, is an indispensable element to guarantee quality assured measurements across the entire network of measurement sites.

In addition, a solid time series is essential for detecting potential emission mitigation measures as well as for retrospective analysis on the impact of various emission mitigation or air pollution reduction policies and measures.

Within the project three topics were addressed:

- Quality assurance of measurements, the network of measurement sites and data management,
- Conceptual design, planning and temporarily testing of additional measurements,
- Modeling of air flows and dispersion of air pollutants during selected episodes.

Specific trainings enhanced the skills of experts from the above mentioned institutions to support air quality control planning with detailed scientific analysis of sources and dispersion of air pollutants during specific meteorological conditions with high pollution loads in the city center of Ulaanbaatar typical for winter time. However, the trainings and the analysis of measured data as well as the use of emission data for dispersion modeling also revealed needs of further investment in equipment and software of measurements and dispersion modeling, further investigation on meteorological drivers and emission sources as well as on efficiency of emission mitigation measures.

Ulaanbaatar is surrounded by mountains. Parts of the city's settlements spread out over the valleys and slopes to the north. A survey about the existing and additional air quality and meteorological measurement locations of this project is given in Figure 3.1.

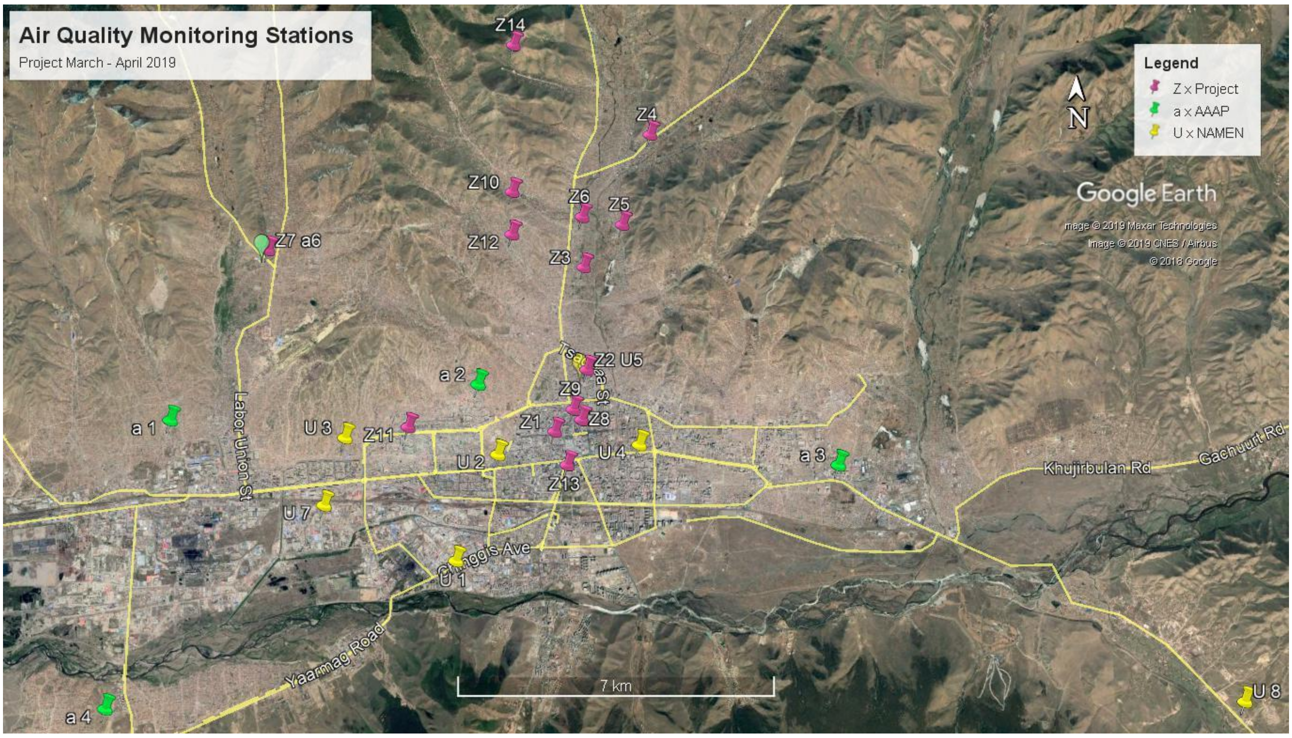

Figure 3.1: Air quality monitoring stations and locations of additional measurements within the current project (Z-locations of additional measurements (red) in Selbegol Air Quality Valley Flow survey during the project in 2019), a-stations of AAAP (green), U-stations of NAMEN (yellow)

In Ulaanbaatar local wind systems are dominating the air flows determining the transmission of local emissions, especially mountain/valley-wind systems generally oriented north and south. The locations of additional air quality and meteorological measurement locations of this project (Z-locations) were mainly inside the Selbegol Valley. This area was also taken into focus by cold air modeling.

3.1 Enhanced data analysis

Reliable and well checked and documented air quality monitoring data is essential for analysis. These data is the basis to identify the causes of high pollution episodes and to reduce the load of pollution. The training sessions demonstrated the variability of pollution load in different parts of Ulaanbaatar. The complex situation needs also a vertical description and an adjusted time resolution of the load. Figure 3.2 gives a short impression of the complex situation in UB. The length of the paddles of pollution-roses depend on the frequency of counts of PM_{10} intervals depending on wind direction (%), the color gives the share of different concentration classes (in $\mu g/m^3$) within each paddle.

Figure 3.3 demonstrates the day and night time load distribution for the monitoring station U8 (see Figure 3.1) in the south-east of Ulaanbaatar. There is a high load of PM_{10} by north westerly wind coming from the municipality but the polluted air is also coming back to Ulaanbaatar with changing wind direction. Figure 3.2 and Figure 3.3 give an impression of what detail of analysis of spatial and temporal behavior of air pollutants is possible and of what was part of the training sessions.

