Sustainable Development—East Asia and Pacific Region

52970

DISCUSSION PAPERS

MONGOLIA

Air Pollution in Ulaanbaatar

Initial Assessment of Current Situation and Effects of Abatement Measures

December 2009

Ambassade van het Koninkrijk der Nederlanden

환경관리공단 Environmental Management Corporation

THE WORLD BANK

Air Pollution in Ulaanbaatar

Initial Assessment of Current Situation and Effects of Abatement Measures

Discussion Paper

December 2009

Sustainable Development Series: Discussion Paper
Sustainable Development Department
East Asia and Pacific Region

THE WORLD BANK

This study was prepared by the Sustainable Development Department (EASSD) of the East Asia and Pacific Region, and was mainly funded by the Bank-Korea Environmental Partnership (BKEP) and the Netherland-Mongolia Trust Fund for Environmental Reform (NEMO).

Sustainable development issues are an integral part of the development challenge in the East Asia and Pacific (EAP) Region. The World Bank's Sustainable Development Strategy for the region provides the conceptual framework for setting priorities, strengthening the policy and institutional frameworks for sustainable development, and addressing key environmental, social and rural development challenges through projects, programs, policy dialogue, non-lending services, and partnerships. The EASSD Discussion Paper series provides a forum for discussion on good practices and policy issues within the development community and with client countries.

The publication and primary data are available online at www.worldbank.eapenvironment and www.worldbank.org.mn

Table of Contents

Figures

Tables

Foreword

For people living in Ulaanbaatar (UB) it has for quite some time been experienced that the city unfortunately has high air pollution concentrations, particularly during the winter months, which also have had severe impact on human health. Following the drastic expansion of Ger areas surrounding the traditional city centre, air pollution levels apparently have increased.

In order to get a better understanding of and responses to such questions like how high are the pollution concentrations particularly in expanding Ger areas, what is the exact impact on human health and what would the most cost effective interventions be, the World Bank initiated in 2008 an "*Air Monitoring and Health Impact Baseline*" (AMHIB) study based upon recommendations from several Mongolian counterparts. The study, which is part of a larger UB Clean Air Program, also intends to provide a reference (*baseline*) upon which the effect of future intervention could be measured within such a program.

This discussion paper provides the information from the first half of the AMHIB period from June 2008 to May 2009. A final report will be presented following the completion of the work in early 2010. Nevertheless, the findings in this paper clearly bring the understanding of the severity of the situation forward.

We would particularly like to emphasize that the study has been initiated and shaped by our Mongolian counterparts, which have left us with a deep impression about their sincere wish for solving UB's critical air pollution challenges as well their professionalism with regard to both air quality and health impact subjects. With these capacities we are convinced that UB one day will become both a clean and green place to live.

Ede Jorge Ijjasz-Vasquez
Sector Manager
China & Mongolia Sustainable Development Unit
The World Bank

Arshad M. Sayed
Country Manager
Mongolia
The World Bank

Magda Lovei
Sector Manager
Social, Environment and Rural Unit
East Asia and Pacific Region
The World Bank

Acronyms

ADB	Asian Development Bank
AMHIB	The Air Monitoring and Health Impact Baseline Study
AQ	Air Quality
AQG	Air Quality Guidelines
AQLV	Air Quality Limit Values
AQM	Air Quality Management
AQS	Air Quality Standards
BKEP	Bank-Korea Environmental Partnership
CHP	Combined heat and power stations
CLEM	Central Laboratory for Environmental Monitoring
EBRD	European Bank for Reconstruction and Development
EF	Emission Factor
EI	Emissions inventory
ESP	Electrostatic Precipitator
EU	The European Union
GDP	Gross Domestic Product
GTZ	Deutsche Gesellshaft fur Technische Zusammenarbeit, GmbH
HOB	Heat only boilers
JICA	Japanese International Cooperation Agency
NAMHEM	National Agency of Meteorology, Hydrology and Environmental Monitoring of Mongolia
NEMO	The Netherland-Mongolia Trust Fund for Environmental Reform
NILU	Norwegian Institute for Air Research
NO_2	Nitrogen dioxide
NRC	Nuclear Research Center (of the NUM)
NUM	National University of Mongolia
PM	Particulate matter. Suspended particles in air
PWE	Population Weighted Exposure
RH	Relative humidity in air
SO_2	Sulphur dioxide
TSP	Total Suspended Particulate
UB	Ulaanbaatar
US EPA	Environmental Protection Agency of USA
WB	World Bank for Reconstruction and Development
WHO	World Health Organistion
WTP	Willingness-to-pay

Acknowledgements

The AMHIB has brought together Mongolian air pollution scientists, leading air pollution monitoring officials, and public health experts to take a synergetic approach of linking public health and air quality issues. This Discussion Paper is built up from the work on air pollution analysis performed by World Bank Consultant Dr. Sarath Guttikunda. Parts of his 2007 report are included in this report with updates.

This Discussion Paper greatly benefited from cooperation and input of a wide range of stakeholders including the AMHIB Steering Committee led by the Ministry of Nature, Environment and Tourism and including, NAMHEM, the UB city administration and Ministry of Health. In addition to the co-project managers of this activity Gailius Draugelis, Senior Energy Specialist and Jostein Nygard, Senior Environmental Specialist, the AMHIB team comprises Tumentsogt Tsevegmid, Senior Infrastructure Officer, World Bank, and experts from the National University of Mongolia, the Public Health Institute of Mongolia, and the Norwegian Institute for Air Research (NILU) and Steinar Larssen, consultant and formerly with NILU. The AMHIB team also wishes to thank the JICA air quality monitoring experts for their kind support and peer review. Comments have been received from several stakeholders and would like to acknowledge contributions from Messrs. Robert van der Plas, Household Energy Specialist, and Crispin Pemberton Pigott, Household Stove Specialist—both World Bank consultants.

This Discussion Paper was prepared under the guidance of co-Task Managers Gailius Draugelis, Senior Energy Specialist and coordinator of the UB Clean Air Program, and Jostein Nygard, Senior Environmental Specialist and lead manager of the AMHIB activities. The primary authors of the analysis and draft report are Steinar Larssen, Li Liu, Sereeter Lodoysamba, A. Enkhjargal, Kristin Aunan, and Gailius Draugelis. Updates of the report are made by Jostein Nygard and Steinar Larssen. Dr. Bruce Denby of NILU contributed to model testing. Ms. Shawna Fei Lee, World Bank Junior Professional Associate, also contributed to the description of the overall project as well as the cover photo. In addition, the Discussion Paper was peer reviewed by Jan Bojo, Lead Economist, East Asia Operations and Policy Unit, Sustainable Development Department, East Asia and Pacific Region; Paul Procee, Environmental Specialist, Environment Unit, Latin America and Caribbean Region, World Bank; Alan Krupnick, Senior Fellow and Director, Quality of the Environment, Resources for the Future; and Mr. Taizo Yamada, Senior Advisor, Environmental Management and Planning, Japan International Cooperation Agency (JICA). The report was designed and typeset by Shepherd Inc.

This Discussion Paper is part of a World Bank response to the Government of Mongolia's request to mobilize a wide range of resources to develop and support abatement measures for air pollution in UB. The wide range of activities is called the UB Clean Air Program, and includes support from the Korean Environmental Management Corporation especially for this Discussion Paper and its related project, the *Air Monitoring and Health Impact Baseline* study. The World Bank also contributed resources toward

this study. Additionally, the Government of the Netherlands (through trust funds managed by the World Bank and through a separate Government-executed, Bank administered trust fund project "NEMO"), Japan (through a Government-executed, Bank administered trust fund project "Capacity Building for the Development of Carbon Financing Projects in Mongolia"), and Korea (through a Bank executed trust fund project "Korea-Bank Environmental Partnership") have all contributed to various activities under the UB Clean Air Program. The Bank has also been asked by the Government to prepare an investment project—the proposed UB Clean Air Project. In addition, the Bank assists the Government in raising awareness among external and internal financiers of opportunities to support abatement measures and is working closely with ADB, EBRD, GTZ, JICA, and many other partners.

Executive Summary

The Discussion Paper presents preliminary findings for dissemination to initiate a discussion on the short-term and long-term emission reduction strategies for reducing UB's air pollution, given its changing demographics—growing population and a growing urbanization. This Discussion Paper assesses the current air quality situation in UB, based on available data from 2006 to 2008, and estimates effects of pollution abatement options on ambient concentrations of particulate matter (PM). Population exposure estimates are used to assess current health damage attributable to air pollution in the city and the health benefits that can be achieved from implementing the abatement options. This World Bank Study launched a collection of PM data in seven monitoring stations in UB in July 2008. The final paper is due in early 2010 and will incorporate more recent pollution measurements.

Local authorities and central Government need to develop a well-defined process of action planning to reduce air pollution in UB, preferably based on systematic analysis and built on existing institutional frameworks. There has been much debate on the most cost-effective way to improve the UB's air quality to acceptable levels, which pollution sources to target and the need to develop and implement an effective action plan. The inter-agency National Coordination Committee chaired by the Ministry of Mineral Resources and Energy and vice-chaired by UB city administration is an excellent platform to develop a well coordinated process for action planning, linking proposed policy options with an air pollution assessment to evaluate, prioritize and measure results.

This Discussion Paper lays out the approach that the ongoing World Bank study will follow through to its conclusion in early 2010. The World Bank and its study partners invite comments on this approach and analysis so that it can be as helpful as possible to the scientific community in air pollution analysis and to Government for action planning. The World Bank launched with its partners a technical assistance project that intends to introduce a systematic way of evaluating abatement options. The AMHIB Technical Assistance Project will develop a baseline for Particulate Matter (PM), source contributions and health effects and prepare a dispersion model that estimates effects of abatement options. This Discussion Paper introduces the approach and model using data collected by Mongolian air quality experts, including data collected during the first half of *AMHIB*.

Air quality data in UB is improving, but there are significant shortcomings in data quality that should be addressed. Some of the data used in this Discussion Paper is collected by government agencies and research institutions prior to the start of the World Bank *AMHIB* study,[1] while other data presents the first seven

[1] Collected in conjunction with the air pollution analyses carried out by World Bank consultant Dr. Sarath Guttikunda in the report titled "Urban Air Pollution Analysis for UB" (draft 2007).

months of data collected through the AMHIB study up to the end of December 2008.[2] Air quality monitoring devices vary in quality and state of operation and the inventory of emissions from main sources needs more accurate emissions factors through measurements. Due to data quality shortcomings, the key findings presented in this Discussion Paper must be considered *preliminary*. The results from the modelling of estimated effects of abatement options could be subject to changes when a better emissions inventory is constructed. The *AMHIB* team, however, considers the model itself is well suited for UB. It is able to replicate the current air pollution patterns observed in data collected from UB's air quality monitoring stations. Better data on emissions and air quality monitoring that also extends to the ger areas, like the AMHIB network starting in June 2008 for the entire period to May 2009, may result in a need for model adjustment and improvement. Additionally, data collected from air quality monitoring stations provides sufficient observations for the *AMHIB* team to establish findings about air pollution levels and its severity.

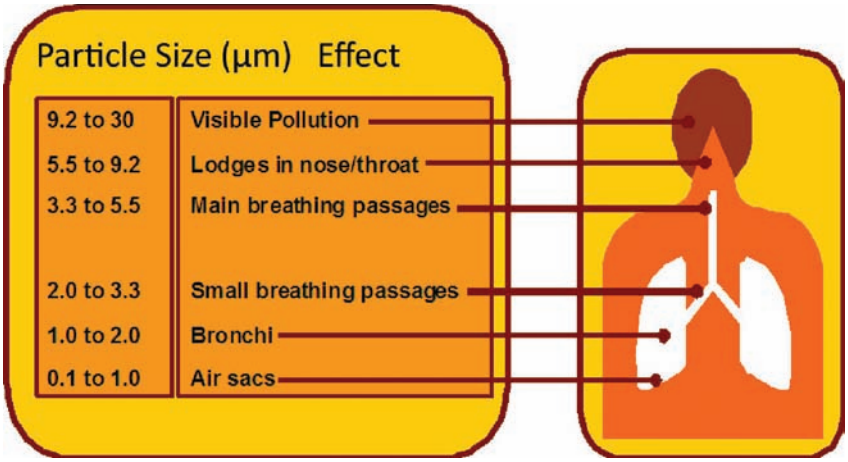
There is room for optimism as newly refurbished monitoring stations have been installed by CLEM as well as through a GTZ program and additional state-of-art monitoring stations supported by the French Government are expected soon. JICA is working on upgrading emissions factors and inventories for boilers and power plants. This should contribute significantly to data quality and accuracy of analysis in the future and hopefully prior to the final *AMHIB* report, due in early 2010.

Although pollutants such as SO_2 also are higher than international standards, Particulate Matter (PM) is the largest and relatively most severe air pollution problem in UB. In terms of PM, UB is among the most polluted cities in the world. Measurements carried out in UB show that PM is by far the most serious air pollution component. It is well documented that particles (primary PM_{10}, $PM_{2.5}$, and secondary PM due to SO_2 and NO_x emissions) cause negative health effects when inhaled by people. In UB the main sources of ground level $PM_{2.5}$ (fine particle) concentrations are primary carbonaceous particles from coal combustion for heating and cooking (Ger households) and industrial activities (heat-only-boilers and power plants). Suspension of dust from streets and other surfaces contribute to larger yet also harmful coarse particles contributing up to 50% of total annual average PM_{10} concentrations in one part of the city (NUM station). It is noted that the largest emissions sources may not be the largest contributors to the ground level pollution people inhale.

Inhaling Particulate Matter (PM) can severely affect the lungs and the heart. The size of the particles determines the potential for serious negative health problems when inhaled. The figure below indicates that the smaller the particles are, the further down into the respiratory system and lung they are transported and deposited. Particles in the $PM_{2.5}$ fraction (having diameters smaller that 2.5 µm) passes into the smaller bronchi and air sacks and a fraction of them are deposited there, while more coarse particles (in the size range between approximately 10 µm and 2.5 µm) are deposited in the upper respiratory tract. Once deposited in large enough amounts, the particles can cause health damage.

In the most polluted parts of the city, based on available data, annual average concentrations of PM_{10} are 2–10 times higher than Mongolian and International Air Quality Standards (AQS). The $PM_{2.5}$ concentrations are less well documented by measurements but available data indicate that the $PM_{2.5}$ situation is equally severe compared to AQS. Annual average concentrations of PM_{10}, measured at the National University of Mongolia (NUM) campus area to the east of central UB (the station with the longest series of PM measurements) were as high as 141, 157 and 279 µg/m^3 for 2006, 2007 and

[2] Here PM monitoring data were collected from research institutions and government agencies, including National University of Mongolia (NUM), National Agency of Meteorology, Hydrology and Environmental Monitoring of Mongolia (NAMHEM), and Mongolian Central Laboratory for Environmental Monitoring (CLEM). NUM also provided a statistical assessment of source contributions to PM emissions based upon the chemical analysis of the dust particles collected at its monitoring station in UB.



Source: Guttikunda, draft 2007.

2008 respectively. Measurements at monitoring stations in other parts of UB since June 2008 under this *AMHIB* study give even higher concentration levels. Based on this *AMHIB* study's modeling results, the concentrations are likely to be higher in the north-central areas of UB than at the NUM station. These measured UB PM_{10} levels are 2–5 times higher than Mongolia's AQS of 50 µg/m³, 5–10 times higher than the WHO Guideline Value of 20 µg/m³, and 3–7 times higher than the European Limit value of 40 µg/m³. WHO has set interim target values realizing that the Guideline Values cannot be met in the short term in many developing countries. The highest interim target value is 70 µg/m³. Thus, the present PM_{10} level in UB is at least three times higher than this target in the most polluted areas of the city. The spatial distribution of the pollution is wide spread across UB city and its surroundings. The $PM_{2.5}$ concentrations are less well documented by measurements but limited samples taken in November 2008 indicate the severity of the $PM_{2.5}$ situation. The measuring equipment used until the end of 2008 is affected by sampling artifacts, resulting in too low $PM_{2.5}$ levels. A measurement campaign during the last part of November 2008 provided parallel $PM_{2.5}$ and PM_{10} measurements indicating that 50–60% of PM_{10} was in the $PM_{2.5}$ fraction on those days. The $PM_{2.5}$ concentrations reached as high as over 400 µg/m³ as daily average and maximum hourly levels of up to 1300 µg/m³.

Some cities in northern China and south Asia still have high annual average concentrations, i.e. above 200 µg/m³ up to a few years ago, but PM levels are coming down in Chinese cities. The annual average PM_{10} concentrations in European and US cities are much lower, the highest levels are in the range 60–100 µg/m³ (although some desert cities in the US have higher levels), and in most cities the concentrations are below 40 µg/m³.

Wintertime air pollution drives annual average concentrations of PM to their very high levels. Hourly average concentrations observed thus far are at least as high as 2,300 µg/m³, and daily averages above 1,000 µg/m³ in the most polluted parts of the city (AMHIB monitoring data). These episodes occur regularly and often throughout the winter periods, caused by the special climatic and meteorological situation of UB, and bring the annual average concentration to its very high level. Some industrial cities in Europe still have maximum daily concentrations in the range 400–700 µg/m³ approaching those in UB, but they occur on very few days of the year, unlike in UB. Most cities in the US and Europe have much lower daily maximums.

The wintertime episodes of extremely high hourly and daily concentrations are likely to represent the highest urban scale short-term peak PM concentrations anywhere, ranging from 4–14 times Mongolian and international standards. During winter, the limited data available show that daily average concentrations of PM_{10} reach at least 7 times the Mongolian AQS for 24-hour average concentrations, 4 times

the highest interim 24-hour target values for developing countries and EU standards, and 14 times the WHO Global Guideline Value. During the winter, AMHIB data show daily average concentrations reach at least as high as 1,000 µg/m³. These episodes occur regularly throughout the winter months, and bring the annual average concentration to its very high level.