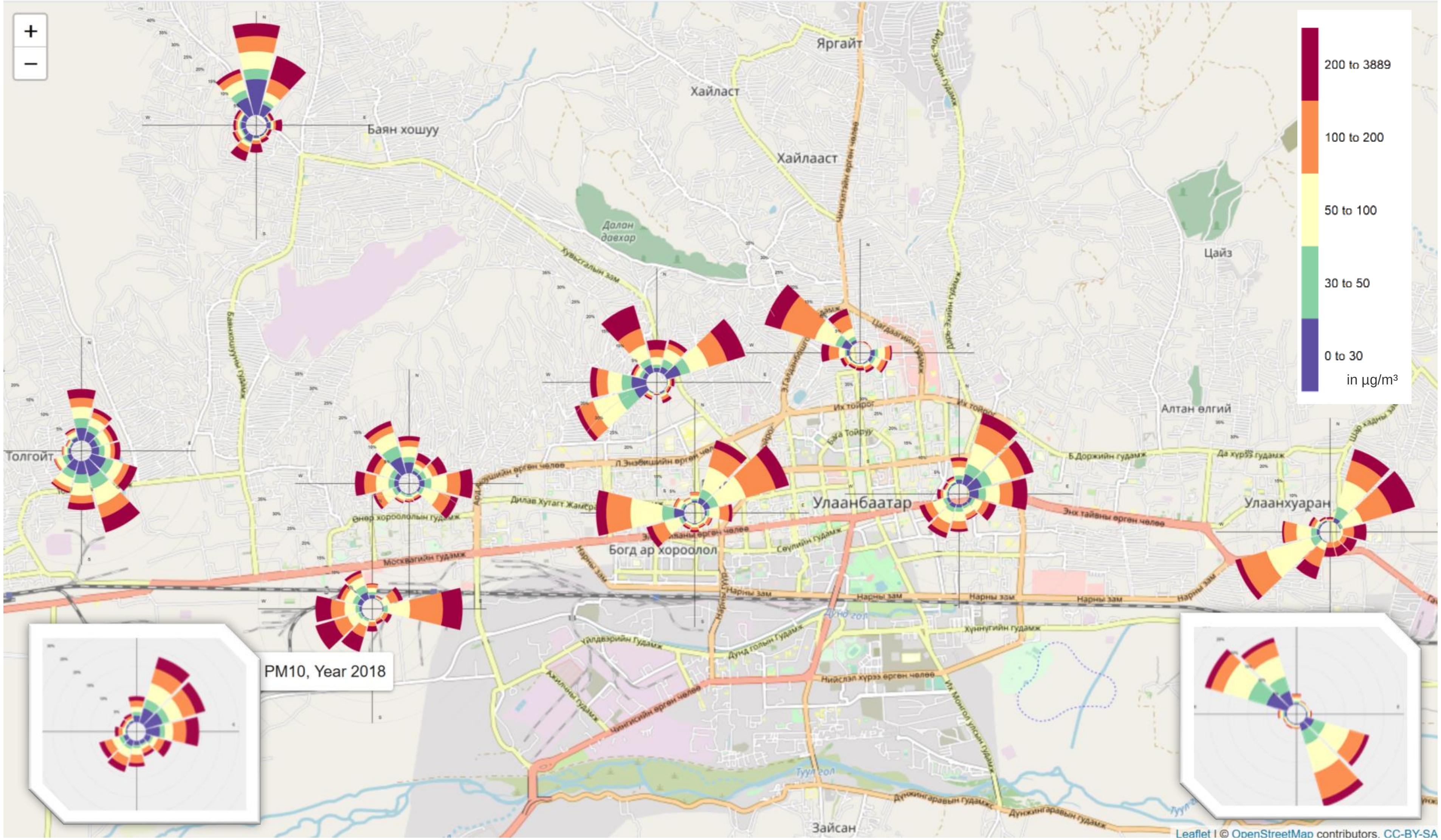

Figure 3.2: Pollution-roses, year 2018, frequency of counts of PM_{10} concentration intervals (µg/m³) depending on wind direction (%). Station a4 (left, southwest) and station U8 (right, southeast) are moved from outside the map inside the map area.

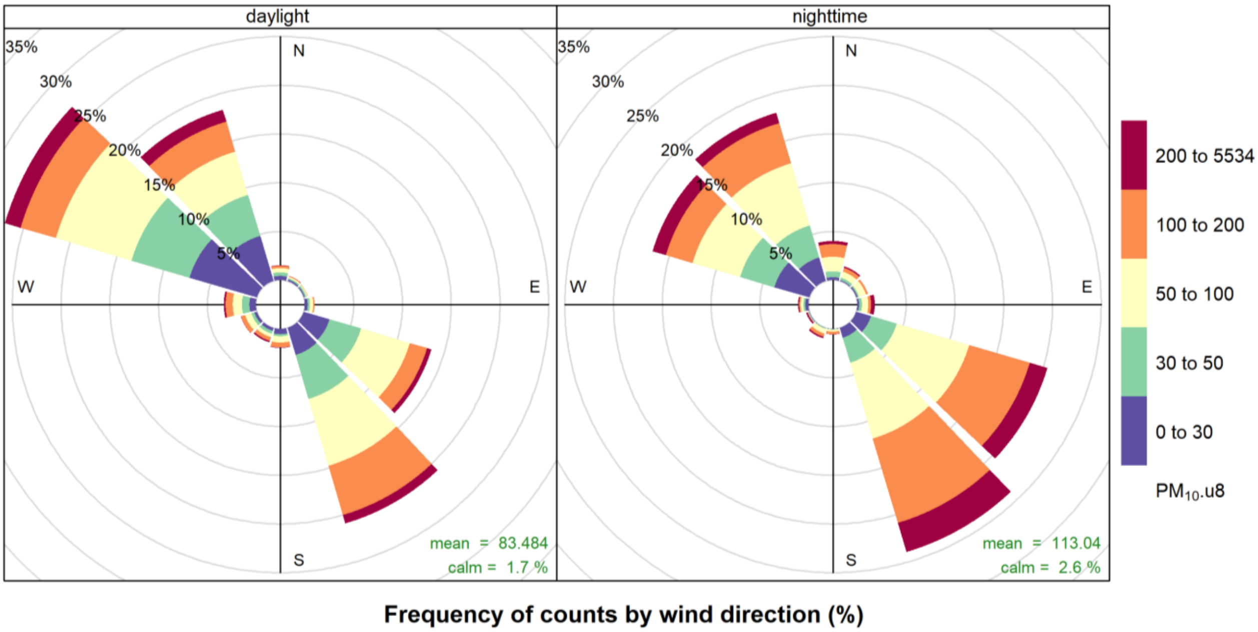

Figure 3.3: Pollution-rose for station U8, daytime and nighttime of year 2018, frequency of counts of PM_{10} concentration intervals (µg/m^3) depending on wind direction (%)

The locations of the air quality monitoring stations should be carefully checked under consideration of surrounding emission sources and elements that are influencing air flows. In addition, the need to get information in higher altitudes was figured out, because the vertical distribution of the concentration is caused by temperature inversion. On the other hand, typical vertical distributions are indicating the presence of a temperature inversion.

Beside the well-known PM issue, also high concentrations of nitrogen dioxide (NO_2) were measured in the inner city of UB.

An essential part of the trainings was to introduce a faster methodology to check the reliability of monitoring stations raw data – more than 1.5 Mio units per year – to ensure consistency for further evaluation.

3.2 Quality assurance – calibration and validation

The check of all air quality monitoring data is based on different levels of calibration and comparison with worldwide chemical standard procedures.

Basically CLEM is monthly doing a calibration of the instruments in the monitoring stations. Also, after repairing or replacing some part a calibration is done. The gas analyzers have auto zero function and it works every day at midnight. A reference lab with the required instruments is existing. To operate the reference lab, certified standard test gases and a portable dilution or permeation system as transfer standard is necessary.

Quality assurance of PM monitors should be done by comparison with gravimetric PM reference methods. A comparison between PM analyzers and gravimetric reference measurements was already carried out once by the Japan International Cooperation Agency (JICA) four years ago. During the training program comparison tests between three new low-cost PM samplers and four gravimetric PM_{10} samplers (partisol) were carried out on the roof of the NAMEM building. In Figure 3.4 the training is shown at three (from 4) gravimetric partisol reference instruments for calibration of the three low-cost PM samplers (positioned on the partisol samplers). The test was also designed for the determination of the comparison deviation between the PM sampling with the four partisol instruments.

Figure 3.4: Measurement training at partisol gravimetric PM samplers on the roof of the NAMEM building (Photo: G. Baumbach 2019)

3.3 Additional measurements

Objectives and overview

The objectives for training on additional measurements were the following:

- To get more information about the spatial pollutant distribution, especially in Ger areas which are not covered by automated monitoring stations but where many people are living.
- To demonstrate how to get the needed information through exposition of a certain number of low-cost passive samplers and low-cost PM sensors which has been used and distributed at many points (also to find hot spot pollution points for possible installation of further automated monitoring stations).
- To get information about pollutant compounds which have not been measured yet, but are significantly health relevant such as carcinogenic Polycyclic Aromatic Hydrocarbons (PAH) which are adsorbed on particulate matter (PM_{10} and $PM_{2.5}$).
- To find out the interaction of air pollution and behavior of temperature inversion layers and cold air flows which can transport the pollutants through the Selbegol Valley into the inner city (modeling supported by measurements).

To demonstrate the possibilities of performing additional measurements an intensive exercise together with NAMEM, CLEM and National Mongolian University (NUM) has been carried out to investigate the air pollution caused by Ger heating. At first, a strategy of the monitoring campaign was developed. As study area the valley of Selbegol was selected. The structure of the bright valley with a steady downslope and intensive population density is suitable to develop an exemplary investigation design including additional chemical parameters.

The following measurement subjects were components of this training program:

- PM_{10} gravimetric samplers (existing Partisol instruments) put into operation and exposition at several points for PM sampling for further analysis of Polycyclic Aromatic Hydrocarbons (PAH).

- PAH lab analysis in cooperation with the National Mongolian Academy of Science to estimate the contribution of some typical coal and wood burning compounds to Particulate Matter (PM) pollution.
- Implementation and calibration of low-cost PM sensors for mobile PM measurements.
- Implementation and exposition of passive samplers for SO_2, NO_2 and BTX (Benzene, Toluene and Xylenes) at many sampling points and lab analyses of the samples.
- Operation of one existing and one provided ultrasonic wind sensor at selected sites for determining the nocturnal cold air flow transporting pollution load to other parts of the city of UB.
- Implementation and exposition of automatic recording temperature sensors on the bottom of the Selbegol valley and at several heights at slopes and on top of a hill adjacent the valley. The vertical distribution of these monitoring points is the first step to describe the influence of the stratification by vertical temperature inversion in a very detailed way (at points Z3, Z12, Z10, Z14 in Figure 3.1)
- Vertical temperature and pollutant measurements at the TV tower.

The measurements were started in February 2019 based on a detailed timetable accompanied by the German experts until beginning of March and continued by the Mongolian partners until end of April 2019. The sampling respectively monitoring points of these additional measurements are depicted in Figure 3.1 with the numbers Z 1 to Z 14. Of course, not all parameters are measured at all points.

PM_{10} and Polycyclic Aromatic Hydrocarbons – PAHs

The PM_{10} samplings for PAH analyses were carried out at the three points “Kindergarten” – Z3, at Dambadarjaa – Z4 (Stove test laboratory) and at the Bayankhoshuu monitoring station – Z7 (=a6), see Figure 3.1. Here exemplarily, results from the measurement point Z3 are shown. In Figure 3.5 the Partisol PM_{10}-sampling instrument is shown together with two PM low-cost samplers located on the roof of the “Kindergarten”.

Figure 3.5: Measurements on the roof of “Kindergarten” - Z3. (Photo: G. Baumbach 2019)

In Figure 3.6 the determined PM_{10} concentrations of 10 sampling periods are depicted (line). According to the collected PM samples the analyzed PAH concentrations adsorbed at PM are shown as total number of detected different multi-ring PAHs (bars). The samplings were always carried out over two days to get enough PM mass on the filters for PAH analyses.

It can be seen that PAHs are most of the time correlated to the PM_{10} concentrations. It means that high PM_{10} concentrations at this site are indicating high PAH concentrations at the same time.

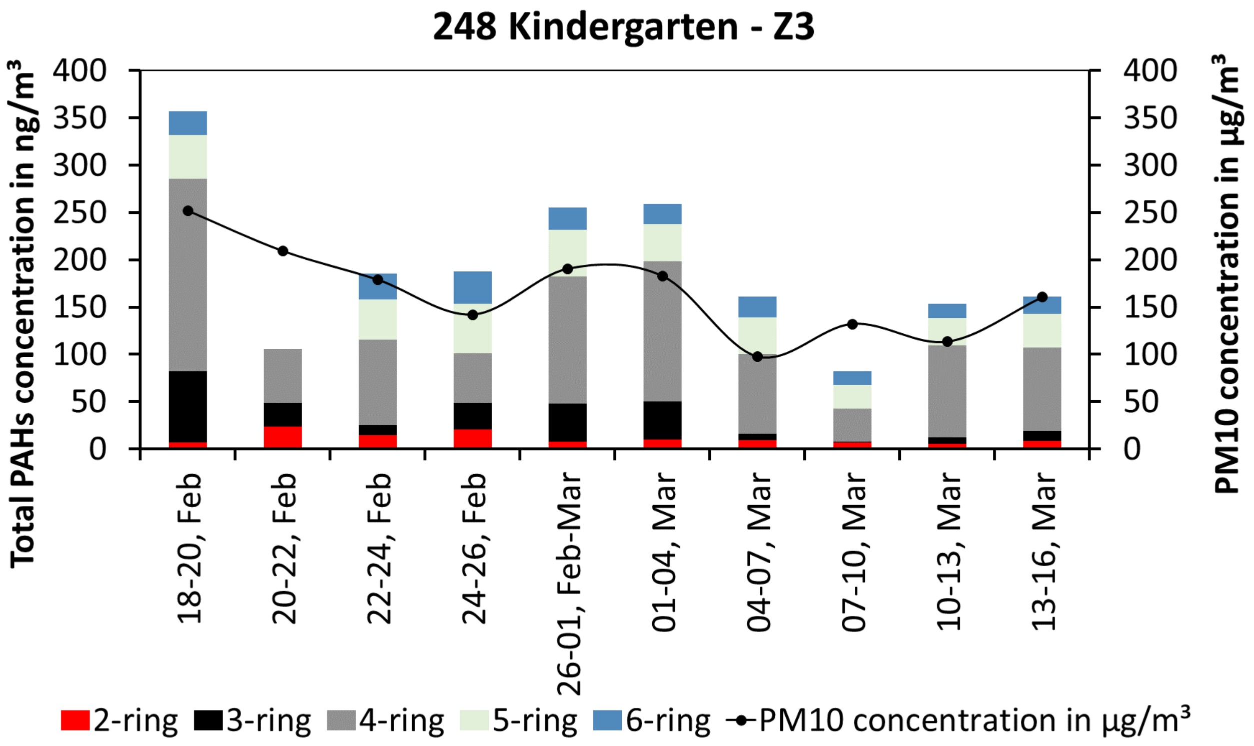

Figure 3.6: PM_{10} concentrations ($\mu g/m^3$) (line) and adsorbed PAH concentrations (ng/m^3) (bars) at measurement point Z3 ("Kindergarten") [Khulan Tsermaa, 2019]

In Figure 3.7 the Benzo(a)pyrene (BaP) concentrations as part of the total PAH concentrations are separately depicted for the three sampling points Z4, Z7 and Z3. Benzo(a)pyrene is the leading compound of carcinogenic PAHs. In Europe the BaP target as annual mean value is set at 1 ng/m^3. The WHO stats a value of 0.12 ng/m^3 with a risk of one case of cancer based on an exposed population of 100,000 (or 8.7 cases per 100,000 population for 1 ng/m^3).