A large share of the PM_{10} concentrations come from these wintertime peaks that may correspond to the cold start ignition and re-loading phases for heating stoves combined with the poor meteorological dispersion conditions at those hours. ***There is an indication that, as a short-term measure, significant reductions in emissions can be achieved from changing the way raw coal is lighted for heating.***[3]

Socially acceptable, technically feasible emission reduction targets should be set to give a clear direction for action plans. Targets

[3] See Lodoysamba & World Bank's *Heating in Poor, Peri-Urban Ger Areas (June 2009).*

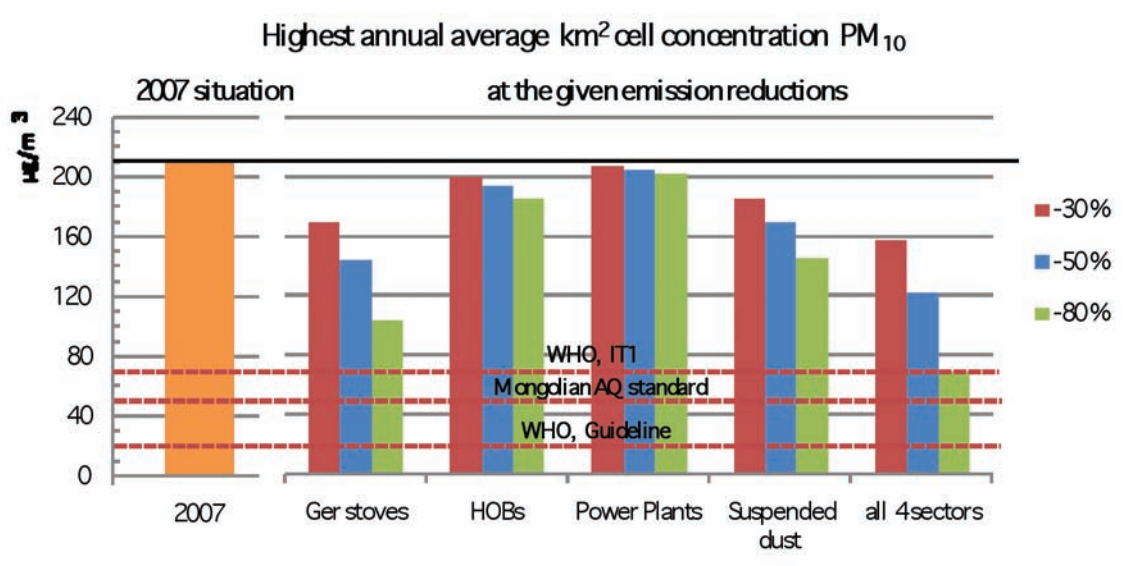
Comparison of UB PM Air Pollution and International Standards 2006–2008

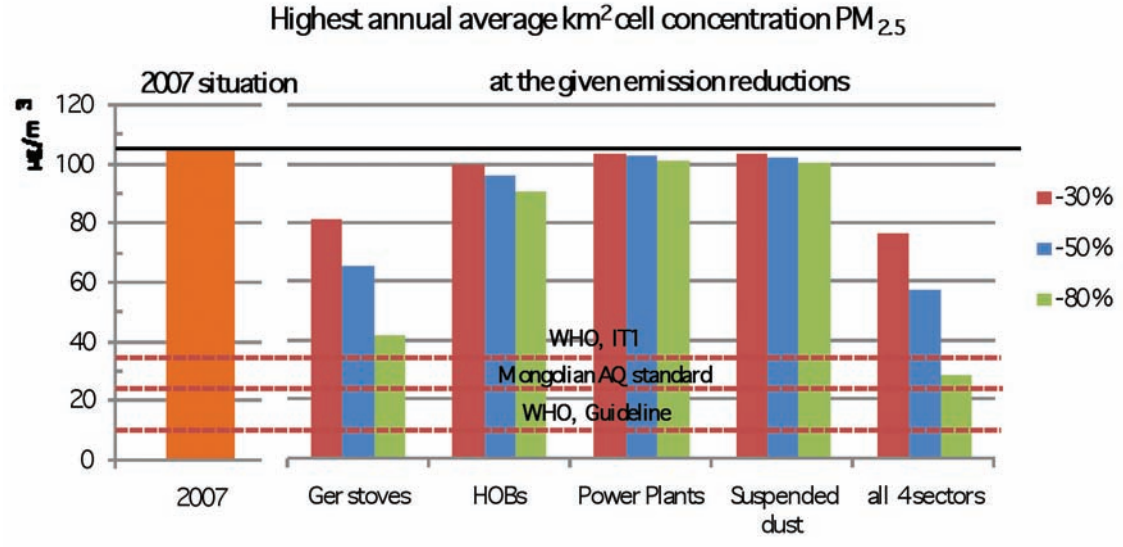
	$PM_{2.5}$		PM_{10}		PM_{10}	$PM_{2.5}$	PM_{10}
	Annual average	24 hour daily average	Annual average	24 hour daily average	Hourly average	Hourly average	Max. hourly
Measured PM concentrations in UB (pre-final AMHIB) (all numbers in µg/m³)							
2006			141				
2007			157	600	1700		
2008			279				
November 17–22, 2008		max. 350		max. 600	2300	1300	2500
Guidelines, standards, limit values (all numbers in µg/m³)							
Mongolia AQS	25	50	50	100			
WHO Guidelines (2005)	10	25	20	50			
WHO Interim Targets							
IT-1	35	75	70	150			
IT-2	25	50	50	100			
IT-3	15	37.5	30	75			
USEPA Air Quality Standards (2006)		15	35[1]	—	150		
EU limit values	25[3] 20[4]	—	40	50[2]			

[1] *7 days above 35 per year is allowed.*
[2] *35 days above 50 per year is allowed.*
[3] *To be met by 2010.*
[4] *To be met by 2020.*

will be determined by technical options and the ability and willingness to pay for pollution reduction by civil society. The costs of air pollution are paid from the pocketbook, the budget and future health costs through higher incidences of pollution related illnesses. What and how to pay for air pollution is a choice to be made by civil society and its representatives. Due to the complex nature of air pollution, an open discussion of options and their estimated impacts based on an analytical framework using best available data is recommended. Cost effectiveness or cost-benefit analysis can be used for each policy option. These estimates together with other factors that are considered important to civil society can be considered in choosing clean air strategies. Setting targets that have been openly discussed helps build widespread support for pollution abatement activities that involve asking people to change behaviors. Many in civil society, especially the poorest, will be asked to change their behavior in some way to improve air quality. They should become active allies in the reduction of air pollution in UB. This approach provides policy makers with realistic options for developing air quality management strategies that are suited to the current socio-economic situation in Mongolia.

To achieve Mongolian AQS, 80% emissions reductions are needed. This can only be achieved realistically in the long term. An emissions reduction strategy that sets ambitious but realistic short-term targets is recommended.





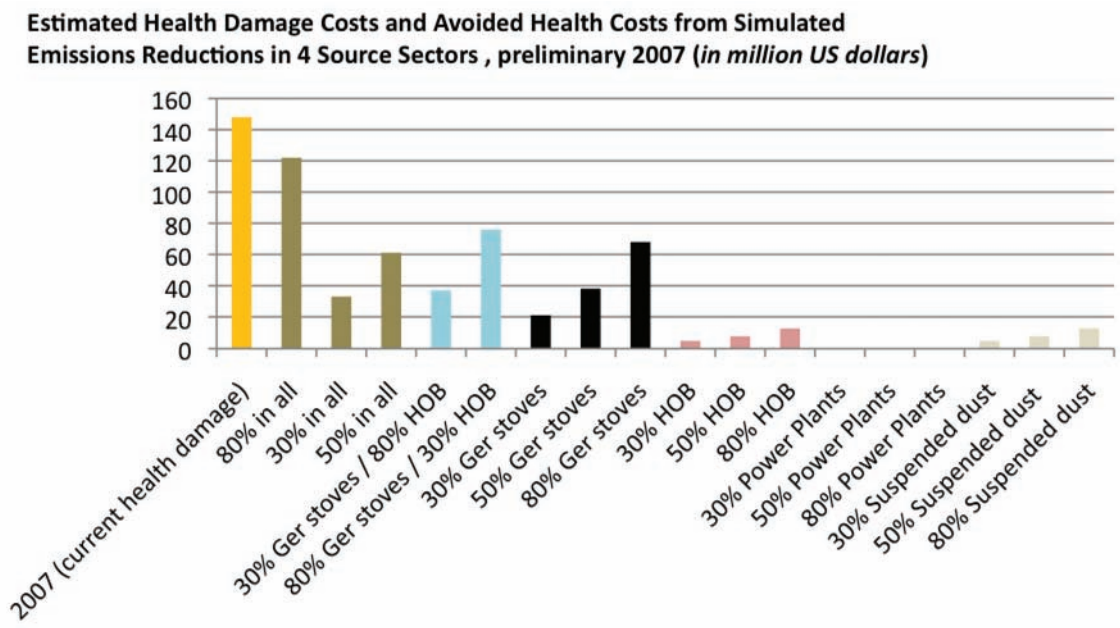
Different sources of air pollution show different impacts on air quality. To meet the Mongolian standard in UB for the most harmful particulates, $PM_{2.5}$, the model predicts more than 80% of emissions reductions are needed. The results also show that different source sectors have different impacts on air quality. Based on available data, reducing emissions in the ger areas by half yields an improvement in PM concentrations by about one-third—much more than similar emissions reductions in other source sectors.

The AMHIB has also started a process to evaluate the health effects associated with air pollution in UB. Part of the AMHIB project is collecting data from hospitals in UB located close to the air pollution monitoring stations. These include 8 family and village hospitals, 7 district hospitals, 1 ambulatory facility, and 3 tertiary hospitals. Data on daily admissions connected to respiratory and cardiovascular diseases, based on diagnoses, will be collected to perform statistical analysis with variables connected to PM concentrations. The analysis should be completed before the end of 2009.

In order to make preliminary estimates of associated health costs, the Discussion Paper uses the *population weighted average PM concentration*, in short the *population weighted exposure*

Estimated health damage due to PM pollution in Ulaanbaatar and number of cases avoided due to interventions (in annual number of cases)

	All-cause mortality (chronic)	Chronic bronchitis	Hospital admissions (respiratory disease)	Hospital admissions (CVD)
2007 (current health damage)	*614*	*379*	*735*	*448*
80% in all	504	308	664	406
30% in all	129	107	245	151
50% in all	244	184	411	252
30% ger stoves / 80% HOB	146	119	271	167
80% ger stoves / 30% HOB	308	220	487	299
30% ger stoves	83	71	165	102
50% ger stoves	149	121	277	170
80% ger stoves	273	201	446	274
30% HOB	18	16	39	24
50% HOB	31	28	65	40
80% HOB	51	45	104	65
30% power plants	1	1	1	1
50% power plants	1	1	2	1
80% power plants	2	1	3	2
30% suspended dust	18	16	38	23
50% suspended dust	30	27	63	39
80% suspended dust	49	43	101	62



(PWE). When compared to annual average concentrations, the PWEs more accurately reflect exposure of UB's population to air pollution by adjusting for the spatial distributions of the pollution and the population. The calculated PWEs were used as basis for calculating health effects and their reduction as a result of the reductions in emissions. The base year of this assessment is 2007 and the threshold for excessive air pollution is taken as the WHO Guideline Value. In 2007, it is estimated that the *maximum* health costs associated with the air pollution in UB correspond to US$147 million equivalent, representing 8.0% of UB's GDP and 3.8% of national GDP. A sensitivity analysis using an income elasticity of Willingness to Pay of 0.5 rather than 1.0 gives a health damage cost of 4.1% of UB's GDP and 1.9% of national GDP or $74 million per year.

Note on Data Quality and Modelling Approach

This is an interim report intended to generate discussion on how best to measure and evaluate air pollution reduction programs in UB. Assessments of air pollution and the costs and effects of specific abatement measures on selected source categories, carried out according to air quality management practices, require a multitude of data, ranging from data on measured concentrations, inventory of population and of the emissions and their spatial and temporal distribution, meteorology and dispersion data, and cost data on abatement measures.

The monitoring data available for this work was limited to 4 stations for SO_2 and NO_2, and one station for $PM_{2.5}$ and PM_{10}, until June 2008, when the PM measurements at 7 additional stations started under the AMHIB project. During this work, all the available monitoring data from before June 2008 has been utilised, and their quality assessed. The monitoring data was used partly to assess the present air pollution levels, partly to validate the dispersion modelling carried out to map the pollution situation as a basis for assessing the contributions to the pollution levels from the various main sources. A PM monitoring mission was carried out, in order to assess the quality of the PM measuring instruments presently used in UB. Data from the AMHIB monitoring network from the period June–December 2008 became available after the modelling work had been carried out. The modelling work is futher updated in the final AMHIB report.

The existing preliminary EI developed under a previous World Bank consultant report

was improved somewhat based upon additional available data. Some road traffic data have been established, based upon a small traffic counting effort. This improved, but still preliminary EI is used as input to the dispersion modelling carried out under this work.

The Bank team intends to work with the Air Quality and Health Impact Baseline (AMHIB) Study Steering Committee (comprising Ministry of Nature, Environment and Tourism (chair), NAMHEM, CLEM, UB Air Quality Department), JICA, GTZ and others to improve data quality to strengthen the analysis in the Final AMHIB paper. Preliminary results shared in May 2009 from an ongoing JICA study of emissions factors and inventories for HOBs, which also included measurements of CHPs and a ger stove differ from the emissions factors used in this Discussion Paper. The preliminary JICA results would modify the source contributions to ground level PM concentrations. The CHP contribution would be larger, and heat-only-boilers (HOB) and ger contributions relatively smaller. Time is needed to fully evaluate these most recent findings. The Bank endeavours to work closely with JICA on improving the emissions inventory by the final AMHIB paper due in early 2010.

The emissions inventory (EI) used for this work includes the main source categories but it requires improvement. Emission factors (EFs) used are uncertain and would benefit from more measurements, especially for the coal and wood combustion in ger heating systems and HOBs, as well as the suspension of dry soil dust from roads and surfaces.

Several donor initiatives are underway which will help improve data quality. The GTZ installed several air quality monitoring stations in January 2009 that have recently produced reliable air quality data. In cooperation with World Bank consultants, EBRD has conducted fuel-stove tests that should help improve emission factor estimates for ger heating systems. ADB has proposed Technical Assistance that will purchase equipment to set up a local laboratory to carry out more fuel-stove testing. JICA is preparing technical assistance to reduce emissions.

Modelling Approach The effects of abatement measures on the annual average PM_{10} and $PM_{2.5}$ concentrations are simulated on the following basis.

The links between the emissions from the various source categories and the resulting contributions to ground level concentrations were investigated using air pollution dispersion models, calculating hour-by-hour concentration distributions in the UB urban area over an entire year. The results from the modelling compared well with the available pre-June 2008 monitoring results. Maps have been produced showing the spatial distribution of the contribution to PM concentrations (PM_{10} as well as $PM_{2.5}$) for 2007 from the following source categories: Ger household stoves, HOBs, CHPs, road traffic vehicle exhaust, and suspension of dry dust from paved and unpaved roads. Industrial process emissions affecting the populated area are limited especially during the winter period and have not been included in the calculations.

The main sources of the high ground level PM concentrations in UB are the approximate 130,000 Ger household (2007) heating systems (stoves, heating walls and coal water heaters) that use raw coal and wood for heating and cooking, the about 250 HOBs in the city using raw coal, and the suspension of dry dust from paved and unpaved roads and other surfaces. CHP plants have very large emissions of SO_2 and PM, although their tall stacks limit their contribution to the ground level concentrations. The spatial distribution of the sources, with ger households distributed in the areas around the city central area, the HOBs distributed more close to the centre and the road traffic more concentrated in the central urban areas, provide the setting for air pollution modelling as a necessary method for assessing spatially distributed contributions.

The quality of the AMHIB data is further evaluated in Appendix C.

Introduction: Nature of the Air Pollution Problem in Ulaanbaatar

Geology, topography and population

Mongolia's continental position in east central Asia and its high altitude (average height above sea level is about 1,400 m) gives the country a generally cold and dry climate. Its extreme continental climate is characterized by long, cold winters lasting 7–8 months (mid-September to mid-May) and short, temperate and relatively wet summers. The annual average temperature is presently typically around 0°C, making it the world's coldest capital city. The temperature has increased over the last 60 years of temperature recording, from around –3–4°C 60 years ago. Monthly average temperatures are typically –20°C for winter months such as January and February, and night time temperatures can go as low as –40°C. July, the warmest month, has an average of 15–18°C. Precipitation is scarce, about 200 mm annually, falling mostly during the short summer period, so winters are extremely dry.

UB is located in a valley within the northeastern mountainous area of Khentij, with the highest peaks up to about 2,800 meters (Figure 2). UB is about 1,300 m.a.s.l., at the foot of the mountain Bogd Khan Uul to the south of the city. The valley floor with its river Tuul runs due east-west. The north-south width of the valley is some 4 km at the UB central area.

The current population of UB (2008) is 1,030,000 inhabitants. This covers the 9 districts shown in Figure 1.

Table 1 gives the population by district. This work concentrates on the 6 westernmost districts, see Figure 1, with a total population of 930,337 (2007), about 90% of the total 9 district population. Figure 2 shows a gridded area which is the area of air pollution concentration modeling in this work.

Figure 1: The administrative districts of Ulaanbaatar

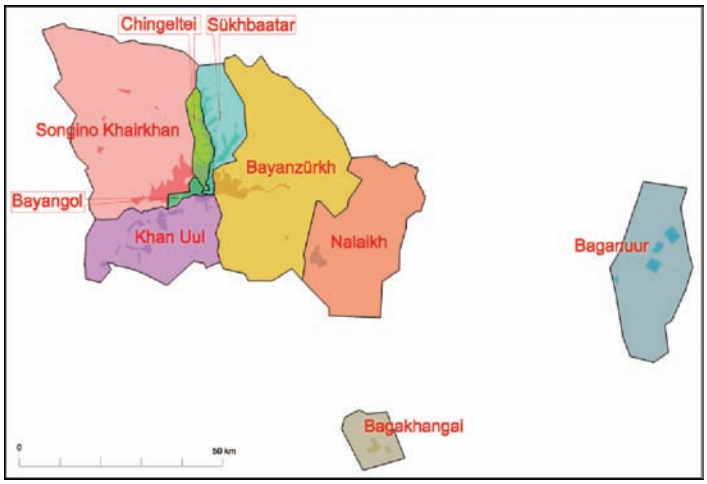
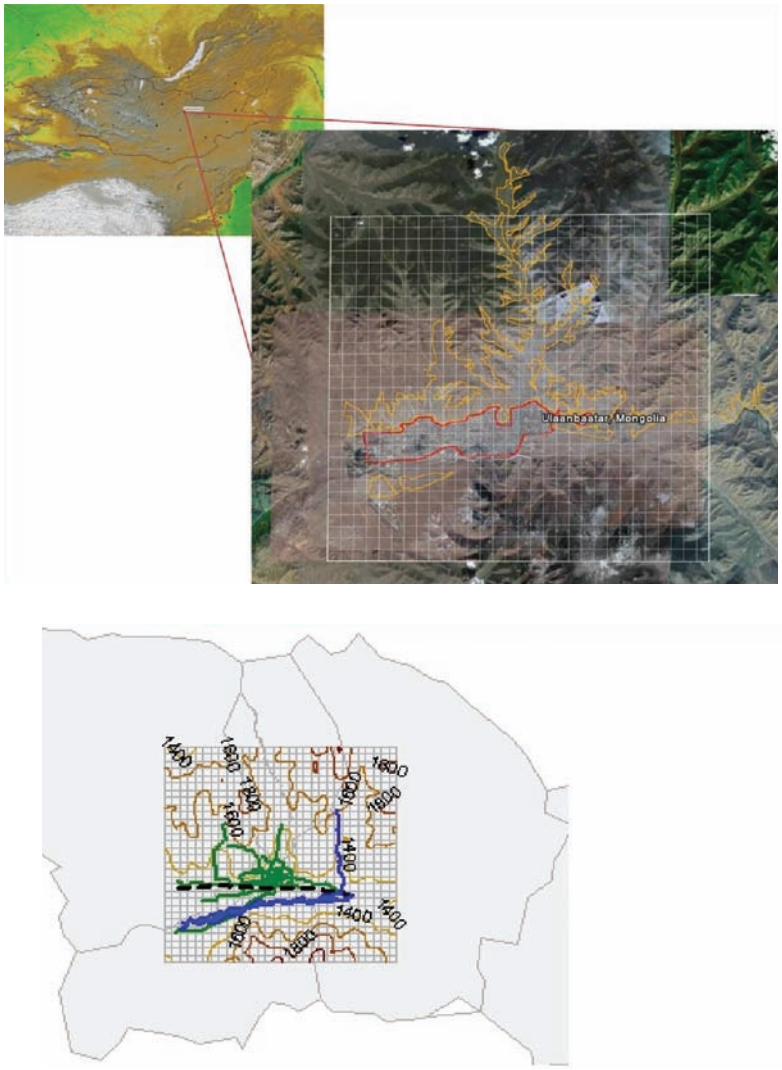


Table 1: UB population by district, 2007 (total population, 2008)

District	Population	District	Population	District	Population
Bayangol	160,818	Khan Uul	90,925	Bagakhangai	3,827
Bayanzurkh	211,614	Songino Khairkhan	211,056	Baganuur	25,731
Chingeltei	132,883	Sukhbaatar	123,041	Nalaikh	27,297
Total population, 2008: 1,030,000					

Figure 2: Location and topography of Ulaanbaatar



Upper figure: Red lined area: Central UB (no gers). Yellow lined areas: Ger areas.
Lower figure: Shows topography, as well as water (blue), roads (green) and urban districts.

Air pollution sources: Types, importance, spatial distribution

The main sources of air pollutant emissions in UB are related to the demand for heating and cooking, as well as the road traffic and industrial activities. The dry ground conditions also represent a pollution source, a depot of particles that become airborne with turbulent action from the wind as well as from vehicles traveling the roads.

About half of the population live in apartments, about 80% of them supplied with central heating and hot water from 3 combined CHPs located to the west of the city centre. The rest of the apartments are supplied from heating boilers; a few are also heated by individual stoves. The rest of the population live in traditional Mongolian tents (gers) or small individual houses. These are all heated by small, inefficient stoves fed mainly with lignite coal and also wood.

The apartment houses are located in the central areas of the city, while the ger areas are scattered around the city, mainly in the east-north-west sector. The ger/house heating systems, there are some 130,000 of them within the UB populated areas, represent the dominating source of ground level pollution in UB because of their distribution throughout the ger areas, obviously close to people's quarters, and their low level of emissions (short stacks from the gers, some 2–3 meters above ground). The power plants, with large emissions, affect the average ground level urban air relatively less because of their tall stacks (100–250 meters), although they give large concentrations occasionally when their plumes hit the ground during unstable meteorological conditions.