The measured BaP concentrations are not annual means. But it can be seen that they are in dimensions higher than recommended target values.

Benzo(a)pyrene (BaP) has the highest carcinogenic potential of all PAHs. From the International Agency for Research on Cancer (IARC) other PAH compounds are weighted with a BaP equivalent factor. After multiplying the other PAH compounds with these factors (factors are lower than 1) they can be added to the BaP concentrations and the sum is stated as Benzo(a)pyrene toxicity equivalents (BaPeq).

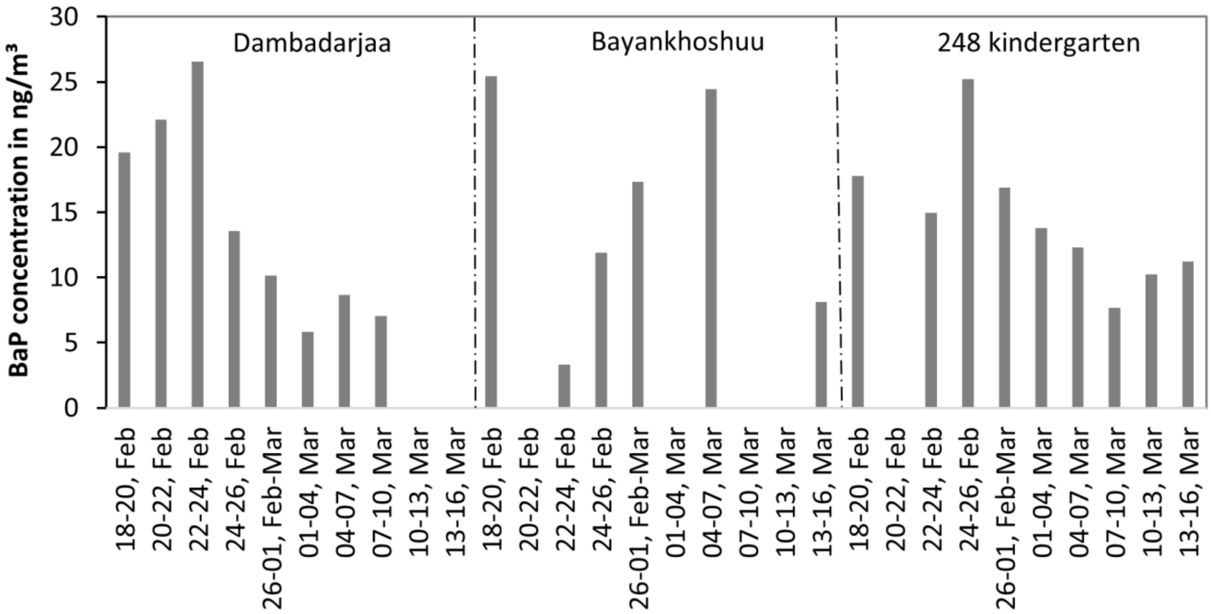

Figure 3.7: Benzo(a)pyrene (BaP) concentrations at the three sampling sites Dambadarjaa Z4, Bayankhoshuu Z7 (= a6) and "Kindergarten" Z3 [Khulan Tsermaa, 2019]

For all measured PAHs within the period February – March 2019 the average BaPeq has been determined as average with its deviation. The result is shown in Table 3.1 together with a comparison with results of international studies.

Table 3.1: Benzo(a)pyrene toxicity equivalents (BaPeq) determined by different studies [Khulan Tsermaa, 2019]

Location	BaPeq (ng/m^3)	Period	Source
Ulaanbaatar, Mongolia	32±17	2019.2-2019.3	This study
Tianjin, China	29.7±15.1	2014.3	Jing et al. 2018
Tianjin, China	38.8±11.3	2008.4 - 2009.1	Shi et al., 2010
Dettenhaussen, Germany	2.6	2005.11–2006.3	Bari et al. 2010
Nagasaki, Japan	1.3	1997/1998	Wada et al. 2001
Apin	2.0	1996 оны өвөл	Marino et al. 2000
Bangkok	2.1	2002.11–2003.04	Norramit et al. 2005
Roman	2.5	1996/1997	Menichini et al. 1999
Copenhagen	6.3	1992.01-1992.03	Nielsen et al. 1996

These results show that the population in Selbegol area during its exposure to particulate matter is affected by unhealthy carcinogenic PAH compounds comparable to a study of a high polluted city in China. All other mentioned studies showed much lower concentration levels.

Implementation and application of low-cost passive samplers and PM sensors

The combination of measurements with low-cost diffusive samplers and low-cost sensors can help to understand spatial and temporal distribution of air pollution in a city better.

The running permanent continuous measurements by monitoring stations at different sites in Ulaanbaatar are very important to monitor the temporal behavior of concentrations of different air pollutants and to determine their development over long time periods. This is also important to see if emission mitigation measures, e.g. the substitution of fuel by "cleaner" fuel types, have a noticeable effect on air quality.

To supplement the network of monitoring stations, additional use of low-cost diffusive samplers and low cost sensors is an option that can help to understand better the spatial distribution of air pollutants and to identify hotspots where further measurement should be recommended.

Low-cost passive samplers for SO_2, NO_2 and BTX (Benzene, Toluene and Xylenes) had been located at almost all Z-sampling points in different polluted zones. An example of the results of BTX samplings at 6 points and analysis in the NUM lab with the gas-chromatographic equipment there is shown in Figure 3.8. BTX are gaseous compounds from combustion processes, especially from combustion engines in vehicles. There was a BTX sampler exposed in the high traffic and bad ventilated area near the Bayangol hotel (Z13). The results of this and other points are subject of further evaluation as well as the results of the PM low-cost sensors at different points.

Benzene is known to be carcinogenic. The target value of the EU is 5 µg/m³ as annual mean, the WHO target value is 1.7 µg/m³ with a risk of one case of cancer based on an exposed population of 100,000 (or 3 cases per 100,000 population for 5 µg/m³).