Road traffic is a significant source of air pollution in UB. There were in 2007 about 93,000 registered vehicles in UB, of which 75% are light duty, 15% trucks and 7% buses. Car ownership is thus low, less than 0.1 per person, close to 10 times lower than in Europe and the US. However, they operate on a limited road network, so traffic volume is high on the main streets, and traffic jams are frequent. Traffic countings indicate that the most trafficked road sections have more than 60,000 vehicles per day. The main road network is mostly paved, while small roads, especially in the ger areas, are mostly unpaved. Suspension of road dust, contributing significantly to airborne particle pollution, takes place from all roads, and especially from the unpaved ones.

Greater UB has a fairly broad industrial manufacturing base: machine tools, cement, bricks, pharmaceuticals, carpets, textiles and food processing. These industrial activities need energy which is mainly provided by small size heat only boilers and by district heating provided by the three large power plants. In terms of process emissions, the brick industry is the main emitter, with PM and SO_2 emissions from the burning of coal and other combustibles in the brick kilns.

The main source of fugitive dry dust other than from roads is the suspension of dust from open soil surfaces. Most of the land surfaces in UB have no vegetation, and the dry soil is available for suspension by wind action most of the time because of the dry climate. The top soil layer is very fine grained, and dust is easily picked up by wind action. The magnitude of this source is difficult to assess, but the source apportionment methods used and shown later in the report indicates that this dust source is significant in terms of contribution to airborne particle concentrations.

Other fugitive dust sources include dust from construction activities (from the construction itself as well as construction related traffic on, to and from the construction sites. This is a source of considerable strength which is difficult to assess accurately, but it is relatively small compared to the continuous dry PM source that the roads represent, hour-by-hour and day-by-day. The power plant ash ponds are another noticeable fugitive dust source in UB. This source is intermittent, active in periods of gusty winds, and although it is in such periods a dominating source in their neighborhoods, it is not a significant source in terms of annual emissions.

Figure 3: Typical winter air pollution situation in Ulaanbaatar (Guttikunda, 2007)

As in most cities in Asia, the uncontrolled burning of garbage and waste contributes to the air pollution problem. Such emissions are visible also in UB.

Meteorological conditions and impact on the pollution situation

With its location and climate, the conditions in UB are well positioned for creating a winter air pollution problem (see Figure 3) while the summer period is unproblematic in that respect. Its population of about 1 million people depends upon coal and to some extent wood for the generation of energy for almost all purposes, most importantly for the space heating needs, as well as for cooking. The cold climate means a large coal consumption for heating, the lack of precipitation means conditions for suspension of dust from the ground and streets, and the valley/mountain topography creates periods of calm conditions with temperature inversions that trap the pollutant emissions within a relatively thin layer near the ground, thus creating very high ground level concentrations of pollutants that the population is exposed to. It so happens that low wind conditions typically occur in the late winter afternoon/evenings at the same time as the heating and cooking demands are at its highest, a combination that results in periods of extremely high air pollutant concentrations.

The wind direction and speed distribution for UB (Figure 5) shows that the main wind directions are aligned with the valley axis, although a bit skewed towards the northwest and southeast. Low wind speeds, below 2 m/s, occur close to 40% of the total time, providing frequent potential for high pollution levels.

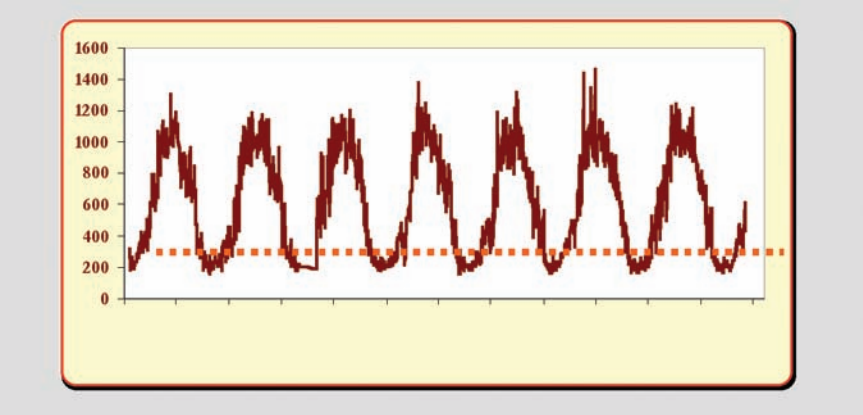
The air pollution problem in Ulaanbaatar: A descriptive summary

The contributions from the main sources and their spatial distribution causes the air pollution problem to be widespread across UB city and its surroundings. The ger areas are more affected than the central parts of the city.

The emissions are dominated by contributions from the coal burning and from the road traffic. The road traffic contributes both with suspension of road dust as well as exhaust emissions.

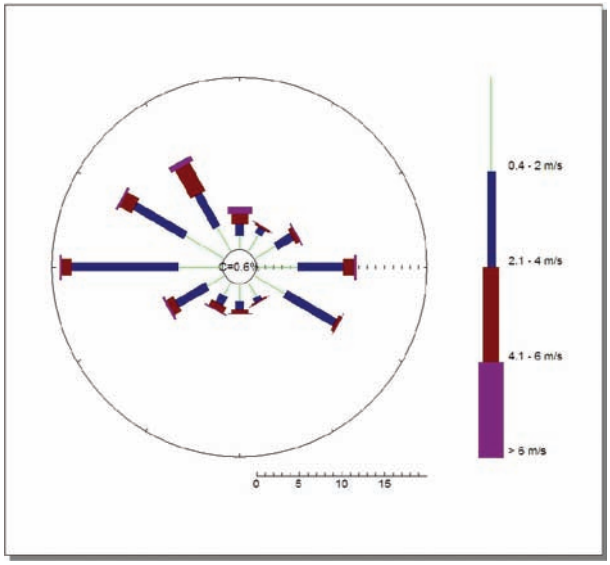
The resulting air pollution problem is characterized by very high concentrations of airborne particles, PM, and by less severe sulphur dioxide and nitrogen oxides levels. Measurements carried out in UB (see Chapter 3) shows that PM is by far the most serious component of the air pollution problem. Annual average concentrations of PM_{10} (particles that are inhaled into the lungs and causes health damage), measured at the National University of Mongolia campus area to the east of UB centre area, the only station with a long series of measurements, were as high as 141, 157 and 279 $\mu g/m^3$ for 2006, 2007 and 2008

Figure 4: The height of the mixing layer (daily average) in Ulaanbaatar (meters) as a function of time of the year*



**Dotted line: Average mixing height during winter season (December–February) for all years included.*
Source: Guttikunda, 2007.

Figure 5: Wind speed and direction distribution (wind rose) for Ulaanbaatar, 2007, UB meteorological station (Ref: NAMHEM)



Source: NAMHEM

respectively (see Chapter 3). Measurements at several new stations since June 2008 (under the AMHIB study) give an even significantly higher concentration level. These levels massively exceed the Mongolian air quality standard (which is 50 µg/m^3), as well as the WHO guideline value (which is 20 µg/m^3), and the European Limit value (which is 40 µg/m^3). (Appendix A). WHO has set interim target values, realizing that the guideline cannot be met in the short term in many developing countries. The highest interim target value is 70 µg/m^3, so the present PM_{10} level

in UB is several times higher than that target in the most polluted areas of the city.

The dynamics of the air pollution situation in UB results in extremely high short-term concentrations during the winter, with daily and hourly average concentrations reaching above 1,000 μg/m^3 and 2,000 μg/m^3 respectively. These episodes occur regularly throughout the winter months. Taking into account that at least 50% of this PM_{10} mass is derived from emissions from coal combustion, there is no doubt that the PM pollution in UB affects the health of the UB population in general.

The measured PM levels are among the highest, probably *the* highest, measured in urban areas globally (see Chapter 3).

The air pollution also affects the visibility in the city to such an extent that airplanes at certain occasions are prevented from landing at the city airport. The PM particles are hygroscopic due to their contents of sulphur. SO_2 from the coal burning is adsorbed to and converted to sulphate on the particles due to the sometimes very high relative humidity (RH) on evening/night/morning hours, due to the low temperatures. At RH above 67%, the hygroscopic particles grow much larger due to water absorption, and this reduces the visibility considerably, sometimes so much that dense fog forms.

1. The Analytical Framework for Air Quality Management in UB

Air quality management concept

In order to successfully implement effective quality management to combat urban air pollution in UB, it is important to understand the characteristics of the various pollutants prevalent in the city, their sources and their effects. An integrated approach to air quality management is needed.

The integrated approach to air quality management enables an effective assessment of the air pollution levels, the contributions from the various sources to ground level concentrations as well as to the exposure of the population to damaging air pollution, and to develop cost-effective abatement strategies[1].

The basic concept of Air Quality Management includes:

- Air Quality Assessment;
- Environmental Damage Assessment;
- Abatement Options Assessment;
- Cost Benefit Analysis or Cost Effectiveness Analysis;
- Abatement Measures Selection (Action plan); and
- Optimum Control Strategy.

[1] The integrated air quality management concept is described in detail in the Urban Air Quality Management Strategy in Asia Guidebook: http://books.google.com/books?id=9G0cd7d_nQcEC&printsec=frontcover&dq=Urban+Air+Quality+Management+Strategy+in+Asia&source=bl&ots=9pWuVliGhw&sig=XzXl8UYXbqqwUoVpiod5aQ3lJE&hl=en&ei=63JOS_fmN5XklAeokoSODQ&sa=X&oi=book_result&ct=result&resnum=3&ved=0CBEQ6AEwAg#

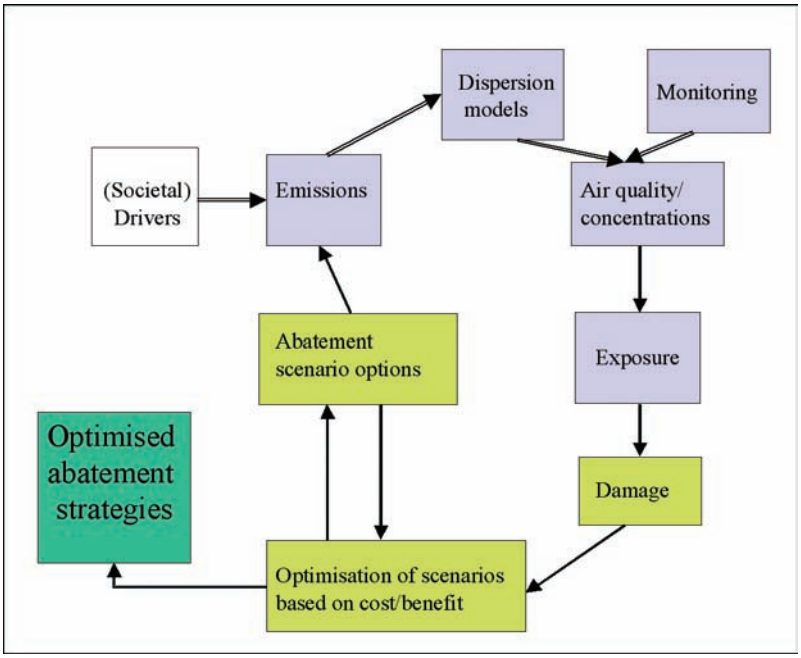
This concept, which provides the analytical framework for the air pollution and control analysis carried out in this work on air pollution in UB, is visualized in Figure 6.

Air quality assessments can use two different modelling approaches, separate and in combination. The *dispersion modelling approach* builds on an *Emissions Inventory (EI)* of main stationary sources of air pollution. This then feeds a *dispersion model* that together with metereological and other statistical data can model the effects of sources on annual and daily concentrations of major pollutants such as particulate matter (PM), SO_2, NO_X ozone (0_3) and others. The *receptor modelling approach* collects monitoring data from air pollution monitoring stations and uses sophisticated filter analysis to determine sources of pollution. Both are then compared to evaluate their completeness and accuracy. The AMHIB study used both approaches and despite significant shortcomings in the emissions inventories and monitoring data, attempted to systematically put together an air quality assessment for UB. This is meant to kick-start an ongoing process to ensure new analysis can be as complete and accurate as the data can offer.

In order to develop an emissions inventory, the basic methodology for estimating emissions from industrial or household fuel consumption, as well as traffic activity, is a standard formula applied universally regardless of emission type:

$$Emissions = Activity \times Emission\ Factor$$

Figure 6: Concept for development of cost-effective Air Quality Management Strategies



For industrial or household sources with emission reduction and control technology such as scrubbers, electrostatic precipitators, and desulfurization devices, the following equation applies:

$$Emissions = Activity \times Emission\ Factor \times (1 - Efficiency\ in\ \%)$$

Emission factors are either developed empirically through source testing or cited from publications by authorities such as the United States Environmental Protection Agency, the European Environment Agency, the International Energy Association, and accredited academic sources. The selection of good emission factors is crucial to compiling an accurate and dependable emissions inventory; otherwise, an unreliable emission factor could translate into large discrepancies in the total emission estimates, and further in the concentration assessment.

Emission estimates from all stationary (including point and area) and mobile sources provide a relatively complete emissions inventory for policymakers to identify major contributing sources to urban air pollution in UB. In order to target these sectors for effective air pollution reduction measures, it is necessary to translate the emissions contributions into the contributions they make to the ground level air pollution concentrations, using modelling methods. The emission inventory also establishes baseline emission levels to track changes in emissions and ground level air pollution in response to new developments and policy measures for air pollution abatement. Additionally, with a baseline emission inventory and modelling capabilities, the Government of Mongolia can evaluate and compare policy options in terms of their respective effectiveness to curtail future emissions, thus facilitating the selection of the optimal control option(s) for implementation.

Data from the emissions inventory are maintained in a database which is then fed into an air pollution dispersion model. To provide a valid and unbiased basis for modeling air pollutant concentrations in the city of UB, the project team introduced factors such as spatial distribution of emission sources, temporal variation of emissions, and other physical characteristics of the sources

(e.g. height of the release point, temperature, etc.) to render an accurate depiction of UB's air quality. The modeling tool employed to perform the spatial and temporal distributions of ground level air pollution concentration analyses, as well as the air quality management software used for the analysis carried out is described in Appendix H.

Air pollution and population exposure assessment, and impact on public health

In addition to the physical damages done to infrastructure and degradation of the environment, air pollutants such as SO_2 and PM also affect the well being of the public. A wide selection of literature and studies have documented the association between elevated levels of urban pollutants and increases in mortality rates, and illness related rates such as respiratory infections, the number and severity of asthma attacks, and the number of hospital admissions.[2] The concentrations of pollutants in the atmosphere and the size of the affected population determine the magnitude of the impacts on public health. Both of these two factors are high in UB, especially during the winter season, and thus, could lead to serious public health implications.

The analysis presented in this Discussion Paper is restricted to the three major so-called "health end-points"—premature deaths, chronic bronchitis and hospital admissions. Based on exposure-response functions[3] from the literature, health impacts are derived using the equation below.

$$E = ((RR - 1)/RR) * f_p * POP$$

where E is the number of cases of each health endpoint attributed to air pollution ('excess cases'), RR is the relative risk of health effect between two levels of pollution (here the current level and a lower level obtained from an intervention or the lower threshold level), f_p is the current incidence rate of the health effect, and POP is the exposed population considered. Except for the mortality function, where we rely on WB (2007) (except we use 20 µg/m^3 as a threshold level instead of 15), RR is given by:

$$RR = \exp(\beta * (C - C_t))$$

where β is the exposure-response coefficient, C is the current pollution level and C_t is the target pollution level obtained from an intervention or from reaching the threshold value. We calculate the remaining number of cases attributable to air pollution after each intervention, and derive the number of cases that can be avoided by subtracting these figures from the calculated excess cases in the current situation (which is calculated by using the threshold levels described above). To determine costs of air pollution, this Paper uses a willingness-to-pay methodology (see, e.g., WB, 2007) to monetize health impacts and estimate the economic value of avoided health damage.

Due to the considerable attention these preliminary calculations may have when disseminated, more background information is provided in Chapter 4

In air pollution analysis worldwide, a lot of attention is paid to population *exposure,* i.e. what is the actual concentration level that people are exposed to. It is of importance to assess the specific contributions of each key pollution source to population exposure, or the 'source sector specific contribution to population exposure'. This is a good indicator for comparing the importance of each source to the health effects of the population, as opposed to just comparing emissions amount per source, or even the average ground level concentration contributed by each source. The population exposure should ideally be calculated based upon data on each person's movements within the various parts of the city day-be-day, or even hour-by-hour. Obviously, such data are

[2] OECD: 2000, "Ancillary Benefits and Costs of Greenhouse Gas Mitigation", Proceedings of an IPCC co-sponsored workshop, Washington, DC, USA

[3] Exposure-response functions measure the relationship between exposure to pollution as a cause and specific outcomes as an effect. They refer to damages/production losses incurred in a year, regardless of when the pollution occurs, per unit change in pollution levels. The function is defined as the percentage change in effects incurred per unit change in concentrations (µg/m3) per capita.

not available in Mongolia, and this detail of population exposure assessment has hardly been carried out anywhere in the world.

In this Discussion Paper we use a population exposure assessment typically used when the data described above is unavailable, and that can be supported by data available in UB. This is the *population weighted average exposure, PWE*, which sums up the average pollution concentrations in 1 km^2 cells on a distribution map (a grid of 1 km^2 cells in the six central districts of UB) multiplied by the total number of persons in each cell and divided by the total population. Because pollution and people are unevenly distributed across UB, their exposure levels are different, depending on where they live. The result of this calculation is the exposure summarised as one number, PWE, as representing the whole population. This PWE exposure number is based on the outdoor concentration in the grid cell where each individual lives, and does not, as mentioned above, take account of the difference in exposure that people get when moving outside their area when going to work and school, etc. A time-activity pattern would need to be established which is unavailable. In UB this may be less important, since the highest concentrations occur during early morning and late afternoon/evening hours when people tend to be mostly around home. The PWEs are used to calculate health effects.

The steps carried out in this work to assess the exposure and the effects of abatement of sources on the exposure are as follows:

1. Analysis of all available monitoring data. This gives an overview of the current air pollution problem, and a basis for evaluating the air pollution dispersion model (sections within Chapter 3).
2. Establishing an emissions inventory, which includes all main sources: ger heating systems, heat-only-boilers, power plants, road traffic (section from p. 29 in this paper).
3. Air pollution modelling (see section from p. 40 in this paper). A Eulerian grid model was used, which has embedded subgrid models for calculation of pollutant concentrations resulting from different types of sources (area-, line- and point sources). The model solves the time dependent advection/diffusion equation in a 3 dimensional grid. The model grid used for the UB modelling is 30×30 km, and the grid cell size used is 1×1 km (Appendix H).
   Input to the model includes the emission inventory and meteorological and population data. The emissions are preprosessed to provide hourly emissions in each of the grid cells to the model.
   The model gives as output hourly concentrations throughout the modeled period (here: one full year) in each of the grid cells, as well as in specific points, such as the locations of the monitoring stations.
4. Calculating the annual average population weighted exposure, total and contribution from each of the source categories, by combining the air pollution and population distributions in the grid.

Assessing the effects of abatement measures

In this work, the effects of abatement measures on the reduction of their impact on people's health is carried out as follows (Chapter 4 of this paper):

1. The emissions from each abated source category is reduced by a given percentage amount, as a result from the abatement measure.
2. The resulting reduction in average population exposure is calculated based upon the dispersion modelling runs.
3. This is the basis for evaluating the cost effectiveness or cost-benefit ratio of the abatement measure, when combined with abatement cost data and health effects reduction data and their monetary value.

2. The Main Problems in Air Pollution Assessment in UB

Assessing with certainty the air pollution levels in an urban area and the effects of abatement measures requires quality data and information of several types:

- Measurements of pollutant concentrations
- An emissions inventory covering all the main sources
- Meteorological data as input to dispersion modelling
- Population data and its distribution
- Technical and cost data related to abatement options
- The assessment should cover the spatial aspects of the pollution situation (mapping), and should also cover the temporal scale: concentrations and contributions both on short term (hour, day) and longer term averages (annual)
- In addition to describing the existing situation, the assessment should also look towards the future in terms of scenarios for development with and without abatement actions
- When the assessment should also cover health effects of the pollution level, data are required on the present health situation of the population, and dose-response relationships between pollutants and their effects, applicable to the local area and population in question
- Valuation of health costs is needed to establish net benefits

In UB, data and information are scarce on all these topics, and the accuracy and quality of the data has often not been assessed, especially regarding data on emissions from the main sources.

Monitoring system weaknesses

Air pollution has been measured for several years at a few stations. The formal measurements carried out by the government has covered SO_2 and NO_2 at four stations for many years, while PM has been measured at one station, by a National University of Mongolia (NUM) group since 2006. Data from these stations has provided a valuable basis for assessment, but there are questions related to the data quality and suitability of samplers used for routine monitoring purposes to assess compliance with air quality limit values.

Thus, a proper baseline for air quality does not yet exist for UB. The AMHIB project was launched to assist in setting this baseline.

There is a need for upgrading of the monitoring system for air pollutants, both in terms of number of stations, their location and type (urban, traffic, industrial, etc) and choice of methods and equipment (from the present manual methods to continuous state-of-the-art monitors). Appendix B presents criteria that can be used to improve the monitoring network, as well as suggestions for an improved network to complement ongoing efforts by NAMHEM/CLEM supported by programs financed by Germany and France.

Upgrading activities started during the last half year of 2008. Germany and France had

offered assistance in improving the monitoring in UB, while NAMHEM/CLEM where implementing their own improvements, by establishing more stations and updating the methods and equipment.

Incomplete emissions inventory

The existing preliminary emissions inventory (EI) for UB does not meet internationally acceptable standards. In many areas it is incomplete or needs updating. Based on available inventories and data at that time, a preliminary EI has been developed as part of the World Bank activities in UB environment improvement (Guttikunda, draft 2007). The EI used in this Discussion Paper is a combination of the NAMHEM EI and improvements carried out by Guttikunda and AMHIB. However, this EI needs to be further improved and completed to provide a proper basis for air pollution modelling.

A number of project activities are presently (2009) underway that will provide improved data for EI, e.g. HOB inventory and emissions measurements from HOBs, CHPs and Ger stoves carried out under a JICA project, as well as an EBRD project on Ger stove and fuel improvements, which also involve emissions measurements.

3. Preliminary Results of Assessment Work in 2008

Extent of the assessment work for this Discussion Paper

In line with the concept of air quality management (AQM) presented in Chapter 2, the objectives of the assessment work are:

- to assess the present air pollution situation from available pollution concentration measurement data
- to map the spatial air pollution distribution based upon a preliminary emissions inventory and local meteorological data
- to model the contributions to ground level concentrations from the various main source categories
- to calculate the effects of some selected abatement measures on some sources, on the air pollution levels and on the population exposure
- to assess the health effects situation in UB
- to distribute the results of the assessment, solicit comments and suggestions, to improve the work leading to a construction of a baseline for 2008–2009 in a final report due in early 2010.

Summary of the present air quality situation

High concentrations of particles in air, PM, is currently the main air quality problem of UB. This can be assessed from measurements carried out since 2006 at the monitoring station at the National University of Mongolia (NUM), as well as measurements carried out at several stations as part of the AMHIB baseline project, measurements carried out during June–December 2008 (first part of the AMIHB study). These measurements are continuing. SO_2 and NO_2 are measured routinely in the CLEM monitoring network since several years. These measurements do not provide a sufficient basis for a definitive assessment of UB air quality, and this is the reason for launching AMHIB, but the data are sufficient to give an indication of the severity of the situation.

UB's SO_2 daily average values can be 125 µg/m^3 or even higher which significantly exceed the WHO Guideline of 20 µg/m^3 (24-hour mean). According to data from these measurements, SO_2 levels are at times higher than AQ standards of the WHO Interim Target 1 (24-hour average, IT-1, 125 µg/m^3), the highest target for developing countries, but the excess is limited.

The Discussion Paper finds the PM problem in UB more severe than the SO_2 problem. The PM concentrations in UB are extremely high. There is a very strong seasonal variation with very high winter concentrations and much lower summer concentrations. The annual average PM_{10} concentrations measured at the NUM monitoring station since 2006 where 141, 157 and 279 µg/m^3 for 2006, 2007 and 2008 respectively. The real concentration is expected to be higher, since the sampler used underestimate the concentration (section 4.3.2 and Appendix C). The measured concentration increase may indicate that the PM concentrations in UB have been increasing over the later years, although it is possible that the seeming increase might be explained by factors such as meteorology. The measurements carried out under the AMHIB study at several new

stations since June 2008 give even considerably higher concentration levels, confirming the severity of the PM concentration level in UB.

Annual concentrations in UB are very much higher than international or Mongolian air quality standards. The measured levels can be compared with the Mongolian standard of 50 μg/m³, the WHO Guideline of 20 μg/m³, and the EU Limit Value of 40 μg/m³ (Appendix A). WHO has set Interim Targets (IT), since it is not realistic that some developing countries will be able to meet the Guideline within reasonable time. The WHO IT-1 is at 70 μg/m³.

The PM levels place UB among the most PM polluted cities in the world, and it is probably *the* most PM polluted. Compared to such high concentrations, some cities in northern China and south Asia also had concentrations above 200 μg/m³ up to a few years ago, but the PM levels in Chinese cities are being reduced over the latest years (see Appendix D). The highest annual average PM_{10} concentrations in European and US cities are much lower, in the interval 60–100 μg/m³, and in most cities the concentrations are below 30 μg/m³.

Daily concentrations in UB are also much higher than Mongolian or international standards. The extremely episodic nature of UB PM pollution, which is caused by the combination of ger heating practices and the meteorological situation, causes extremely high short-term PM concentrations. The extremely high hourly and daily concentrations may represent the highest urban scale PM levels anywhere, with hourly PM_{10} concentrations approaching 2,500 μg/m³ or higher and daily averages above 1,000 μg/m³ in the most polluted parts of the cities, i.e. the ger areas.

These levels can be compared with the Mongolian standard of 100 μg/m³, and the WHO Guideline of 50 μg/m³ (Appendix A). The EU Limit Value is 50 μg/m³ as 90th percentile (allowing 36 days per year to exceed that level). The US allows 150 μg/m³, which is the same as the WHO Interim Target 1 (IT-1) for developing countries.

The $PM_{2.5}$ concentrations are even less well documented by measurements, but limited samples taken in November 2008 indicate the severity of the $PM_{2.5}$ situation. A measurement campaign during the last part of November 2008 provided parallel $PM_{2.5}$ and PM_{10} measurements indicating that 50–60% of PM_{10} was in the $PM_{2.5}$ fraction on those days. The $PM_{2.5}$ concentrations reached as high as over 400 μg/m³ as daily average and maximum hourly levels of up to 1300 μg/m³.

Current air quality situation in UB, assessed from pre-AMHIB data

SO_2 and NO_2 data from the CLEM monitoring network in UB, 2001–2006

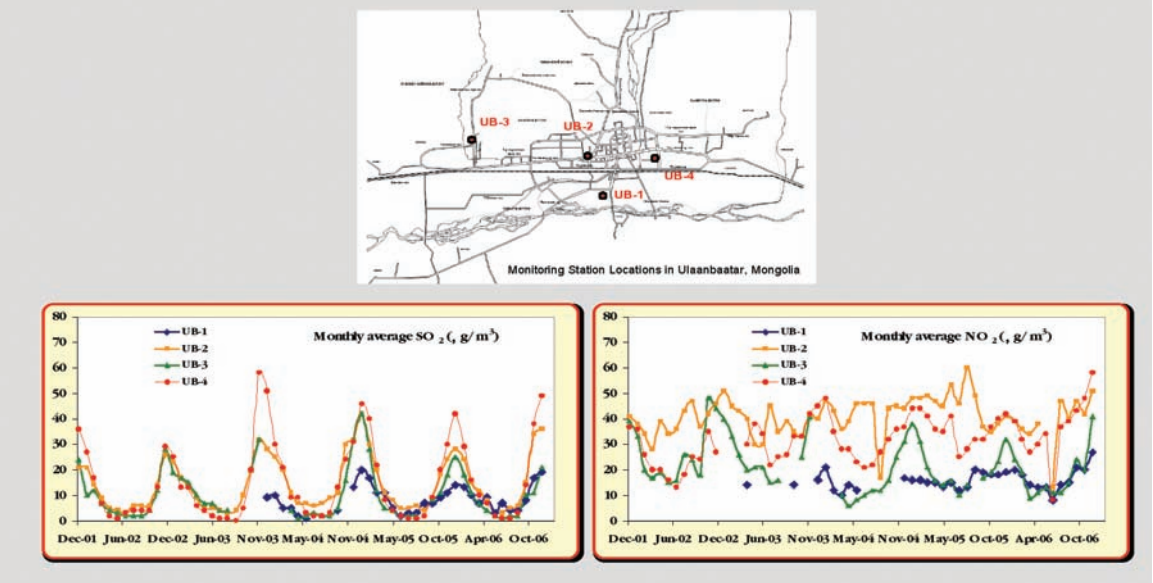
The Mongolian Central Laboratory for Environmental Monitoring (CLEM) under NAMHEM is operating an air pollution monitoring network in UB. Until 2007 there were 4 stations in the network which had been operated over several years.

Figure 7 shows results from the daily measurements taken of SO_2 and NO_2 at stations UB1–4, located as shown, between December 2001 and October 2006. Since 2007, the network has been developed and has presently 6 stations in operation.

The very strong seasonal variation in the compounds are related to emissions from coal burning, such as SO_2. NO_2 is a compound more representative of emissions from road vehicles. Here, the seasonal variation is less pronounced, since the source is present at all times, but the generally poorer dispersion conditions in the winter still give higher concentrations.

The figure indicates that there are large spatial differences in the pollution level, especially during winter, with the highest SO_2 levels at UB4 in the east and lowest levels at UB1 in the south. The main wind direction in winter is from west and northwest, making the UB4 station the most exposed one to the urban and ger emissions, as they are brought by the wind across the city and accumulated from west towards east. UB1 is far

Figure 7: SO_2 and NO_2 measurements in Ulaanbaatar, December 2001–October 2006, at stations UB1–4. Daily average concentrations (µg/m³). (Guttikunda, draft 2007)



enough from the main emission areas to be less exposed.

Particulate matter (PM) concentrations measured by NUM, NAMHEM and NILU

Particulate matter (PM) data from National University of Mongolia

The Nuclear Research Centre of National University of Mongolia (NUM) has provided data from measurements of $PM_{2.5}$ and PM_{10} at the NUM monitoring station to the east of UB centre area, for the period 2004–2008 (Tables 2 and 3). The monitoring is carried out using a GENT Sampler, Schulberger Model 250[4], separating airborne particles into two size fractions: $PM_{2.5}$ (fine fraction) and $PM_{10–2.5}$ (coarse fraction). PM_{10} is the sum of the two fractions. Samples are taken routinely on 2 different days each week.

Figure 8 shows monthly average PM concentrations for 2006 and 2007. The results show that the coarse fraction[5] (PM_{10}–$PM_{2.5}$) dominated over the fine fraction ($PM_{2.5}$), and both fractions have a very strong seasonal variation, high during winter and low during summer months. Monthly average PM_{10} concentrations reached close to 400 µg/m³ in December 2007. The main contributor to the fine fraction particles is the coal and wood burning in the city, while the suspension of dry dust, partly from road surfaces and partly from open soil surfaces, contributes mainly to the coarse fraction in all seasons, and also gives a contribution to the fine fraction.

[4] http://cat.inist.fr/?aModele=afficheN&cpsidt=2097174

[5] The coarse fraction is the share of particulates with size (diameter) between 2.5 and 10 µm. The fine fraction is the share of particulates with a size equal to or below 2.5 µm. This is important because the fine particulates are universally in literature shown to have particularly harmful effects on human health.

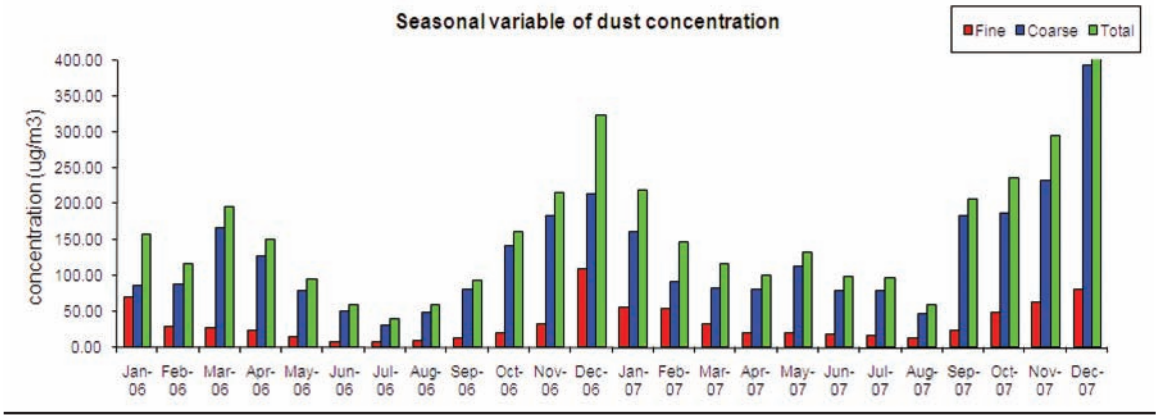
Table 2: PM concentrations in UB, measured by NUM at its monitoring station, monthly averages, 2004–2006

	2004			2005			2006		
	Fine	Coarse	Total	Fine	Coarse	Total	Fine	Coarse	Total
I				85,25	110,74	196	85,1	100,43	185,5
II				95,65	104,88	200,5	30,4	88,52	118,9
III				79,86	159,17	239	28,1	151,04	179,5
IY				17,75	201,82	219,57	24,7	132,65	157,35
Y							15,48	80,65	96,1
YI							8,53	50,45	59
YII							7,54	31,97	39,5
YIII							10,3	52,98	63
IX							14,91	80,44	95,3
X	70,7	308,1	378,7	86,22	189,61	275,8	17,83	138,35	156,2
XI	67,45	268,83	336,3	65,88	209,64	275,5	32.33	182.64	214.97
XII	52,56	151,68	204,2	108,23	134,25	242,5	111.1	215.53	326.63

Table 3: Summary of PM measurement results carried out by NUM

Year	Period	Fine PM	Coarse PM	PM_{10}
2004	Oct–Dec	64	243	307
2005	Jan–April and Oct–Dec	77	159	236
2006	Jan–Dec	32	109	141
2007	Jan–Dec	33	124	157
2008	Jan–Dec	63	216	279

Figure 8: Summary of PM measurements at the NUM station, 2006–2007 (monthly averages) (Lodoysamba et.al., 2008)



The data for the last 3 years cover the whole year. The data indicate an increase in PM_{10} concentration at the NUM station, from 141 µg/m³ in 2006, to 157 µg/m³ in 2007 and a substantial increase to 279 µg/m³ in 2008. Figure 10a shows the large increase to 2008 is associated with a period with very large coarse fraction concentrations during January–March 2008, while $PM_{2.5}$ is also elevated in general and especially during the fall period. These variations could result from meteorological variations, and this warrants closer study.

Figure 9 shows individual daily PM concentrations for 2007. There is large variability between individual days, and daily PM_{10} concentrations were as high as 600–700 µg/m³ during the winter period.

Measurements carried out by NAMHEM provide another source of PM data in UB. NAMHEM uses an instrument of type KOSA, a Japanese beta absorption method PM monitoring instrument. Results for 2007 are shown in Figure 11 for the NAMHEM station, located on the 5th floor of the NAMHEM building in UB centre. The average PM_{10} concentration from these measurements was about 50–60 µg/m³, considerably lower than measured with the NUM method at the NUM station, where the annual average PM_{10} concentration was 157 µg/m³. Parallel measurements with the KOSA and NUM (Ghent) instruments (as well as other instruments) co-located showed that the KOSA gives a much lower concentration than the Ghent sampler. (In Appendix C, discrepancies between the results from various instruments in UB are described in more detail). The strength of the NAMHEM-Kosa results is that they confirm the strong daily and seasonal variation in the PM concentration. This variation is mostly due to the variations in amount of coal combusted at various times determined by the temperature variations and daily domestic rhythm, while meteorological variations also play a role. The morning peak is generally shorter than the evening peak. This is so partly because the wind usually picks up during the late morning hours to improve the dispersion of the emissions, while in the late afternoon the wind slows down and the inversion layer establishes itself again and builds up during the evening, while the heating of the gers sustains until the night hours.

NILU carried out PM measurements during the week 17–22 November 2008, using a GRIMM 107 PM monitor[6]. The instrument recorded the concentrations of PM_{10}, $PM_{2.5}$ and PM_1

[6] http://www.grimm-aerosol.com/Environmental-Dust-Monitors/107-spectrometer.html

Figure 9: Individual PM fine and coarse measurements at the NUM station, 2007

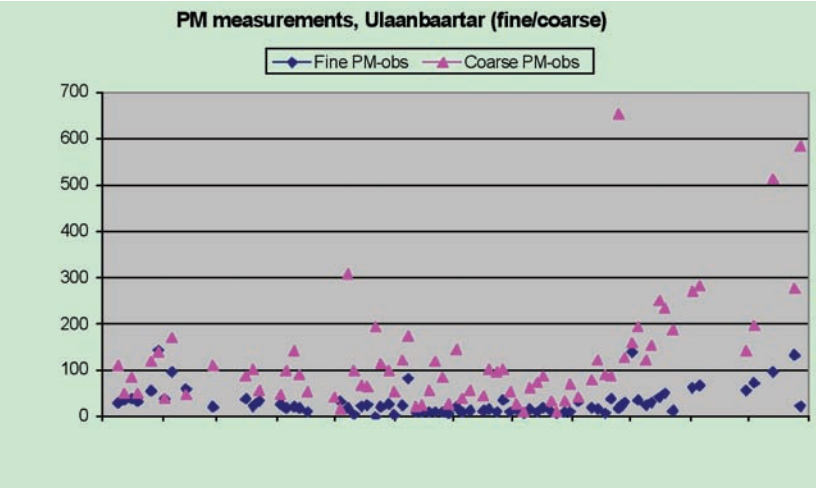
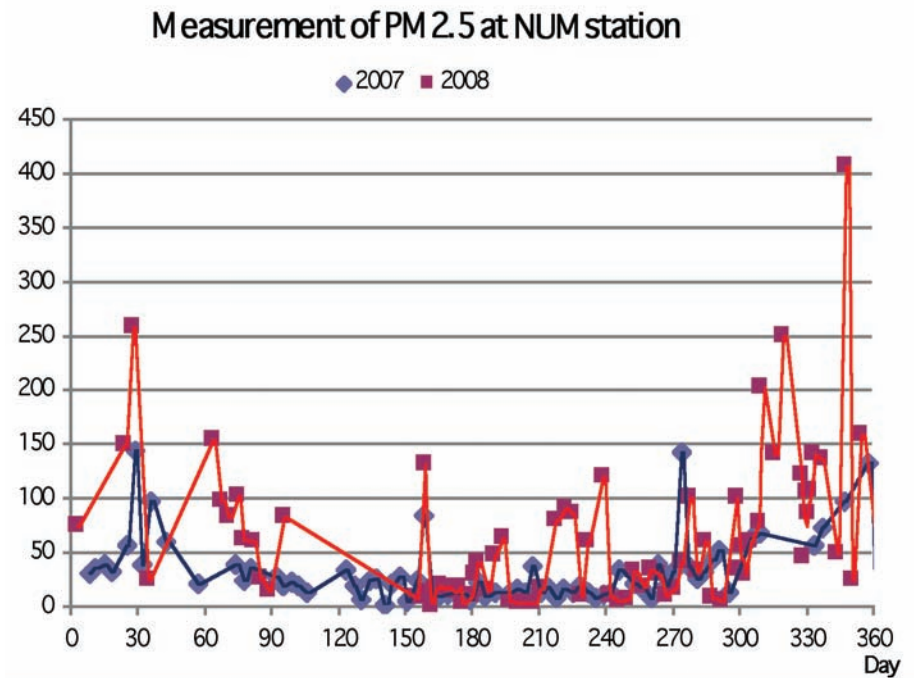
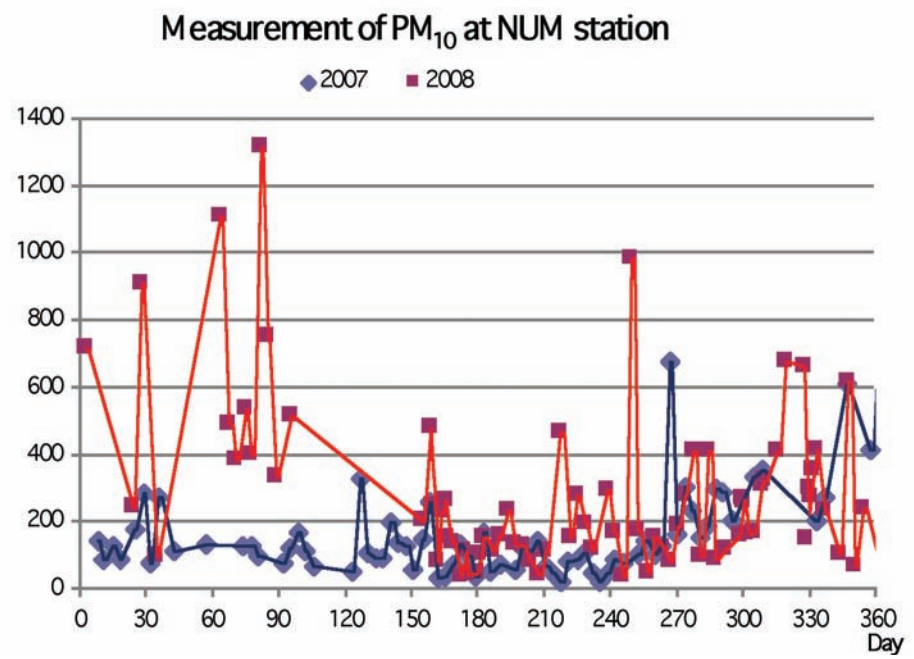