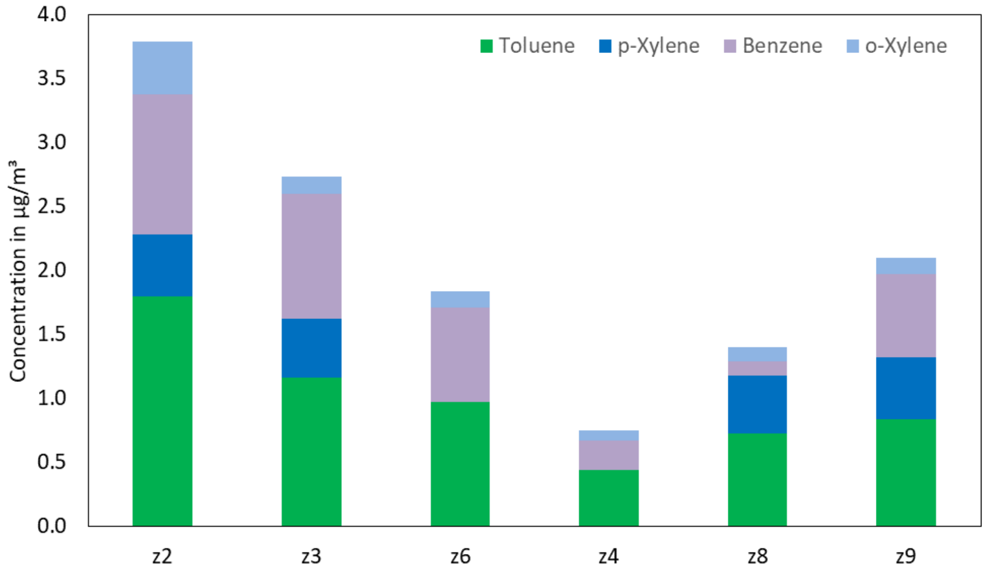

Figure 3.8: Average BTX concentrations from passive sampling at six study sites (Khulan Tsermaa, 2019)

Mobile measurements with low-cost PM sensors

Within the training a PM low-cost sensor was also used for mobile measurements. The sensor was fixed on the roof of a car. The car went through different roads with low speed (approx. 30 km/h) to avoid disturbing influence onto the results. The measurements started in the city center of Ulaanbaatar and continued up to the Selbegol valley. The colors along the route and the graph on the right site of Figure 3.9 show the variation of the concentrations up to 500 µg/m³ as peak values. Time and distance averages were calculated and gives an indication of the concentration by different colors. On the basis of lot of regular repeated measurements an evident information about the spatial distribution of PM load will be the result.

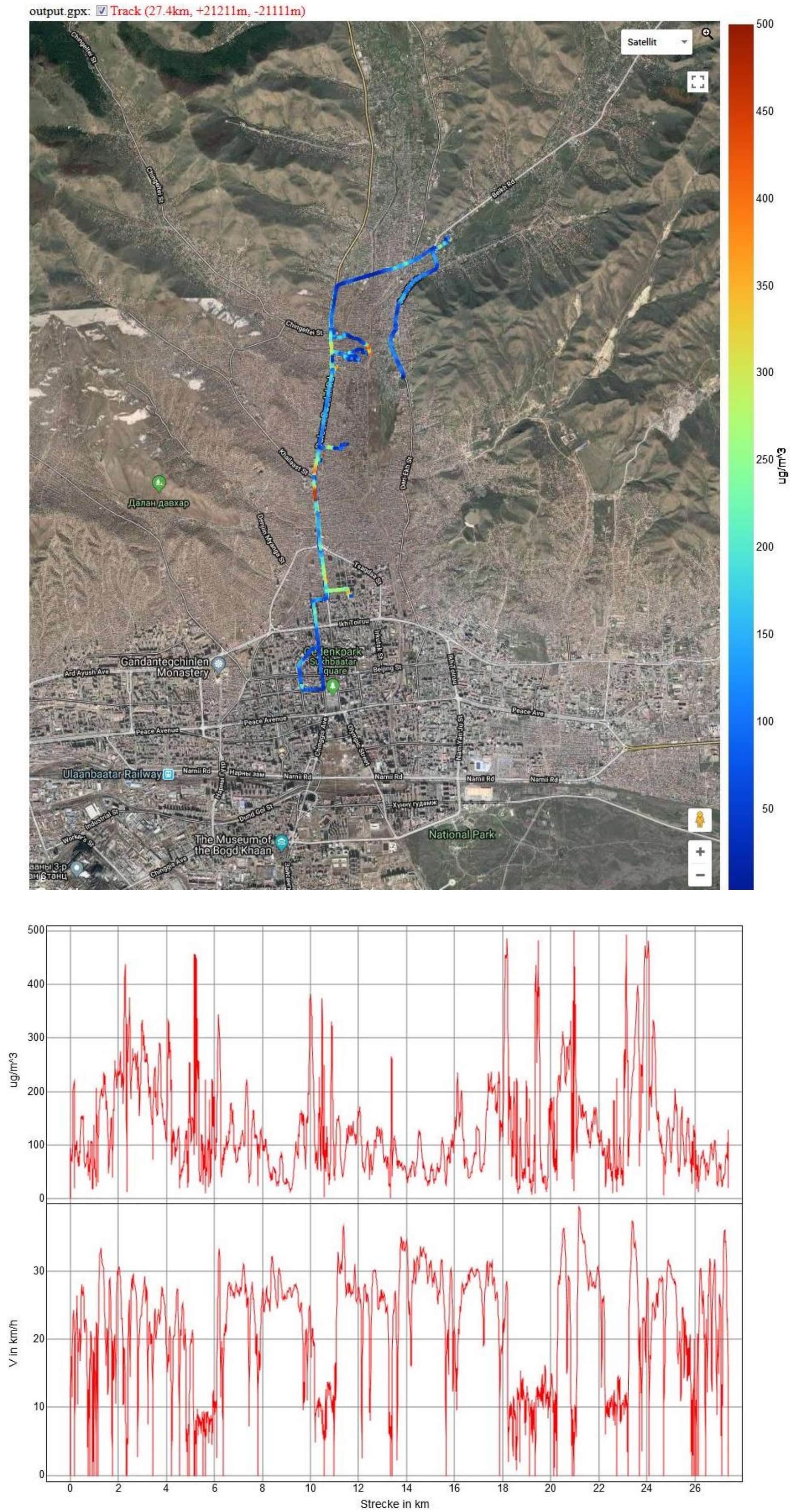

Figure 3.9: Top: Example of PM_{10} mobile measurements with a low-cost sensor in Ulaanbaatar (color legend indicates the concentration level), Bottom: first PM10 concentration and second velocity depending on distance

Benefit of the additional measurements

- The results of the additional measurements have shown that the population in the affected areas during its exposure to particulate matter is also affected by high levels of unhealthy carcinogenic PAH compounds, compared to levels determined in international studies.
- The additional measurements have shown the spatial pollutant dispersion of PM, PAHs, BTX, NO_2 and SO_2 by passive sampling.
- Follow-up measurement campaigns should investigate more in detail the influence of nocturnal conditions on dispersion situation in the case of temperature inversion in the Selbegol valley through passive sampling.
- The practical training on additional measurements enabled and encouraged the Mongolian partners to carry out additional measurements in the field using low-cost sensors and samplers and to analyze PM samples with the existing lab equipment.