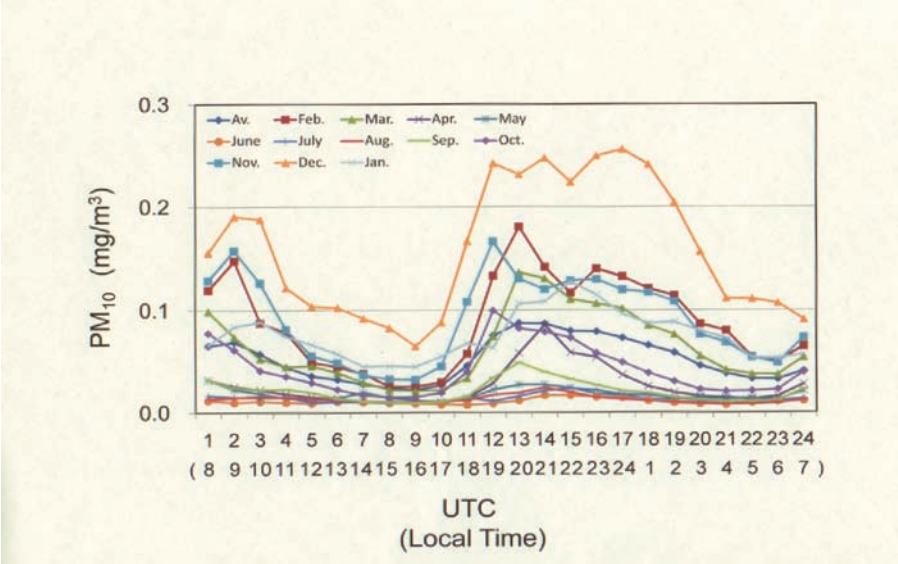
Figure 10: Individual $PM_{2.5}$ and PM_{10} measurements at NUM station in 2007 and 2008





continuously at 15-minute averages throughout the week. This provides the possibility to see the variations in PM concentrations as a function of time of the day as well as of the meteorological conditions. Figure 12 shows the results, and they are summarised in Table 4. As noted in the table, the actual concentrations in the air during the first two days are about 60% of those recorded by the instrument, due to the high relative humidity (above 70%) which results in hygroscopic particle growth affecting the response of the instrument.

Figure 11: Results of PM_{10} monitoring using a beta absorption method instrument (Japanese type 'KOSA'), for the period February 2007–January 2008



Source: NAMHEM.

Table 4: PM concentrations in UB during the week of 17–22 November, measured with the GRIMM monitor. Daily and max hourly averages, µg/m³

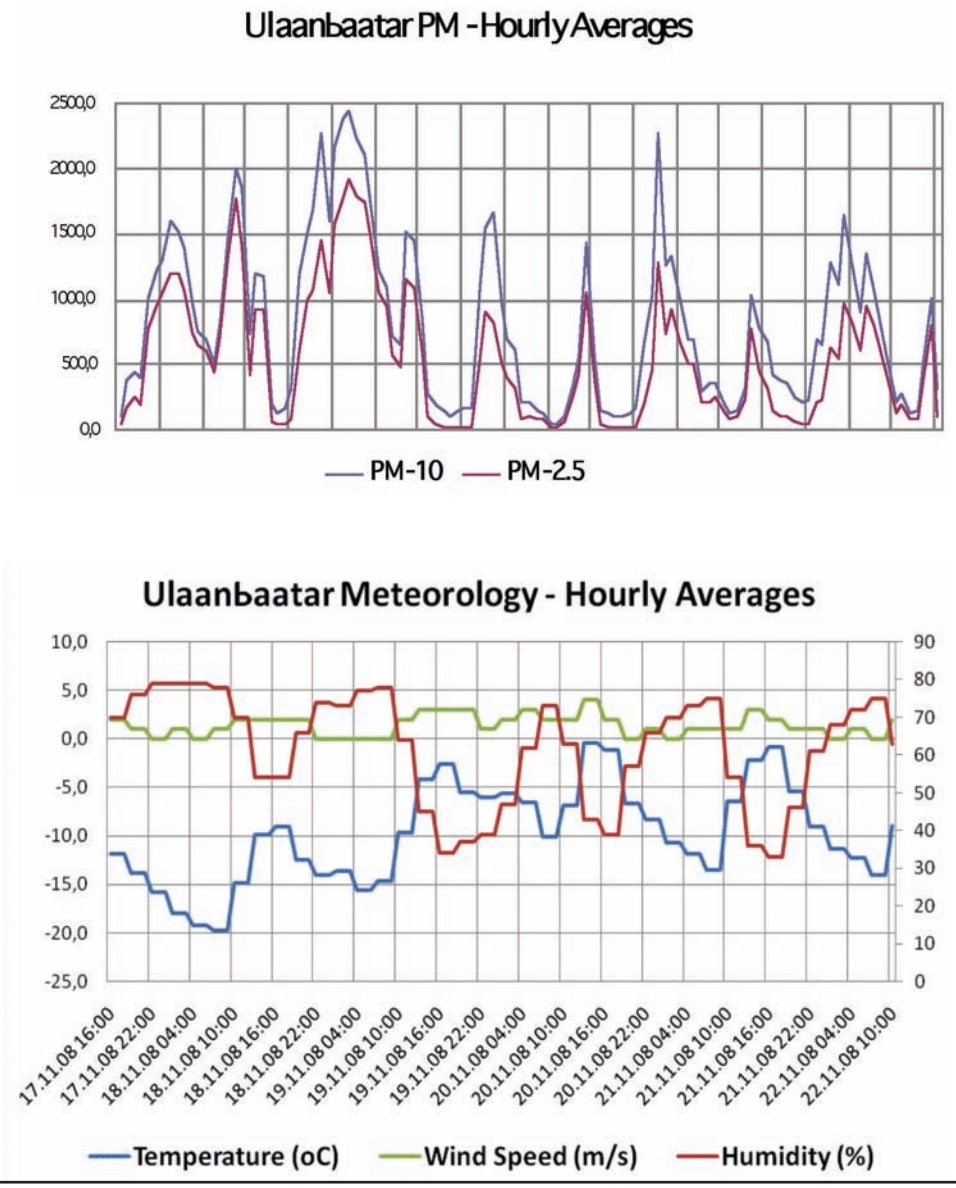
	PM_{10}		$PM_{2.5}$	
Date	**Daily average**	**Max hour**	**Daily average**	**Max hour**
17–18.11 [1]	620	1200	480	1080
18–19.11 [1]	770	1440	560	1080
19–20.11	487	1700	272	1000
20–21.11	619	2300	363	1300
21–22.11	703	1600	418	900

[1] Approximate concentrations. Concentrations recorded by the instrument during these days are affected by the high relative humidity, resulting in growth of hygroscopic particles.

The concentration level is much higher in these results with the GRIMM monitor than the KOSA instrument operated by NAMHEM, for reasons indicated above (see Appendix C). However, both instruments show similar variations across the day, demonstrating how the heating practices and the meteorological conditions (low wind speed and ground level morning and evening inversion) combine to give the strong daily variations in the PM concentrations.

Maximum daily concentration measured with the GRIMM instrument during this week was about 700 µg/m³ for PM_{10} and about 400 µg/m³ for $PM_{2.5}$, adjusting for the effect of high relative

Figure 12: PM monitoring in Ulaanbaatar 17–21 November, 2008, using a GRIMM 107 PM monitor (µg/m³). Meteorological data are from NAMHEM



humidity on the instrument. The highest hourly averages were extremely high, about 2300 µg/m³ and 1300 µg/m³ for PM_{10} and $PM_{2.5}$ respectively.

The afternoon/evening PM peak is usually the longest and highest, and the one that most determines the level of the daily average. The daily average PM concentration is highest on days with low temperature and wind speed during the afternoon and evening/early night hours.

Another observation of interest is the very low $PM_{2.5}$ concentrations between the morning and the afternoon peaks, although the PM_{10}

concentration does not go that low (Figure 12). An interpretation is that ger stove use is very low during mid-day, while the coarse PM fraction is contributed by dust suspension, probably mainly from road dust, a source which operates throughout the day.

Source contributions to PM assessed from measurements

The PM sample filters taken by NUM are weighed (before and after exposure), and then subjected to state-of-the-art analysis of elemental composition.[7] Such data provide the basis for a statistical analysis which gives an estimate of the main source categories to the PM pollution, as well as their relative contribution to the PM mass. The approximately 100 filter samples taken over the period covered in Table 2 were subjected to such analysis, providing the following estimate of contributions to the PM_{10} concentrations at the NUM station: coal burning: 35%, windblown (suspended) dust: 50%, motor vehicles (exhaust particles): 12%, wood burning: 3%.

The Nuclear Research Centre (NRC) at NUM has carried out updated statistical analysis of the elemental composition of PM, for the fine and coarse fractions separately. The updated statistical analysis, based upon the 2006–2007 measurement series (see Table 4) modified the picture regarding the source contributions somewhat. When studying the pie charts (see figures on previous pages), note that the coarse fraction concentration is some 3–4 times larger than the fine fraction. The updated analysis indicated two separate sources of dry dust, called 'soil' and 'construction'. It is believed that important sources to the 'soil' factor are suspension of dust on roads due to traffic as well as the suspension of soil dust from all ground surfaces. A 'sulphur' source appeared in the coarse fraction, as well as a 'zinc' source in the fine fraction.

The interpretation of sources, as they appear from the statistical analysis, is not always straightforward. There are uncertainties in this kind of statistical analysis that should be noted. But it is clear that the 'sulphur' source in this UB case is related to coal combustion, while the 'zinc' source is often interpreted as associated with road traffic. However, it should be expected to find a 'sulphur' source predominantly in the fine fraction, and the most recent version of their statistical analysis also shows a sulphur source in the fine fraction.

Still, the conclusion from the updated analysis is that the main sources of $PM_{2.5}$ are coal combustion, dry dust and motor vehicles (40%, 38% and 18–22% respectively in Figure 13) and to coarse fraction PM it is dry dust, coal combustion and motor vehicles (63%, 22% and 3% respectively).

There is a large contribution from the dust source especially to the coarse fraction both in summer and winter. This corresponds well with the general knowledge that suspended dust from the ground is predominantly in the coarse size fraction (and most of it even on particles much larger than PM_{10}). It is also known from literature that suspended dust has also a fine fraction, especially when the suspension is caused by vigorous turbulence such as created by vehicles driving on roads. The results in Figure 13 on the fine fraction are in agreement with this. The dust source is estimated to contribute with 38% of the fine PM mass in summer, while it is somewhat reduced to 35% in the winter, because then the coal and wood combustion sources are much stronger. Vehicle exhaust is estimated to contribute with 6–18% of the PM mass, dependent upon the size fraction and season.

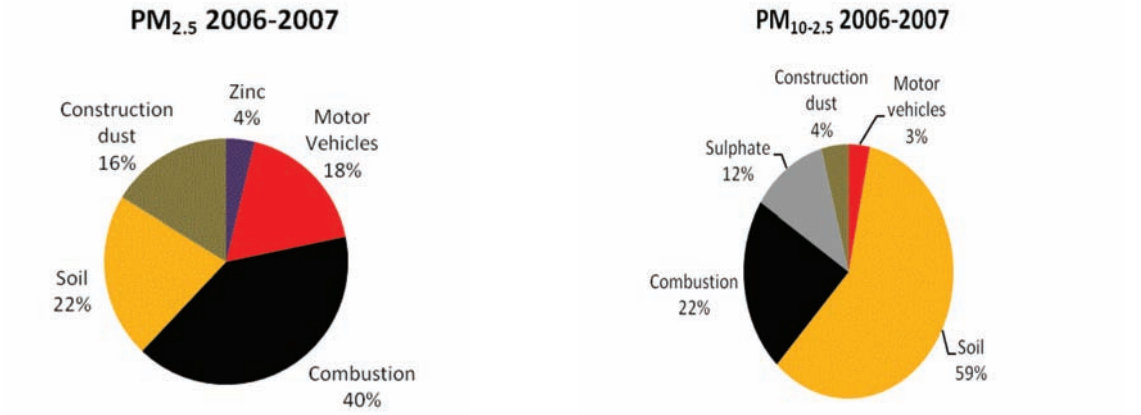
Sulphur dioxide (SO_2) concentrations

Measurement data for SO_2 for 2007 was also provided. Figure 14 shows SO_2 measured at stations UB1-4 (locations: see Figure 14) by CLEM in 2007.

SO_2 has an even more clear seasonal variation than PM has. The dominating source of ground level SO_2 concentrations is the coal burning in the gers and HOBs. Occasional peaks can be expected also from the power plant stacks. The

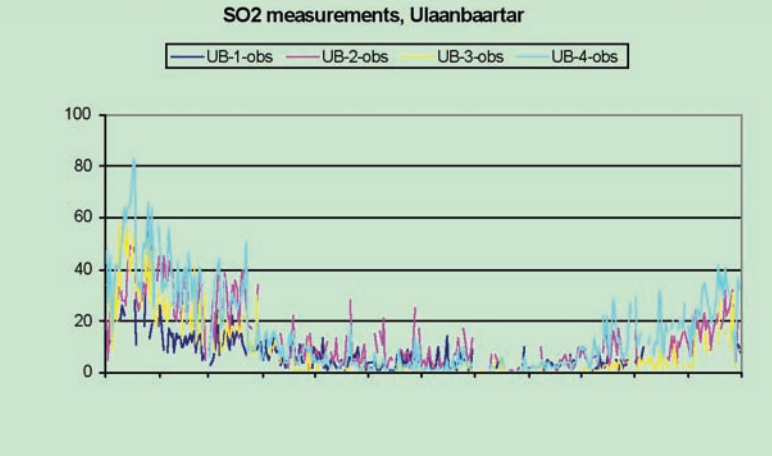
[7] http://www.cse.polyu.edu.hk/~activi/BAQ2002/BAQ2002_files/Proceedings/PosterSession/16.pdf

Figure 13: Estimated contributions to the fine ($PM_{2.5}$) and coarse fraction ($PM_{10-2.5}$) of PM at the NUM station, based upon the 2006–2007 measurement series



Lodoysamba et al., 2008.

Figure 14: SO_2 data for the CLEM stations UB1–4, daily averages, for 2007



ger contribution has a strong seasonal variation which also shows up in the measurements.

During the measurement campaign carried out by NILU during 17–22 November 2008, SO_2 was measured by NILU using the passive sampling method. Passive samplers were installed at four of the UB monitoring stations. The result was that the NILU passive samplers gave approximately twice as high SO_2 concentrations as measured by CLEM, using their standard manual method. It is necessary to check better the quality of the CLEM SO_2 measurements.

International guidelines and limit values for SO_2 are mainly given for the daily (24-hour) average value. According to the CLEM measurements, daily SO_2 concentrations reached up to and above 80 µg/m³, highest at station 4 to the east of the city centre. Allowing for the possibility that the method used gives too low values, the SO_2 levels can at times be higher that the EU Limit Value of 125 µg/m³ (US AQ standards allow 365 µg/m³ as daily average). Levels are very much higher than the recent WHO Guideline of 20 µg/m³, while the WHO Interim Target 1 (IT-1) for developing countries

is 125 µg/m³, the same as the EU Limit Value, and the Interim Target 2 (IT-2) is 50 µg/m³ (Appendix A).

Thus, although SO_2 is also a problem compared to limit values, its importance as an air quality problem in UB is much less than the PM problem.

The AMHIB baseline monitoring: Results and quality assessment

The AMHIB monitoring stations

A PM monitoring network has been established in UB as part of this AMHIB study. The network consists of the stations described in Table 5, and their locations are given in Figure 15. There are many different types of instruments used in the network. The need for comparing the different instruments in terms of their PM results has been recognized. The instruments have been compared with each other during three different periods, when the instruments were all brought together at the same location.

Results from the AMHIB PM measurements June–December 2008

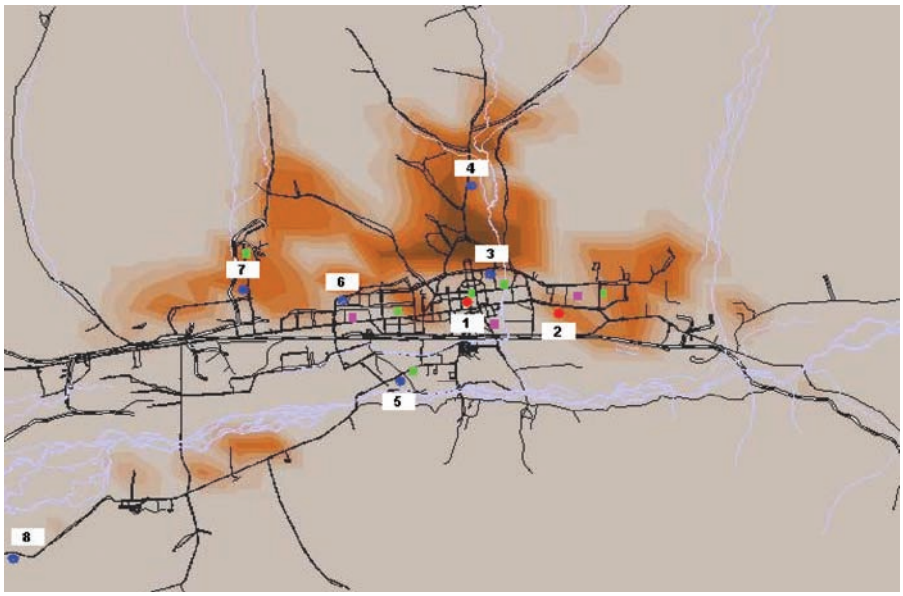
PM concentrations

The results from the measurements carried out at the AMHIB stations during June–December 2008 have been reported by the local UB AMHIB

Table 5: Monitoring sites and monitoring units, their characteristics

Institute/Location	Mobile/ Stationary	Characteristics	Sampling site number/ name	Site position	PM_{10}, $PM_{2.5}$
National University of Mongolia(NUM)	Mobile unit	GENT Sampler, Schulberger Model 250, Measures PM_{10} and $PM_{2.5}$. Polycarbonate, nuclear pore filters	2 / NRC	106°58,311 47°54,811	PM_{10} and $PM_{2.5}$
	Mobile unit	GENT Sampler, Schulberger Model 250, Measures PM_{10} and $PM_{2.5}$. Polycarbonate, nuclear pore filters	3 / 100 ail	106°55,343 47°55,975	PM_{10} and $PM_{2.5}$
National Agency for Meteorology Hydrology and Environmental Agency (NAMHEM)	Stationary unit	Kosa Monitor, Measures PM_{10}. And $PM_{2.5}$, measurement on-line, principle Light Scattering, no filter. Can sample for each hour.	1 / NAMHEM	106°54,704 47°55,220	PM_{10} and $PM_{2.5}$
	Mobile unit	Partisol FRM-Model 2000, Measure PM_{10} 16.7 l/min, filter	6 / 3-r khoroolol	106°52,167 47°55,582	PM_{10}
Central Laboratory for Environmental Monitoring (CLEM)	Mobile unit	Rotary Bebicon, Type 35RC-28SD5, Measure PM_{10} 15 l/min, filter	5 / CLEM	106°52,967 47°53,64	PM_{10}
NAMHEM	Mobile	Dust Trak-8520, measure $PM_{2.5}$ or PM_{10}, based Laser	4 / buudal	106°54,159 47°54,719	$PM_{2.5}$
	Mobile	Dust Trak-8520, measure $PM_{2.5}$ or PM_{10}, based Laser	8 / Niseh	106°45,749 47°51,865	$PM_{2.5}$.
	Mobile	Dust Trak-8520, measure $PM_{2.5}$ or PM_{10}, based Laser	7 / S.K.H.D		$PM_{2.5}$.