3.4 Simulation of air flows and dispersion of air pollutants

The specific meteorological circumstances of Ulaanbaatar with mountain/valley-wind systems affect the spatial distribution of air pollution. Especially cold air flow situations, which appear frequently, contribute to transport air pollution from the Ger areas in the north to the center of Ulaanbaatar. Especially during winter months temperature inversions, sometimes persistent over days or even weeks, trap high concentrations of air pollutants close to the ground. Describing these effects, the GIS based meteorological data base METEOKART GIS was adopted and implemented for Ulaanbaatar. METEOKART GIS provides tools to visualize cold air flow (see Figure 3.10) and spatially differentiated meteorological annual statistics. Furthermore, METEOKART GIS provides interfaces for meteorological inputs for air pollution dispersion models.

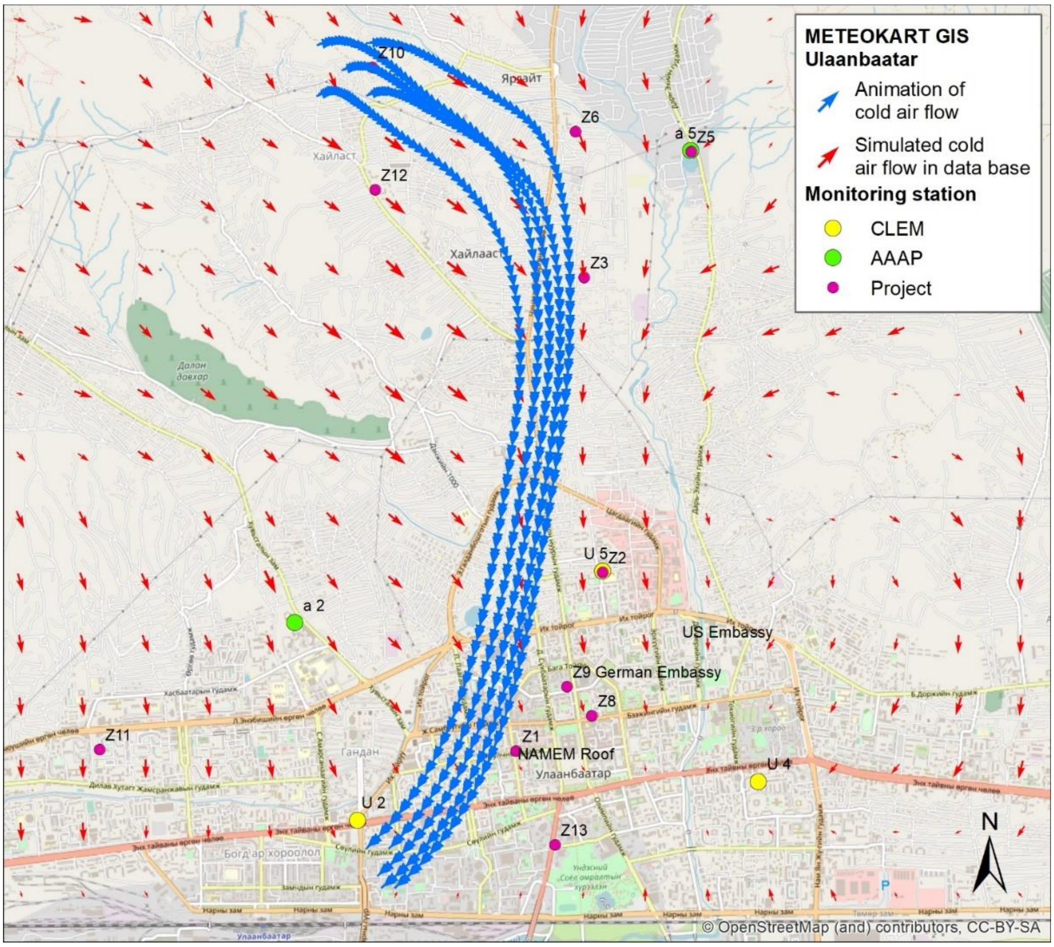

Figure 3.10: Cold air flows simulated with METEOKART GIS, Lohmeyer 2019

During the project period the emission inventory for Ulaanbaatar was started to be enhanced significantly by the municipal environment agency (AAAP). A large number of data was collected by many volunteers. Improved data of the emission inventory can be used to improve dispersion modeling to better estimate the potential of mitigation measures. The training includes showing methods to import emission data to the local dispersion model AUSTAL2000 in combination with the cold air flow modelling system METEOKART GIS.

The applications of METEOKART GIS and AUSTAL2000 were trained, demonstrated and installed on PC Systems at NAMEM and AAAP. METEOKART GIS can be used to visualize meteorological information easily, e.g. for town planning issues.

The additional load of industrial sources or power plants to ambient concentrations in the surrounding as part of permit procedures can be calculated by the dispersion model system AUSTAL2000. This system is also suitable to calculate odor annoyance as odor hour frequencies. A limit value assessment system is in practice in Germany and could be a good basis for further use in Mongolia.

Based on the additional measurement campaign in Selbegol Valley and investigations on obstruction of high buildings along the cold air flow, e. g. in the surrounding area of the monitoring station U5 (=Z2) (see Figure 3.11) pollutant dispersion was further investigated. As a first conclusion from these investigations on cold air flows and simulations of air pollutant dispersion, the necessity of considering nocturnal cold air flows within urban planning is obvious.

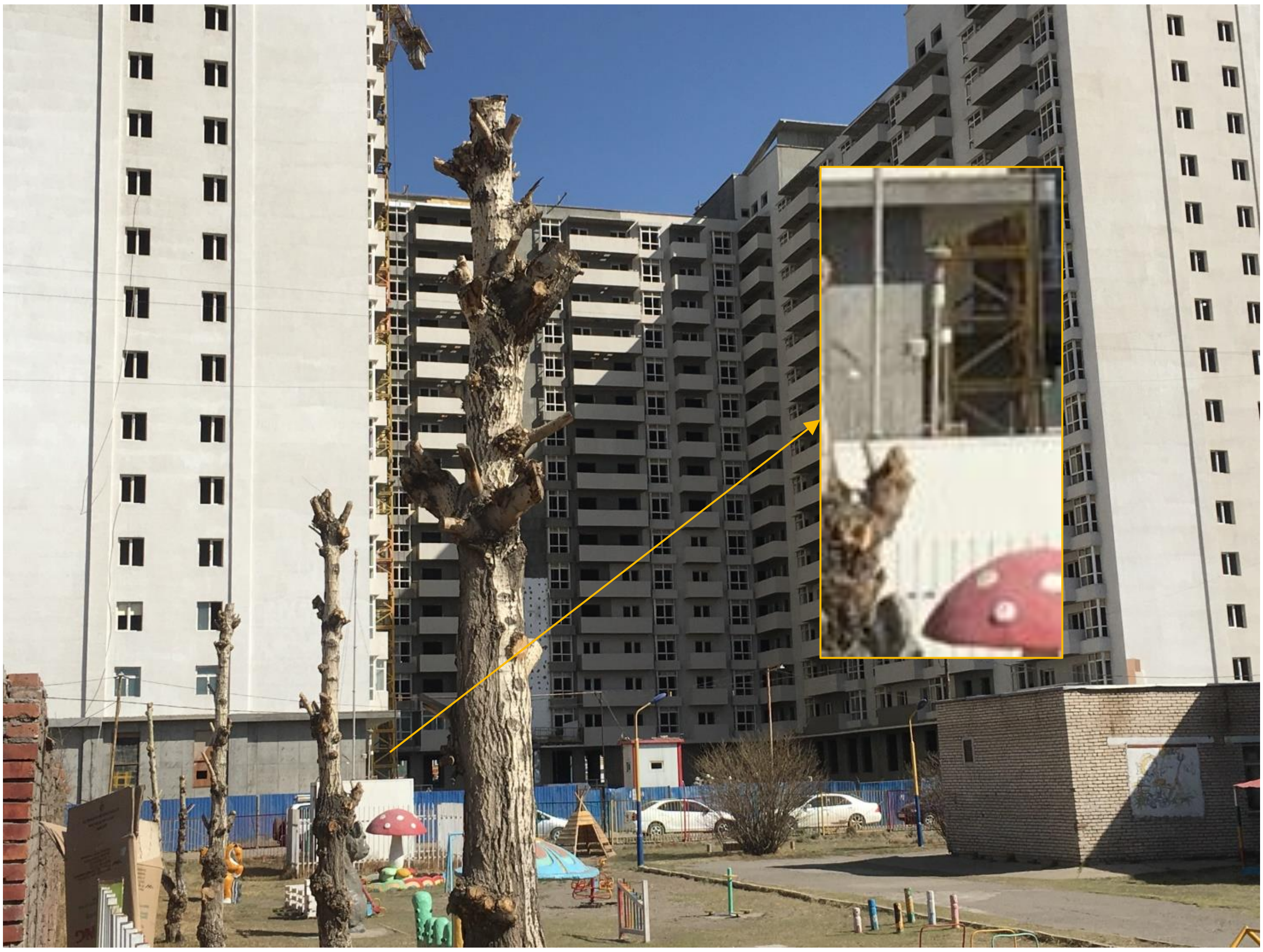

Figure 3.11: Location of the monitoring station inlet of U5, behind the big building barrier (Photo: G. Baumbach 2018)

4 Air quality management system – recommendations for the further development of air quality control planning and air quality monitoring

4.1 Air quality monitoring - solid data base

In addition to the existing air quality monitoring routine and considering the project outcome several further steps are recommended.

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. As trained and demonstrated in the Selbegol Valley, there are several possibilities for detailed measurements to detect i.e. health relevant pollution components like PAHs or BTX. The development and adoption of low-cost monitoring strategies is also an important task to support getting a temporal and spatial resolved image of the air quality situation.

Apart from that, frequent or continuous measurements of air pollutant concentrations should always include measurements of meteorological parameters to describe the transport and dispersion of polluted air. Performance control of emission mitigation measures or strategies must be always accompanied by a monitoring strategy. That might also justify the need for continuously operated measurement stations and for temporarily measurement campaigns or sites.

The simulation of air flows and dispersion of air pollutants has great potential for spatially and temporally differentiated analysis of emission sources and air pollution situation. Simulation runs have to be validated by measured data to prove retrospective analysis of air pollution as well as to reduce the uncertainty of simulated projected impacts of emission mitigation measures. Not least, adequate knowledge, tools inclusive software and well trained and experienced personnel is an essential prerequisite of successful air quality control planning.

Quality assurance – calibration and validation

Basis of all further development topics and also for the ongoing operational work of both air quality networks (NAMEM and AAAP) is quality assurance and traceability of all data back to international standards. Both networks will enhance the “technical exchange of information” about monitor equipment, calibration, quality assurance, data acquisition system and data handling.

Further assistance in ongoing operation procedures and in the enhancement of the technical equipment is also recommended. Not at least there is an essential need to support the National Reference Laboratory in financial and personal way.

A proven calibration strategy for traceability of data as part of quality assurance is summarized in Figure 4.1.

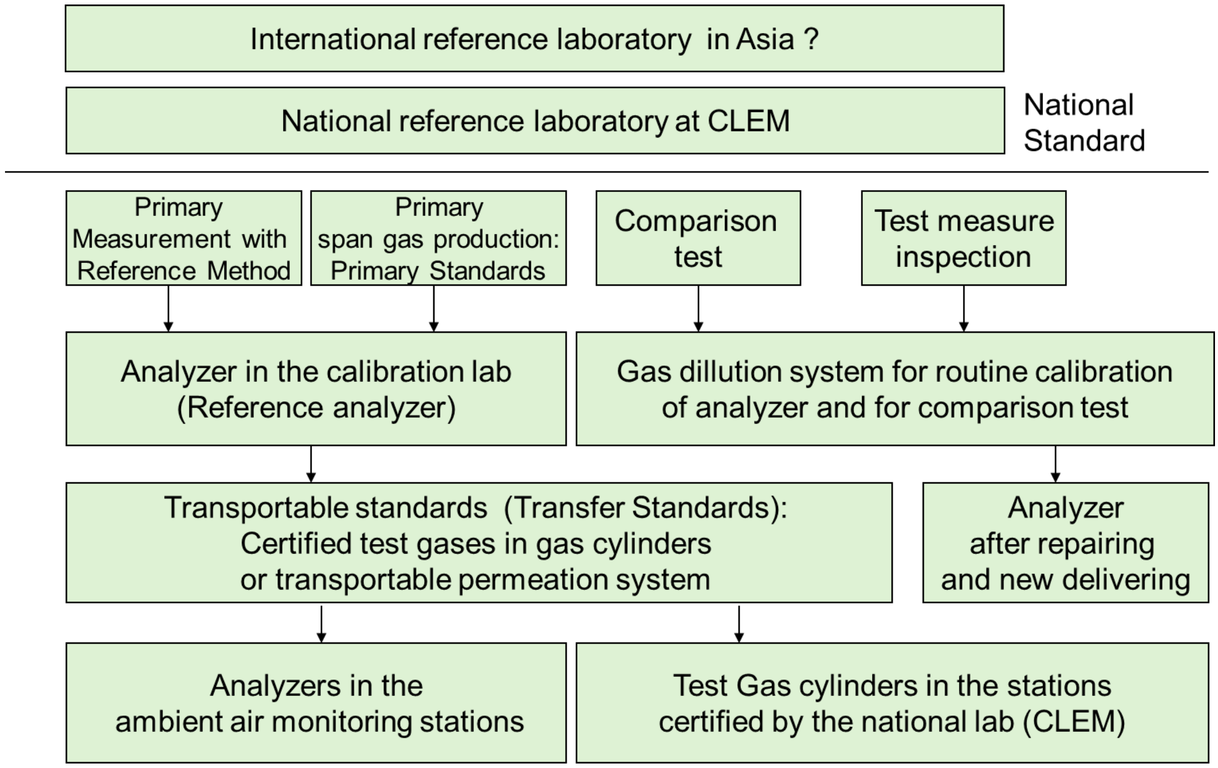

Figure 4.1: Calibration strategy according to the system of Hessian Agency for the Environment and Geology (HLNUG), Germany, 2018

Quality assurance should be supplemented by quality control of measured data and data validation:

- Regular automatic function checks of the instruments in the monitoring stations; e.g. every 23 hours:
  - Automatic status alarms to the measurement center if something is out of a defined range.
  - Automatic function check with test gases.
- Recording the function check data on a control card, which can be used for drift and uncertainty calculations.
- Daily plausibility control in the control center where the data of all monitoring stations are permanently online registered.