Figure 15: Locations of the PM monitoring stations of the AMHIB network



team (Lodoysamba et. al., 2009). A summary description of the results is included below.

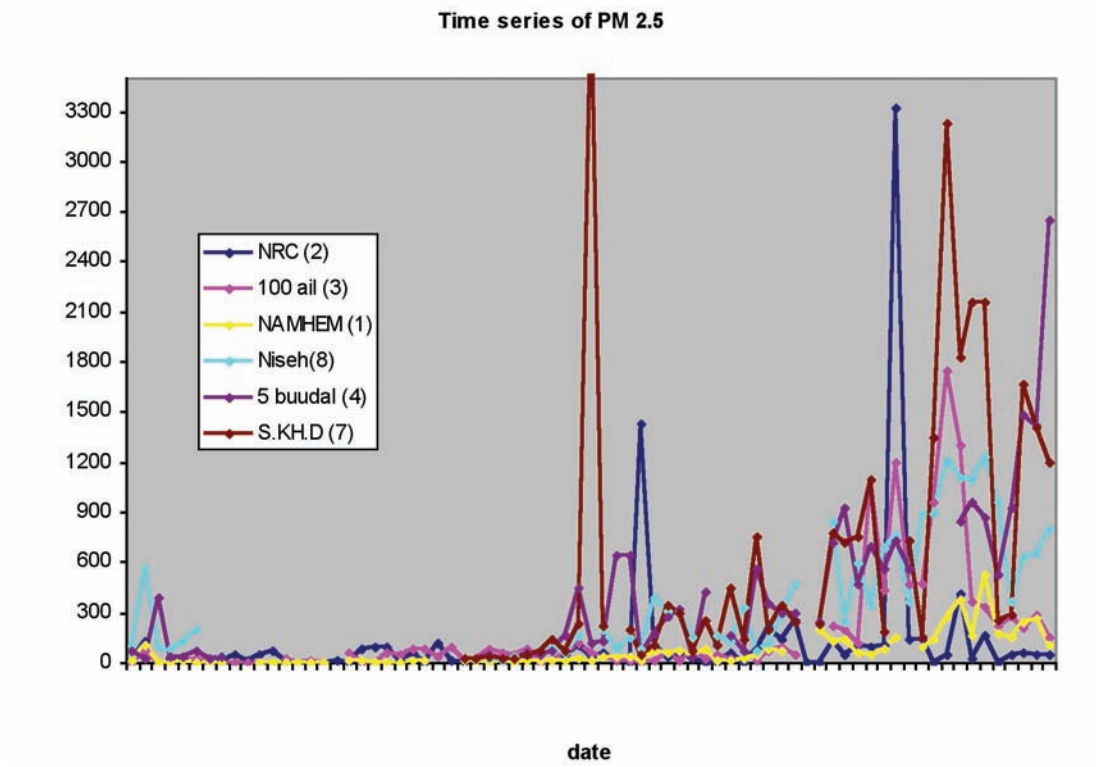
Measurements were carried out two days per week (24-hour samples) during the entire period, and in addition every day during one week in October, November and December. This resulted in 8–9 days of sampling per month in June–September, and 11–15 samples per month in November–December. Sampling is missing on some stations some days because of sampler problems. For $PM_{2.5}$ there is no data from station 7 before 3 September, from stations 4 and 8 during July–August and Dustrac sampling at station 1 (NAMHEM) started in October. For PM_{10} there is no data from station 1 (NAMHEM, KOSA instrument) from early August to 25 September.

The results are shown as time series in Figure 16 ($PM_{2.5}$) and Figure 17 (PM_{10}). Main observations are:

- As expected, the PM concentrations increase steadily and strongly into the winter months (after September).
- Extremely high concentrations at some stations some days, mostly during winter months, up to 4000 µg/m³.
- Generally large differences between stations on any given day.
- These measurements from 2008 show higher average concentration level than measured in earlier years, at stations in ger areas where measurements have not been done before, as presented in the previous sections above. At the NUM station (station 2), the average PM_{10} for the months June–December has increased from 136 to 209 to 224 µg/m³ for 2006, 2007 and 2008 respectively. However, maximum monthly and daily averages measured at the NUM station in 2008 are about the same as in previous years.

The extremely high concentrations measured at the ger area stations (stations 3, 4, 6 and 7) in December especially, are much higher than what has been measured at the NUM station as described in the section on p. 21. There is one important point to consider regarding the quality of the measurements, and that is the effect of high relative humidity (RH) on the response of the instruments measuring $PM_{2.5}$ at the ger stations 4, 7 and 8 (see section from p. 15). The RH was high enough in December to affect the response to the extent that the measured $PM_{2.5}$ concentrations should be reduced by about 40%. Even so, the remaining concentrations are still very high.

Figure 16: AMHIB $PM_{2.5}$ measurements during June–December, 2008. Daily and monthly average concentrations



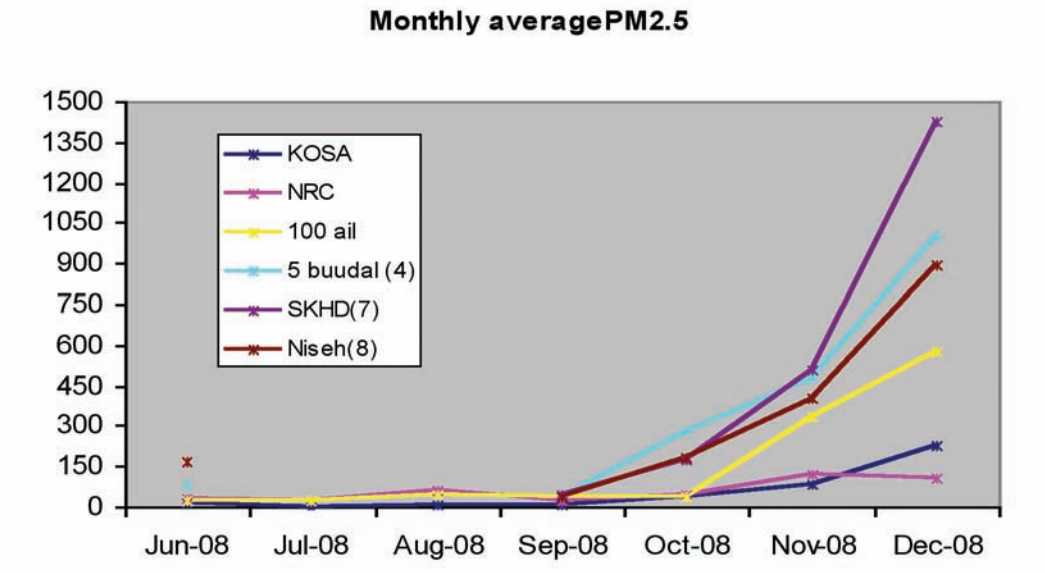
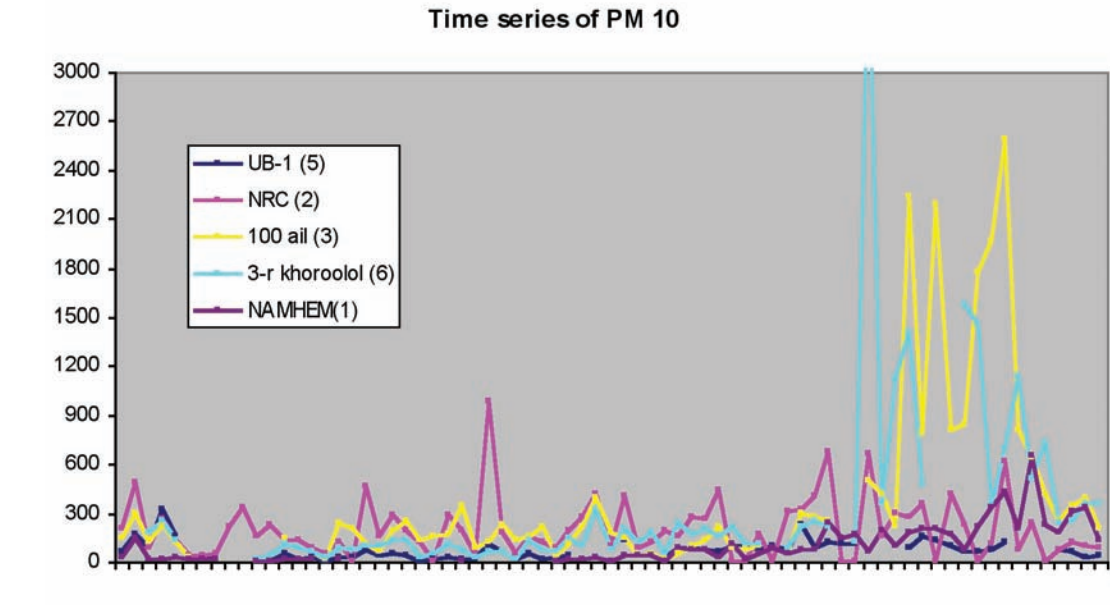
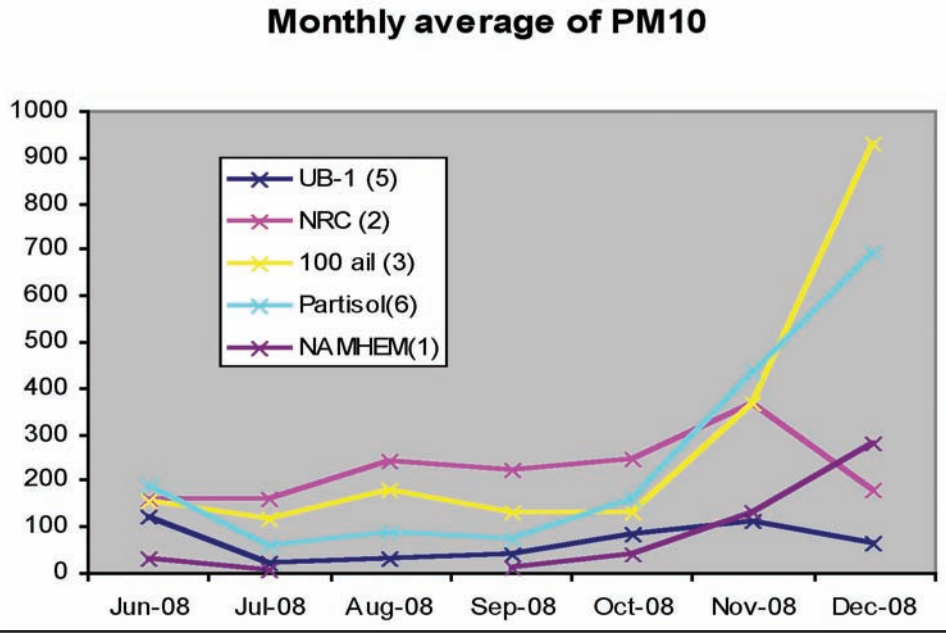


Figure 17: AMHIB PM_{10} measurements during June–December, 2008. Daily and monthly average concentrations





The AMHIB measurement period will run until June 2009, and will, together with the on-going automatic measurements at a number of stations starting early 2009, provide an improved baseline of PM pollution in UB.

The quality of the AMHIB data is evaluated in the next section and Appendix C.

Source contributions

The NUM group has carried out statistical source apportionment analysis on the June–December 2008 filters as well, based upon multiple elemental analysis, similar to that described in section from p. 21.

This 2008 analysis gives the same sources the responsibility for the PM concentrations. The size of the various contributions differ somewhat, e.g. with more from 'soil' and less from combustion in the fine fraction than in the 2006–2007 data. The main conclusion is the same, however: ***The largest contributions to PM at the NUM station comes from resuspended soil particles and from coal combustion, with motor vehicles as a third and less important contributor.***

AMHIB data quality assessment

The PM measurement equipment of the AMHIB network is provided by the various institutions involved, and differs between the various stations. The instruments utilize different measurement principles. It is of interest to compare the instruments in terms of the PM concentration data they provide. To investigate this, co-located comparison sampling has been carried out during three campaigns in 2008, each of 4–5 days duration: 4–5 and 17–20 April, 1–6 July and 18–22 November. The two first campaigns were carried out at the NAMHEM monitoring station at the roof of the NAMHEM building, while the last one in November was carried out at the meteorology station UB3 located in a Ger area to the west of UB centre. NILU participated in the last campaign providing a GRIMM 107 PM monitor.

Details of the results from the monitor and sampler comparisons are given in Appendix C. It can be concluded that the Ghent (NUM and NRC) samplers, the Partisol and the Dustrac instruments give data of reasonable quality, given the shortcomings described in Appendix C. These samplers are used at stations 2, 3, 4, 6, 7 and 8. On the other hand, the Kosa (station 1) and the C-20 instruments (station 5) somehow give too low PM concentrations.

Air pollution health effects in UB: Current situation and ongoing study

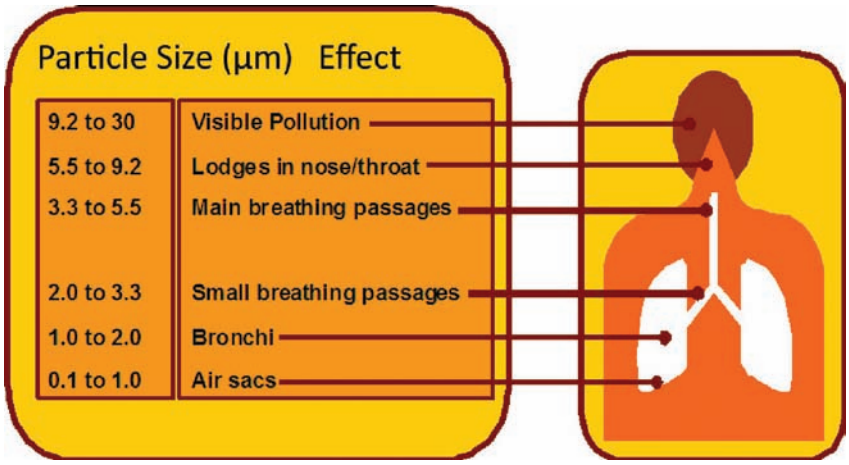
Health effects and air quality guidelines for PM

Particle pollution, also called particulate matter or PM, is a complex mixture of extremely small particles and liquid droplets in the air. When breathed in, these particles can reach the deepest regions of the lungs. Figure 18 visualises where particles of different sizes are deposited in the lung when inhaled. Exposure to particle pollution is linked to a variety of significant health problems, ranging from aggravated asthma to premature death in people with heart and lung disease. Particle pollution also is the main cause of visibility impairment.

Both WHO, the US Environment Protection Agency (USEPA) and the European Union (EU) have set Air Quality Guidelines (AQG), Standards (AQS) or Limit Values (AQLV) for PM, as a measure to protect the public from adverse health effects (see Appendix A).

These guidelines and standards are based upon a large body of epidemiological and other types of studies worldwide. The majority of the epidemiological studies have used PM_{10} as the exposure indicator, since PM_{10} has by far been the most measured PM quantity. PM_{10} represents the particle mass that enters the respiratory tract, and includes both the coarse fraction (particle size between 10 and 2.5 µm) and fine particles (measuring below 2.5 µm, $PM_{2.5}$), that are considered to contribute to the health effects observed in urban environments. $PM_{2.5}$ is now being measured to a larger and increasing extent.

Figure 18: Invasion of various particle size fractions in the human lung



From Guttikunda, 2007.

The present WHO AQGs are based upon studies that have used $PM_{2.5}$ as the exposure indicator.[8] WHO considers, however, that AQGs for $PM_{2.5}$ alone will not provide protection against harmful effects of coarse particles. WHO has consequently kept AQGs also for PM_{10}, and now set its value by applying a ratio between PM_{10} and $PM_{2.5}$ of 2, based upon evidence of this factor as measured in urban atmospheres in developed (a factor of 2) and developing (factor range of 1.25–2) countries. However, WHO does not consider that the evidence is sufficient to derive a separate AQG for the coarse particle fraction. WHO considers that the large body of literature on effects of short-term exposures to PM_{10} is a good enough basis for developing AQGs and Targets for 24-hour PM_{10} concentrations.

The EU has followed the WHO recommendation, and EU Limit Values are set for both $PM_{2.5}$ and PM_{10}. The USEPA has, however, decided differently. The lack of clear evidence of a link between health problems of long-term exposure and coarse particle pollution has led the EPA to revoke its annual PM_{10} standard, while keeping its standard for 24-hour average concentrations, and setting a strict standard for $PM_{2.5}$.[9]

Current air pollution health effects situation in UB, and ongoing study

Many studies internationally have shown a good relationship between air pollution and cardiovascular disease (Jamal et al, 2004; WHO 2002; Spengler 2005; Sunyer et al, 1996; Keil 2005; Stansfield & Shepard 1993). There was much research conducted and still running on air quality effects on health. However, most of the air pollution health impact studies in Mongolia are more concerned with the respiratory diseases (Burmaa & Enkhtsetseg 1996; Spickett et al, 2002; Saijaa 2004; Tseregmaa, 2003). There were not many relevant data about relationship between cardiovascular disease and air pollution in Mongolia. A. Enkhjargal (2006) conducted a survey on health impacts assessment of air pollution and cardiovascular and respiratory system diseases in two cities. This study demonstrated significant correlations between respiratory and cardiovascular morbidity with NO_2, SO_2 and some meteorological parameters. The correlation

[8] World health organization: Air Quality Guidelines for particulate matter, ozone, nitrogen oxides and sulphur dioxide. Global update 2005. Summary of risk assessment. http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf

[9] US Environment Protection Agency: PM Standards Revision–2006. http://www.epa.gov/oar/particlepollution/naaqsrev2006.html

of mainly respiratory case admissions with meteorological parameters is because the cold winter conditions in the two cities result in the accumulation of pollutants in the atmosphere. Thus population exposure to air pollution increases significantly in the winter months.

The rates of cardiovascular diseases in Mongolia during the last 15 years have increased 2 times. Cardiovascular disorders now affect 11.0 per cent of the urban population and 13.8 per cent of the rural population (Ministry of Health of Mongolia, MOH, 2004).

The AMHIB study is investigating, to the extent possible, the relationship between air pollution and health effects in UB. It is hoped that this would kick-off more in depth and robust studies that can complement these efforts.

Part of the AMHIB project is to study the current health effects situation and its relation to the air pollution situation. Connected to the AMHIB monitoring activities, health effects data will be collected from hospitals in UB located close to the monitoring stations, at three levels:

- Primary level: Family and village hospitals (8 hospitals)
- Secondary level: District hospitals and ambulatories (7 hospitals and 1 ambulatory)
- Tertiary level hospitals (3).

Data on admissions connected to respiratory and cardiovascular diseases, according to a number of diagnosis, will be collected on a daily basis from these hospitals, and statistical analysis applied to the data, using the SPSS version 11.5 tool. Independent variables collected are PM concentrations ($PM_{2.5}$ and PM_{10}) as well as meteorological data (temperature, wind speed and relative humidity).

Data collection started in June 2008 and will continue till June 2009, whereafter data analysis will take place.

International comparison of UB air pollution

UB is among the most polluted cities in the world in terms of PM, and it probably *the* most polluted. Some cities in northern China and south Asia also had concentrations above 200 µg/m³ up to a few years ago, but PM pollution is coming down in the most polluted Chinese cities (see Appendix D). Compared to such high concentrations, the highest annual average PM_{10} concentrations in European and US cities are much lower, some cities are in the range 60–100 µg/m³, except some cities in dry regions in the US (Arizona and California), where PM_{10} is dominated by dry surface dust particles, and very little associated with fuel combustion. In most cities in the US and Europe, the concentrations are below 40 µg/m³.

The episodes of extremely high hourly and daily concentrations that are caused by the special climate and meteorological situation of UB probably represent the highest urban scale PM levels anywhere, with hourly concentrations approaching 2,500 µg/m³ and daily averages approaching 700–800 µg/m³ over areas covering much of the city. These episodes occur regularly and often throughout the winter periods, and bring the annual average concentration to its very high level. US and European cities have highest daily averages mostly below 200 µg/m³, while some industrial cities in the Eastern part of Europe still have high maximums, a few cities in the range 400–700 µg/m³. These maximum daily averages approach those experienced in UB, but they occur very seldom, a few days per year.

Emission inventory used for the preliminary air pollution assessment in this paper

The main air pollution sources in UB

It is important to note that the main source of emissions in a city may not necessarily be the dominant source of air pollution people breathe. The inventory of the air pollution emissions in UB was investigated under a previous WB activity (Guttikunda, draft 2007), based upon a significant effort although with limited resources. The main sources of the emissions were listed as follows:

1. Stoves in households in Ger areas
2. Stoves in kiosks and food shops

3. Power plants
4. Heat only boilers
5. Vehicle exhaust emissions
6. Fugitive dust—transport and non-transport
7. Construction industry—Bricks
8. Garbage burning

Summarised descriptions of each of those source categories and their emissions are as follows:

1. Stoves in households in the Ger areas

In UB, the largest source of coal and wood combustion related air pollution at the ground level is from heating/cooking stoves in Ger areas. Many homes are Gers, the traditional Mongolian dwellings consisting of a wooden frame beneath several layers of wool felt. However, by 2007 the majority of Ger residents have built wooden homes within their *hashaa*, or homestead. Depending on the level of income, these wooden homes are heated with stoves with heating walls or coal fired individual household boilers. The households in the Ger areas in UB can be divided into 4 categories in terms of the types of stoves used (World Bank, 2008a):

- households living in a ger and using a heating stove with chimney;
- households living in a small detached house and using a heating stove with chimney to directly heat their home;
- households living in a medium size detached house and using a stove attached to a heating wall; and
- households living in a larger detached house and using a small low pressure boiler (LPB) attached to a system with radiators and circulating water.

The emissions from the household stoves are dominated completely by the small stoves of the traditional type. There are a total of about 130,000 stoves in the UB Ger areas, of which there are 91% small stoves used in the three first types of households in the above list, while only 9% of the households have a individual household boiler. Statistically, most households report to use coal with wood for ignition. Anecdotally, burning of tires, garbage, tarred bricks are said to be used by particularly lower income households.

Heating Stoves and Wood and Coal Bundles for Sale

Source: Guttikunda, 2007.

The average winter period consumption of raw coal and wood per household is 4.2 tons and 4.6 m^3 respectively. The coal consumption varies between 3.5 tons for ger stoves and 6.2 tons for households with household boilers, most of this obviously consumed during the 8 winter months. The total annual coal consumption for this source category is about 550,000 tons of raw coal and 415,000 tons of wood.

Unconventional Fuels Used in Ger Areas

Source: Dr. Sarantuya Myagmarjav, MNE.

2. Stoves in kiosks and shops

A rather unreported category, though less important than household heating, are kiosks and shops. This is a less important source category, however included here because the same type of stove is used also in the kiosks and small shops. The number of such kiosks and shops was estimated to be 4,500 in 2005. In the same period, the number of food shops more than doubled. Total emissions from this category were some 5% of the Ger area household emissions.

3. Power plants

There are three coal-fired CHP Plants in UB, located as shown in Figure E4 in Appendix E). They provide nearly all of the installed power capacity in the city and also are the main source of the district heating system providing space heating and domestic hot water to the apartment and office buildings in the central parts of UB, covering 80% of the energy need for about 60% of the households in central UB.

The power plants consumed almost 3.4 million tons of coal in 2007. The pollution control technology is in poor condition. Power Plants #2 and 3 use wet scrubbers with cleaning efficiency estimated to be around 70% while Power Plant #4 operates an Electrostatic Precipitator (ESP) although it is unlikely it achieves close to the reported 95% cleaning efficiency. As a reference, ESPs usually operate at an efficiency of 99.95%. JICA recently discovered that one or two of the chimneys in the power plants do not have an adequate access to measure flue gases.

In addition to stack emissions, another unaccounted for source in the emissions inventory is the fly ash from the ponds where fly ash is disposed. Removed fly ash is sent to settling tanks where the sedimented dust is collected and sent to the ash ponds. These ash ponds are continually subjected to wind erosion in the dry season as seen in the figure on the next page. The emission rate is likely to be a function of

wind speed, particle size, and area exposed and therefore is a very intermittent source difficult to calculate without specific measurement exercise. Anecdotally, it is a common sight in the spring and summer months along with dust storms from deserts. Due to high moisture content and snow cover, it is unlikely to account for much of the pollution sources in winter.

Fly Ash from Power Plant Ash Ponds

4. Heat only boilers (HOB)

In UB, mainly public facilities and industry not supplied by the central District Heating System from the Combined Heat and Power Plants use small HOBs. These are used in small town centers where extending the District Heating is not feasible. Use of HOBs could increase if the District Heating system is unable to expand to support a growing number of apartment and commercial buildings. The latest inventory of HOBs gives a number of 145 boiler houses with a total of 267 boilers, of various ownership (main city, the military and privately owned) (World Bank, 2008b). The boilers are of various types: mainly Russian, Chinese, Mongolian (German design). Several new boiler installations are not included in the inventory. The efficiency of the boilers vary from about 40% for the Russian boilers to better than 80% for the Mongolian type of German design. The boiler designs have an impact of the emission factor of PM, as well on the emission conditions, such as height, temperature and speed at the outlet (stack).

The HOBs are mainly located in central UB and along an east-west axis along the main road.

5. Vehicle exhaust emissions

As mentioned, about 93,000 vehicles are in use in UB (2007). About 75% of these are passenger vehicles, 15% are trucks and 7% are buses. The toal number of motorized vehicles is growing rapidly (Guttikunda, 2007) due to increased incomes and availability of affordable vehicles. Use of individual automobiles has already caused a severed congestion problem for the municipality. The passenger fleet is a mixture of old and newer vehicles, while the trucks and buses are mostly of older types. The vehicle emissions are spatially distributed along the road network, which is concentrated to the central areas, and less concentrated in the ger areas. The annual daily traffic is large on many sections of the network, the most trafficked sections having an annual daily traffic of more than 60,000 vehicles. The vehicles emit large amounts of nitrogen oxides and carbon monoxide, while the vehicle exhaust PM emissions in UB accounts for less than 10% of the ger household PM emissions.

6. Suspension of dry surface dust

The dry climate of UB creates a large potential for dust suspension from surfaces, both from roads and other near-road surfaces, and other dry non-vegetated surfaces, especially in the winter. The largest dust suspension problem is created by the traffic, as the turbulence from the vehicles stirs up the dust deposited on the streets. This is especially observable on unpaved roads, which are dominating in the ger areas. According

to the results from the PM_{10} monitoring in UB, the dry dust source in UB is of about the same magnitude as the coal combustion source, in terms of its contribution to ground level PM_{10} concentrations.

The main source of fugitive dry dust other than from roads is the suspension of dust from open soil surfaces. Most of the land surfaces in UB have no vegetation, and the dry soil is available for suspension by wind action most of the time, because of the dry climate. The top soil layer is very fine grained, and dust is easily picked up by wind action. The magnitude of this source is difficult to assess, but the source apportionment methods used and shown later in the report indicates that this dust source is significant in terms of contribution to airborne particle concentrations.

Vehicular Suspended Dust Examples in UB

Guttikunda, 2007.

Other non-transport dry dust suspension sources include for example the ash ponds of the power plants (resuspension of deposited fly ash), and the movement of construction vehicles on temporary roads to and from construction sites. The ash ponds are localised sources where dust is suspended by wind action at times with relatively high wind speeds, making that source limited both in time and space. The construction-associated traffic is rather widespread, and is a more continuous source, more like the regular road traffic. It is difficult to assess the magnitude of this non-transport PM source.

Non-transport Related Suspended Dust

Guttikunda, 2007.

7. Industry

The main industrial activities in UB creating process emissions to air are the brick industry and the construction industry. There are 4 larger brick factories and 10 smaller brick kilns in UB. The annual coal consumption in these factories and kilns has been estimated to about 50,000

tons (World Bank, 2008b). Bricks are produced mainly in the period between mid-March to early December. Thus, the contribution to UB air pollution in winter is limited to the November–December period.

8. Open burning of garbage

Backyard burning of trash, waste and garbage is a rather common practice in UB. Garbage is burned in stoves, backyards and landfill sites. Landfill site burning is anecdotally done due to low tariffs (to reduce collection costs) and poor collection. Based upon a study on amount of garbage produced in UB in different seasons, Guttikunda (2007) estimated the PM emissions from this source category to be close to 20% of the ger area household emissions. Much of the garbage is not collected, and burned or illegally dumped. The garbage burning is distributed across all seasons. There is no independent emissions inventory for garbage burning but recent surveys show that second to heating, the collection of solid waste is among the top priorities for Ger residents.[10]

Hospital Waste Burning. In addition to household garbage, another unreported though smaller source is hospital medical waste burning. Hospitals are required to install incinerators that burn trash and infectious medical waste. About 35 hospitals practice bio-hazard waste burning, but do not use regulated incinerators. There is very little information on this source, though it is considered minor.

Garbage Burning Example

Guttikunda, 2007.

[10] World Bank, 2009.

Introduction to the development of an emissions inventory for assessment and modelling purposes

The main objectives of the emissions inventory are:

- To calculate the total emissions per source category and type, as a basis for a preliminary assessment of the importance of each of them to the air pollution situation in the city
- To provide input to air pollution (dispersion) modelling of the air pollution concentrations in the city, which determines the actual importance of each source.

Total emissions versus emission height and location

The first objective relates to calculating total emissions (e.g. tonnes per year), irrespective of the locations and time variations of the emissions. To meet the second objective, it is necessary to specify the locations/spatial distribution of the emission sources, the time variation of the emissions (seasonal/monthly as well as hourly) as well as the emission conditions of each source: height above ground, temperature, etc.

The source-wise total emission assessment points out the main sources in terms of emissions amount. The second step, assessing also their time and space distribution and emission height, usually modifies the impression of importance of sources: location away from population centres as well as tall stacks (often the situation for power plants and large industries) reduces significantly their importance for the urban air pollution levels, while smaller source categories in terms of total emissions may be much more important, when they are located throughout the population centres and emit at low heights. This is the situation for small scale domestic heating by combustion, as well as for road traffic.

Pollutants

In line with the assessment of PM and SO_2 as the main pollution problems of UB, the emission inventory in this paper will be limited to PM and SO_2.

Methods

The basic method for emissions inventorying is utilized in this paper:

- Emissions are the product of an activity (e.g. amount of fuel burnt, kms driven) and an emission factor (EF) (e.g. amount per fuel used or km driven).
- Emission cleaning is either accounted for in the EF, or by reducing the emissions above by a factor (1-cleaning efficiency).
- The EF depends upon many factors that need to be taken into account: e.g. type of combustion process (such as boiler/stove type), fuel specifications, process technology (such as engine and exhaust cleaning technology of a vehicle), etc.

For each source category/type, the emissions can be assessed by top-down or bottom-up methodology.

Example of top-down method: e.g. when the total fuel consumption for small-scale combustion for space heating has been estimated (e.g. from fuel sales or consumption statistics or data), and the total emissions by applying an EF is distributed spatially and over an area where the fuel is burned, as a function of the distribution of the population/density of households. A time variation function can be overlaid, such as daily, based upon heating practices and seasonally based upon temperature statistics.

Example of bottom-up method: e.g. for vehicle exhaust emissions: when the road traffic volume (vehicles per day) and vehicle type distribution is known/estimated for each road link of the total urban road network: the EF is applied to each type of vehicle in the traffic flow, and emissions calculated for each road link. The spatial distribution of the emissions is then known from the locations of the road links, and thus specified in the input to the model. The time variation is also often known from traffic data, or it is estimated from the general activity patterns for the city.

There are many uncertainties linked to this preliminary emissions inventory. The EI used in this Discussion Paper is a combination of the NAMHEM EI and improvements carried out by Guttikunda (draft 2007) and AMHIB. However, this EI needs to be further improved and completed to provide a proper basis for air pollution modelling. Main uncertainties are associated with the emission factors for ger stoves and road dust suspension, for PM_{10} and $PM_{2.5}$, **as well as the amount of suspension of soil dust from dry open surfaces which is not included in the inventory.**

As mentioned in section 3.2, there are project activities presently (2009) underway that will provide improved data for some of the sources in the EI.

Summary of the emissions inventory used for the present assessment work

Each of the main air pollution sources is treated separately. For each source the basis for the emissions inventory is described:

- Description of the source
- Calculation method
- Emission factor(s)
- Total emissions
- Spatial distribution
- Time variation
- Uncertainties

Appendices E, F and G describe the details of the inventory of the emissions per source category. The summary of the inventory is shown in Table 6. Below are given summaries of the information, data and calculations per main source category. The industry (mainly brick) and waste burning sectors have not been included in this assessment work. The brick plants are located away from main populated urban areas and they are operated mainly during the summer season when air pollution is low. The open waste burning source is distributed across the year and urban/ger areas. It has been estimated to contribute possibly up to 10% of the PM emissions (Guttikunda, draft World Bank 2007), but its assessment is uncertain.

Table 6: Summary of the emissions inventory for Ulaanbaatar, 2007 (tons/year)[1] For details, see also Figure 7

Source/ calculation method[2,3]	PM_{10}	$PM_{2.5}$	SO_2	Height of emissions, meters	Spatial distribution
Ger households[2]	16,363	13,262	7,084[4]	5–10	Throughout ger areas Figure 19
HOBs[2]	6,480	3,888	4,360[5]	20–30	Figure 20
CHPs[3]	6,290	2,516	33,600[6]	100–250	3 point sources to the west of UB centre Appendix E Figure E4
Vehicle[3] exhaust	1,161	1,161	1,354[7]	<1	Figure 21
Dry dust from roads[3]					
Paved	5,142	771		<1	Mainly throughout the central city Figure 22
Unpaved	4,812	722		<1	Mainly throughout the ger areas Figure 22

[1] Last update: for all source categories, emissions were updated as part of this work, to various extent, see Appendix E.
[2] Top-down calculation
[3] Bottom-up calculation
[4] 0.65% S in coal (75% Nalaigh coal w/0.7%S/25% Baganuur coal w/0.5%S)[11]
[5] 0.5% S in coal [12]
[6] 0.5% S in the coal (Baganuur coal)
[7] From Guttikunda (2007). Data for 2006

Background material

The main background sources for the inventory are:

- The emissions inventory recently developed by S. Guttikunda for the World Bank (Guttikunda, draft World Bank 2007)
- The draft report: Mongolia: Energy Efficient and Cleaner Heating in Poor, Peri-urban Areas of UB. Summary Report on Activities (World Bank, 2008a). (Referred to below as "The heating report, 2008")
- Report "Small boiler improvement in UB". (World Bank, 2008b). (Referred to below as "HOB report, 2008")
- "Air Pollution Sources Inventory of UB City." Ministry of Environment, National Agency for Hydrology Meteorology and Environmental Monitoring, 2007. (Referred to as "NAMHEM, 2007")

The ger households are the largest source of PM emissions. Their total emissions is estimated to be about 2.5 times larger than the HOB PM emissions. The ger emissions are split about 50/50 between coal and wood (see Table 7). The ger and the HOB sources emit at fairly low heights and are distributed throughout large parts of the urban area, thus giving important contributions to the population's exposure to PM pollution. The CHPs, which have PM cleaning equipment, have about the same total emissions as the HOBs. Their emissions take place at large heights

[11] Source: Japan Coal Energy Center, 16 June 2008
[12] Source: World Bank, 2008b

Table 7: Summary of PM_{10} emissions inventory for coal and wood combustion sources, winter season 2006/7. Including estimate of uncertainty (Δ)

Source	Number of ger households/HOB	Specific consumption (tons/winter)	Total consumption (tons)	Emission factor, PM_{10} (kg/ton)	Total emissions (tons/year)
Ger coal	130,000	4.19	545,000	16	8,715 [1]
Δ	10%	5%	10%	50%	51%
Ger wood	130,000	3.18	413,400	18.5	7,648 [1]
Δ	10%	5%	10%	50%	51%
HOB	267+		400,000	16.2	6,480
Δ	5%		20%	15%	25%
CHP			3,360,000	19.5 [2]	6,290 [3]
Δ			2%	25%	25%

[1] The emissions during the summer season come in addition. For coal, this addition is small, for wood it is larger, since households use mostly wood for cooking during the summer. We add 5% to the consumption to account for the wood use in summer.
[2] This is uncleaned EF. The weighted average cleaning efficiency of the 3 CHPs used is 90%.
[3] Cleaned emissions.

(through the CHP stacks of 100–250 meters), which limits their contribution to population exposure.

Vehicle exhaust particles are a less important source than gers, HOBs and CHPs in terms of mass of emissions. The suspension of dry particles from roads is, however, a more important PM_{10} source, with a total emission mass about 50% larger than HOBs. The suspension particles are mainly in the coarse fraction. Suspension is much less important for $PM_{2.5}$.

The suspension of soil particles through wind action from open surfaces, apart from the roads, has not been included in the inventory. Source apportionment indicates this as an important PM_{10} source, its strength being difficult to assess with existing methods.

The CHPs are the dominating sources of SO_2, but their tall stacks limit their contribution to ground level concentrations relative to sources with much lower heights of emissions.

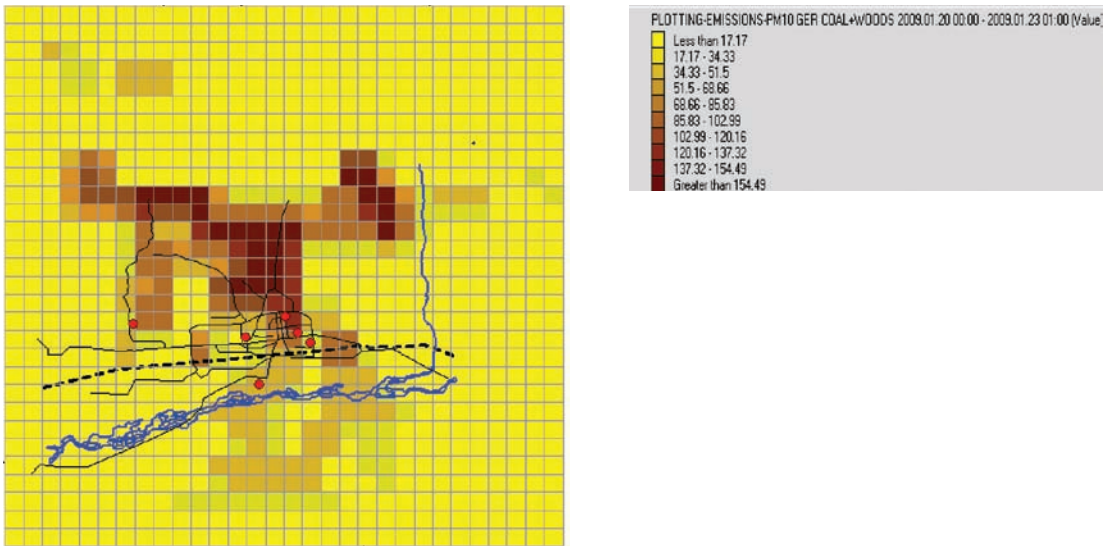
Ger area households

The households in the ger areas live in gers or in small houses, about 50/50 each.

Figure 2 shows the ger area locations around and close to UB. The number of households is about 130,000, and this includes the households in the 6 districts closest to UB as well as gers close to UB centre. The stove types used in the various types of dwellings has been inventorized (World Bank, 2008a). The average consumption of coal and wood in the ger household stoves, for the winter season 2006/7, was there estimated to be 4.19 tons/year and 3.18 tons/year.

The emission factor for PM emissions from ger stoves is very uncertain, there is no good basis in the literature for determining the EF. From what is available, the PM_{10} emission factor (EF) for ger coal is estimated to 16 kg/ton, and the ratio between $PM_{2.5}$ and PM_{10} is set at 0.6. For ger wood, the PM_{10} EF is estimated to 18.5 kg/ton, with a $PM_{2.5}$ / PM_{10} ratio of 0.9 (Appendix F).

Figure 19: Spatial distribution of ger household PM_{10} emissions, in km² grids (tons/year)



The resulting spatial distribution of ger household emissions of PM_{10} is shown in Figure 19. The ger areas far to the north in UB are located behind the hills and do not affect UB air quality directly, the emissions there are thus not included. There is a considerable, unknown, uncertainty associated with the spatial distribution, which cannot be reduced until improved data of population density distribution is available.

Uncertainties in the various data and factors are as estimated in Table 7. The uncertainty estimates are of course themselves uncertain. The fuel consumption data are considered to have the least uncertainty, due to the extensive work reported in the 'heating report'. The emission factors are very uncertain.