Meteorological information

The available meteorological data of the vertical temperature, humidity and wind profile is very important to describe and to analyze the pollution distribution. Existing LIDAR and routine Rawinsound measurements are not able to describe the pro-files near the ground in high vertical resolution. Ger exhaust are emitted below 10 m above ground and from heat only boilers below 40 m. The plumes of these chimneys are affected by low level temperature inversions.

A training exercise was done by a vertical sounding up to 100 m at the Televiz tower. Other possibilities like balloon measurements or video recording of the power station plumes should be tested. The usability of existing additional data measured at the airport was checked and can be integrated in the air quality network dataset, perhaps as part of an ongoing WMO Project between Mongolia and the Korean Meteorological Administration (KMA)[4]. These data would have additional benefit for quality assurance and spatial and vertical distribution of air pollution.

4.2 Air quality control - communication tools

Besides the online available Air Quality Index (AQI) of Ulaanbaatar, giving general information on current air pollutant concentrations as well as estimations of their health implications, further communication tools for public information and policy advice are desirable.

The cold air flow modeling system METEOKART GIS should be used to identify the air flow inside the valley structure as part of urban planning. The combination of air flow and dispersion modeling with measured data gives the possibility to track dispersion of emissions from their sources and quantify their share within pollution loads at the measurement stations – recommended as part of permit procedures.

Climate and air pollution maps for urban planning

For mid-term intervention and to combine urban planning and development aspects with air quality control planning as well as noise reduction issues or issues of cold or heat stress or other environmental issues, climate and air pollution maps should be produced for Ulaanbaatar based on the project trainings. New construction of buildings should for example reflect the influence on nocturnal cold air flows. Reduction of air flow will be an additional contribution to increase the air pollution situation especially during SMOG episodes.

The maps would underline the importance of considering climate functions and dispersion of air pollutants in urban planning processes using data. They will help to discover where air flows transport emissions into the city center and vice versa, the spatial and temporal distribution of air pollution i.e. in different altitudes of the valley. Beyond that, it is also possible to estimate the impact of different emission mitigation measures to identify more effective measures. This will enable to derive target areas for different sets of measures that are most effective to reduce air pollution city-wide.

Alarm system in combination with an action plan

For short-term applications it is necessary to provide a forecast of air pollutant concentrations usually for one to three days. Such concentration modelling based on meteorological forecast is also known as Smog warning system, Smog alarm system or PM alarm system. In many countries of the world there are similar warning systems in operation.

It should be part of further advisory assistance to build up such an information system in combination with an action plan to reduce emissions of relevant emission sources and to avoid the expected high PM concentrations. To set up short term forecast modelling and to evaluate the most effective ad hoc measures, further investment in analysis of the existing situation as well as in modelling tools inclusive training of the responsible personnel is recommended. Further advisory assistance can help

- to analyze the cause of episodes,
- to identify the relevant meteorological parameters,
- to configure a short term forecast for early warning,
- to rank effective ad hoc measures,
- to prioritize areas where ad hoc measures are most effective and
- to assist establishing operational procedures.

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[4] Modernization of the Aviation Meteorological Services of Mongolia, https://public.wmo.int/en/projects/modernization-aviation-meteorological-services-mongolia

A typical positive side effect of action plans to avoid alarm situations is the sensitization of all affected people, stakeholder to effective measures reducing air pollution in general. This could even create acceptance for unpopular measures, e. g. low emission zones or traffic restrictions.

4.3 Air quality plan - cooperation

Intensified exchange of detailed information based on operational experience seems to be helpful for all stakeholders in Ulaanbaatar and international.

In order to derive an integrated clean air strategy for Ulaanbaatar, making use of the data of the air quality measurement network and of the spatially and temporally differentiated analysis of the sources and dispersion of air pollution over the area of the city through simulation, effective emission mitigation measures have to be found and implemented. The dispersion modelling for the entire city area of Ulaanbaatar requires a model system, which is able to simulate the special meteorological situation and considers the relief in a sufficient horizontal resolution. It is proposed to use the combination of a Lagrange dispersion model like LASAT[5] and a 3D prognostic and mesoscale Model like ProWiMo[6].

It is absolutely necessary to discuss potential measures with all relevant stakeholders and at the same time with participation of the public.

Effective measures

User-friendly provision of findings from measured data and from air pollution dispersion simulation can help to keep the discussion and decision-making processes based on facts. There is a need of further evaluation and prioritization of emission mitigation measures to certainly reduce air pollution.

Of course, not one single measure will solve all problems. A detailed analysis of the specific situation of several districts of Ulaanbaatar regarding emission sources and meteorological conditions will help to develop spatially differentiated action plans. Because of the urgent need for action not only long-term measures, like construction of new buildings or a metro, are needed, but also effective and quickly feasible short-term measures.

Promising short-term measures to reduce emissions from the Ger-settlements are better Ger insulation and retrofitting of the installed stoves with electrostatic precipitators. The potential of coal reduction through better Ger insulation is up to 50 %. The potential of the traditional use of additional layer of felt should be checked in detail. Also, the potential to reduce peaks in PM concentrations by scheduled time-shifted ignition for the different districts has to be further analyzed.

Implementation of air quality aspects in urban planning processes

Actual information and now available tools like modelling of cold air flows and dispersion simulation in combination with preliminary findings of additional measurements within this project could be an additional supplementary part of urban planning processes based on the existing JICA-project "Mongolia: Ulaanbaatar Urban Planning Improvement" (Part I: Urban Planning Manual[7], JICA, 2016 and Part II: Ulaanbaatar City - Master Planning 2030[8], JICA, 2019).

[5] https://www.janicke.de/en/lasat.html

[6] http://www.lohmeyer.de/en/content/about-us/work-methods/numerical-models/prowimo

[7] https://www.adb.org/sites/default/files/project-documents/47039/47039-001-dpta-en.pdf

[8] http://open_jicareport.jica.go.jp/pdf/11937158_02.pdf

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Special thanks to Khulan Tsermaa, whose master's thesis[9] was created in cooperation with the advisory assistance project, for the permission to present selected results of her work in this brochure.

[9] Khulan Tsermaa (2019): Determination of Smog Compounds Distribution and Composition in Ulaanbaatar, Mongolia. Master Thesis, Environmental Protection Technology at the National University of Mongolia, School of Engineering and Applied Science, Department of Environmental and Forest Engineering. Supervisors: Assoc. Prof. Soyol-Erdene Tseren-Ochir (PhD), Prof. Dr.-Ing. Günter Baumbach; Official Opponent: Gantuya Ganbat (PhD). Ulaanbaatar 2019.