Heat only boilers

The emission inventory of the HOBs is based mainly upon the data in the World Bank 2008b reference. The number of HOBs is somewhat higher than 267, while the total annual consumption of coal is estimated to be 500,000 tons. The basis for the emission factor is actual measurements carried out on a few HOBs in UB. Based upon this, the average HOB EF for TSP is estimated to 27 kg/ton. The ratios between PM_{10} and TSP, and between $PM_{2.5}$ and PM_{10} are both set to 0.6 (Appendix F).

The resulting spatial distribution of HOB emissions of PM_{10} is shown in Figure 20. HOB emissions take place at a higher level than from ger household, some 10–15 meters, and are somewhat more removed from direct exposure of the population. Even so, this is also an important source to the population's exposure.

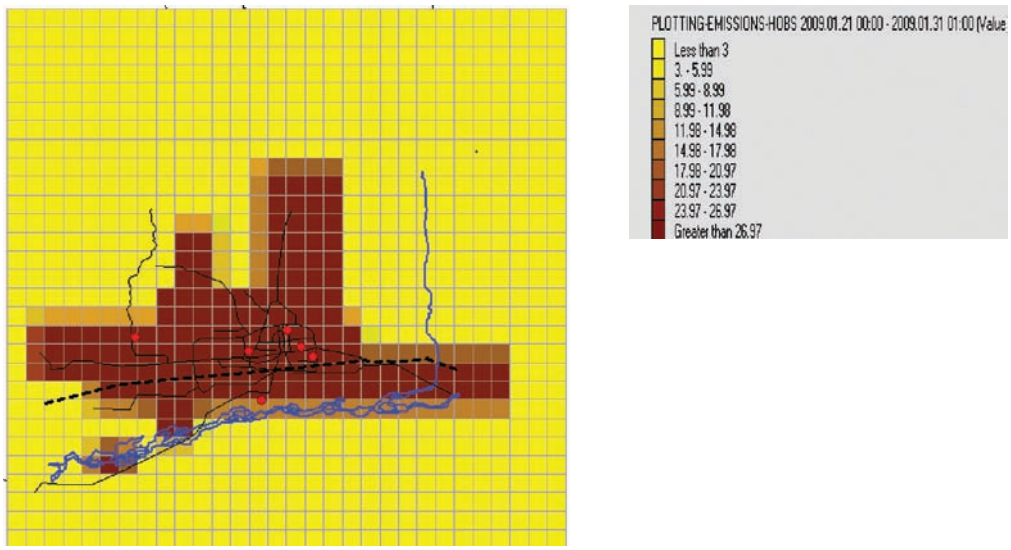
Combined heat and power (CHP) plants

The total consumption of coal in the three CHP plants is 3.36 million tons for 2007 (statistical data from NAMHEM). This is distributed between the plants with 5%, 25% and 70% for the plants CHP1, CHP2 and CHP4 respectively.

For emission factors, those used by Guttikunda (2007) is used also in this report: 19.5 kg/ton for PM_{10} and 7.8 kg/ton for $PM_{2.5}$. The efficiency of the flue gas cleaning for particles is set to 80% for CHP 2 and 3, and 95% for CHP 4.

The CHP emissions take place at a high level (100–250 meters).

Figure 20: Spatial distribution of HOB PM_{10} emissions, in km^2 grid (tons/year)



Vehicle exhaust

Among the referred 92,706 registered vehicles in UB (2007), about 64% of the vehicles run on gasoline, about 34% on diesel and the remaining about 2% on gas.

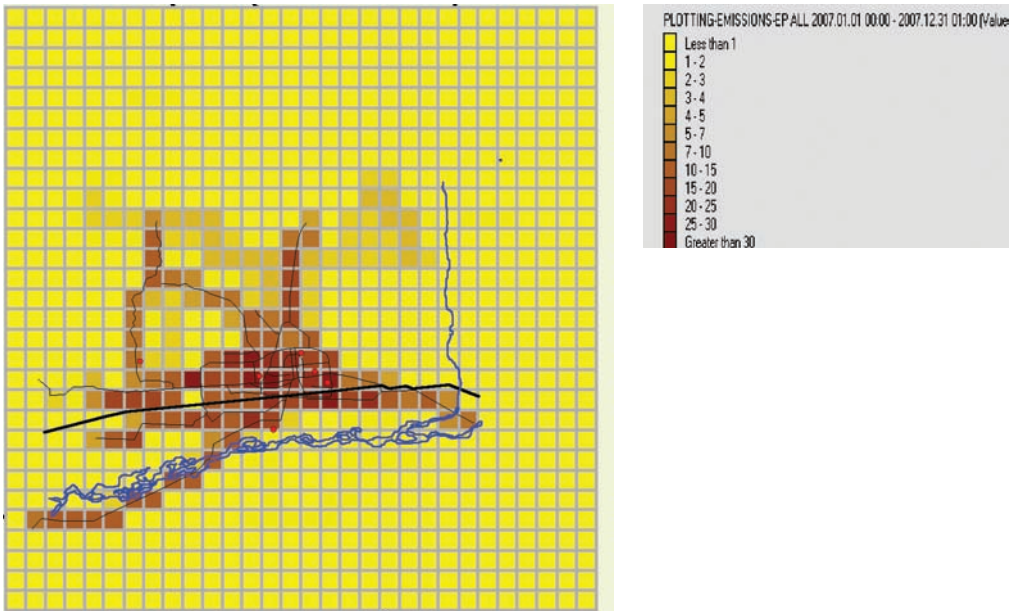
The existing vehicle exhaust regulations in UB does not limit the types of vehicles allowed on the roads. No specific information is available on the exhaust emission levels of the vehicles on UB roads, old or new. As about 50% of the cars were older than 11 years in 2006, it is fair to assume that they are of medium and low technical standard. Mongolian gasoline still contains lead, so to the extent that new vehicles bought and used include catalysts, they do not function after short time driving on local gasoline. Most of the trucks are also old (mostly of Russian types), while the bus fleet has a wide age spread, some fairly new. EFs have been estimated based upon this information, see Appendix F.

A limited program on traffic counting on the main road network has been carried out as part of this work, and as a result of that, the traffic volume has been estimated on as many as about 100 road links (Figure E7 in Appendix E). The exhaust gas emissions are calculated from the traffic volume, the length of the road sections and the EFs. Figure 21 shows the spatial distribution of the emissions from the registered part of the road network (the 100 links). In addition to this, the emissions from the traffic on the smaller roads (estimated to make up 30% of the total main road traffic activity) is distributed over the ger areas in the same way as the ger combustion emissions are distributed, reflecting the population distribution.

Suspension of dust from roads

Dry dust on road surfaces is whipped up, suspended in air, from vehicle turbulence as they travel the road. The extent of suspension increases with the speed of the traffic by about the square of the speed. Naturally, suspension takes place only when the surface is dry, which is most often the case in UB, although conditions with ice on the road may limit suspension. Large vehicles, trucks and buses, suspend much larger amounts of dust than small vehicles. The dust suspension is very much larger from unpaved than from paved roads. The dust suspension problem is much larger per vehicle in the ger areas with the unpaved roads than in UB central areas, although there is substantial suspension also from paved roads in the centre, since there is always a depot of dust on the road surfaces.

Figure 21: Distribution of the emissions of PM_{10} from the vehicular traffic in UB (tons/year/km²)



Most of the mass of the suspended dust is on particles larger than 10 micrometers, thus larger than those affecting humans by breathing. However, a substantial amount is also below 10 micrometers (PM_{10}), and a fraction also below 2.5 micrometers $PM_{2.5}$).

The suspension emissions are calculated using the same road and traffic data as for the vehicle exhaust. The source strength is calculated using suitable formulas (Appendix E, section 2.5). The formulas take account of the dryness of roads and paved/unpaved surface, the speed and the fraction of large vehicles (trucks and buses). Figure 22 shows the resulting spatial distribution of suspended PM_{10} from roads.

This estimate of suspension of PM from roads was used in this work in the first attempt to account for road dust suspension in UB. The representativeness of the formulas have not been tested for UB conditions, although the resulting modelled PM concentrations, with all sources included, correspond well with the measured concentrations at the NUM site, the only site with data available at the time when the modelling work was carried out. The unpaved road emission distribution has the population distribution as a basis, and thus depends on the correctness of that distribution.

Stoves in kiosks and shops

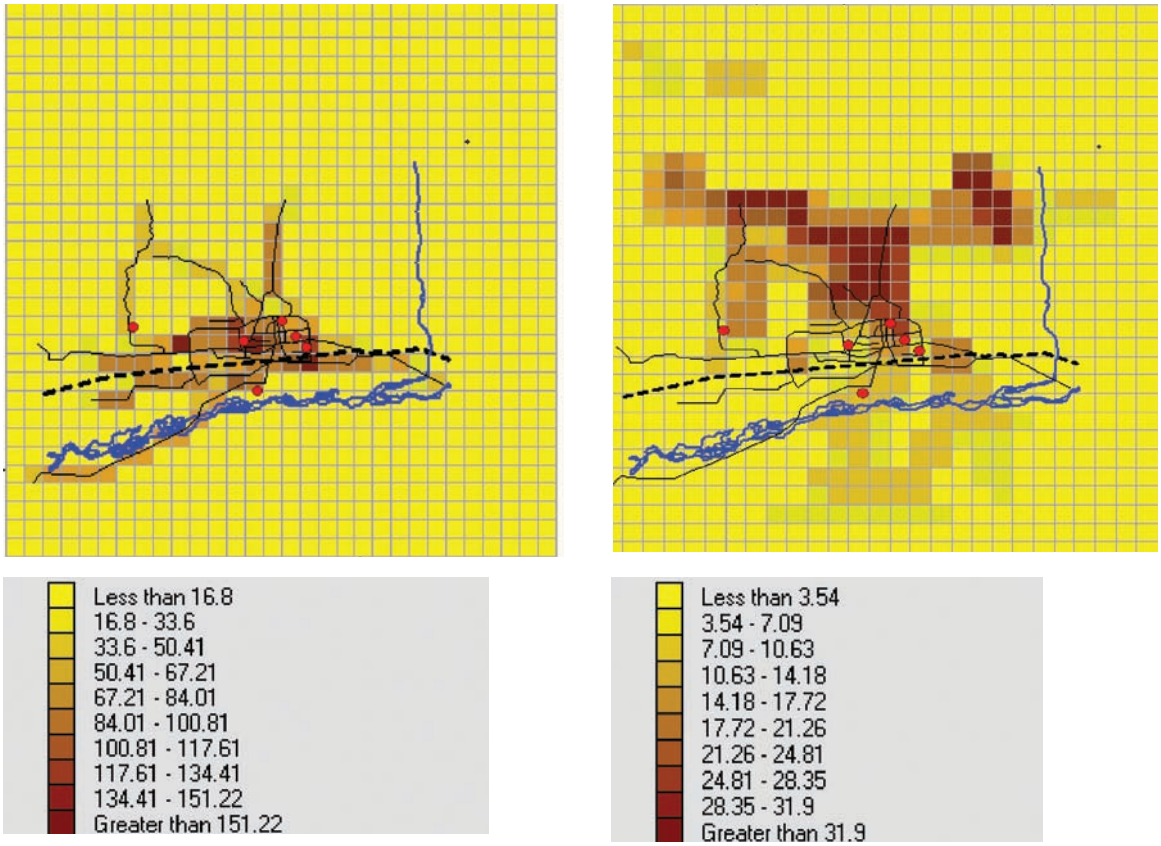
There are some 4,500 kiosks and shops in UB which are heated by the same type of stoves as used by the ger households. This is a less important source, and we do not have its spatial distribution across UB. We use a previous estimate (Guttikunda, draft 2007) and distribution of this source. We allocate 5% of the ger household emissions to this source, and distribute it as the household emissions.

Modelled current spatial pollution distributions, and model evaluation

Methodologies and modelling tools

The spatial distribution of ground level air pollution concentrations in UB is assessed using a dispersion model developed for urban scale applications. The model, EPISODE, is a Eulerian grid model with embedded subgrid models for calculation of pollutant concentrations resulting

Figure 22: Spatial distribution of suspended PM_{10} from road traffic in UB. Left: paved roads. Right: unpaved roads. Note the different scales in the two figures



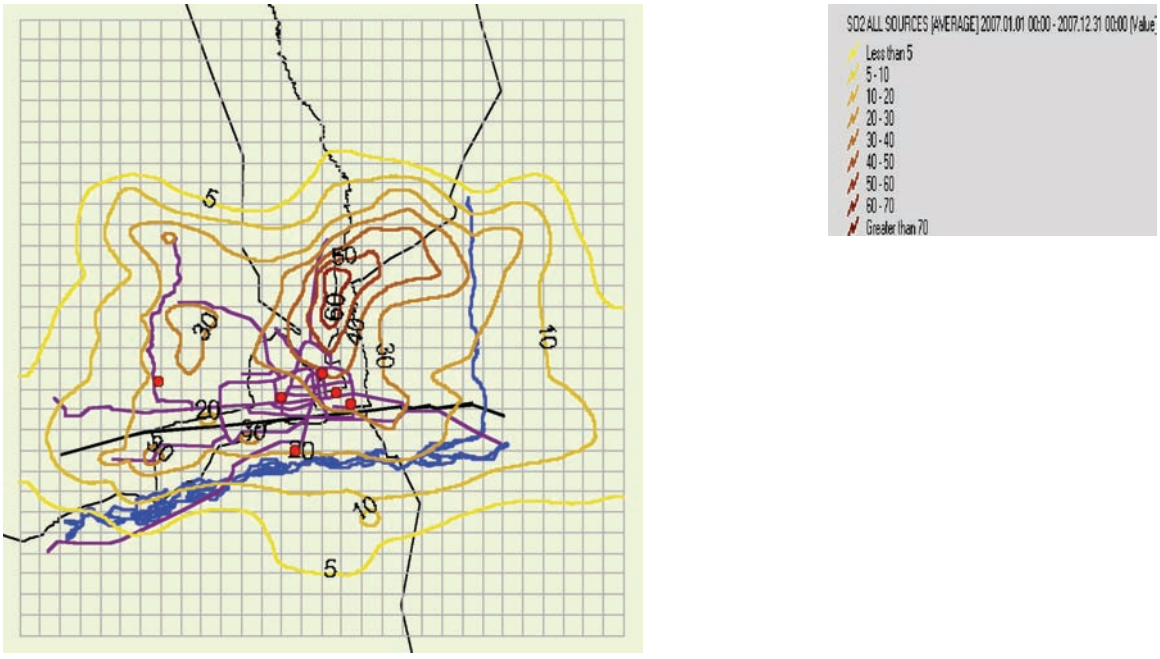
from different types of sources (area-, line- and point sources) (Slørdal, et al, 2003). EPISODE solves the time dependent advection/diffusion equation on a 3 dimensional grid. The size of the grid elements in UB is 1×1 km², and the size of the grid is 30×30 km. The model operates with 10 vertical layers, the lowest one having thickness 20 meters. The model calculates hourly concentrations over the entire modelling period, in this case one full year, based upon meteorological and emissions data that are also measured, calculated and input to the model on an hourly basis. The hourly concentrations can be aggregated to daily, monthly and annual averages. The typical results from the model calculations is iso-lines of ground level concentrations over the 30×30 km area.

The EPISODE model is embedded in the air quality management system AirQUIS (AirQUIS, 2008; Slørdal et al, 2008). The AirQUIS system is an integrated air quality management system on a software platform, described in Appendix H. The integrated system contains different modules, including emission inventory module, GIS related geographical information module, measurement module, and the models module.

The meteorological model TAPM ('The Air Pollution Model', see Appendix H), was used to supplement the locally measured meteorological data for 2007, where data was missing for periods extending over several weeks.

The input data to the modelling includes geographical data (topography), meteorological data and emissions data, as well as population distribution data and measured pollution concentration data.

Figure 23: Modelled spatial distribution of SO_2 in Ulaanbaatar, 2007



Isolines of concentration (µg/m).

Appendix H describes details of the models and tools used, as well as the input data.

Modelling results are given in the next sections, partly in the form of maps. On a background which shows the main road system, rivers, railroad and district borders, the maps show modelled isolines of concentrations.

Modelled current air pollution levels and distribution in UB

The EI, providing spatial and temporal distributions of emissions to the model grid, is input to the dispersion model system. The sections below present modelled spatial distributions for SO_2, PM_{10} and $PM_{2.5}$.

The uncertainties of the EI propagate through the model and give corresponding uncertainties in the modelled concentration distributions. The model is evaluated by means of comparing the modelled concentrations with those measured, at 4 sites for SO_2 and at only one site for PM, the NUM site, located a few km east of UB centre, the only site at which PM measurements were available at the time the modelling work was carried out. The evaluation is described in the evaluation section from p. 50. The correspondence between measured and modelled concentrations at the measurement sites is fairly good. From this, it can not be established how the modelled concentrations, especially for PM, correspond with reality in other parts of UB. Preliminary data from the AMHIB monitoring network for PM may indicate that the model gives too low PM concentrations in the ger areas. This could mainly be the result of the uncertainties of the emissions inventory.

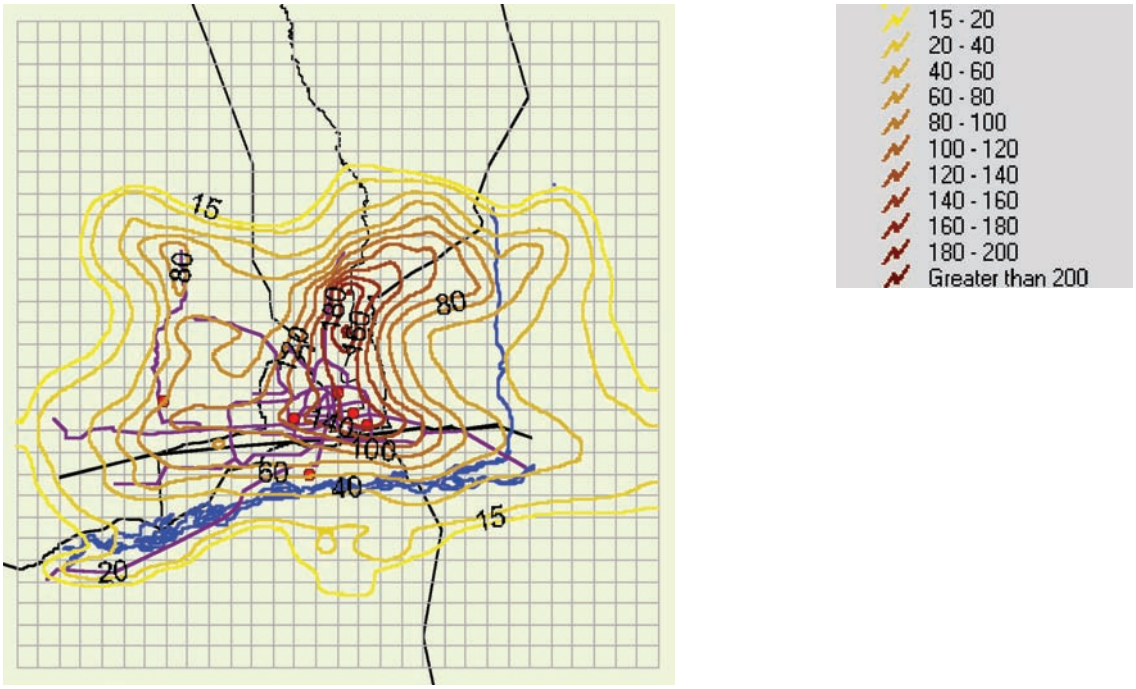
SO_2

The annual average SO_2 concentrations for 2007 are shown in Figure 23 as isolines, based upon the km^2 gridded concentrations. Sources included are ger households, HOBs and CHPs. Including the traffic SO_2 contribution would increase the concentrations in the central UB area somewhat.

PM_{10}

Isolines for calculated annual average PM_{10} concentrations for 2007 are shown in Figure 24. The spatial contributions from each main source are shown in Figures 25–30.

Figure 24: Modelled spatial distribution of PM_{10} in Ulaanbaatar, 2007



Isolines of concentration (µg/m³).

***How to read* isolines?** Modelling results are presented in the form of maps with what look like contour lines on topographical maps. These are called *isolines*. Like contour lines on topographical maps which connect points with the same elevation, *isolines* go through the points that have the same pollution concentration. The *isolines* envelop the areas of consecutively higher concentrations. The maps show that the various sources expose areas in UB differently to various concentrations, dependent upon the location of the sources and the height of the emissions, as well as the wind distribution (direction and speed).

One way to read these maps is to take the table of international and Mongolian standards and follow the isolines to see in which specific areas of UB the standards are exceeded.

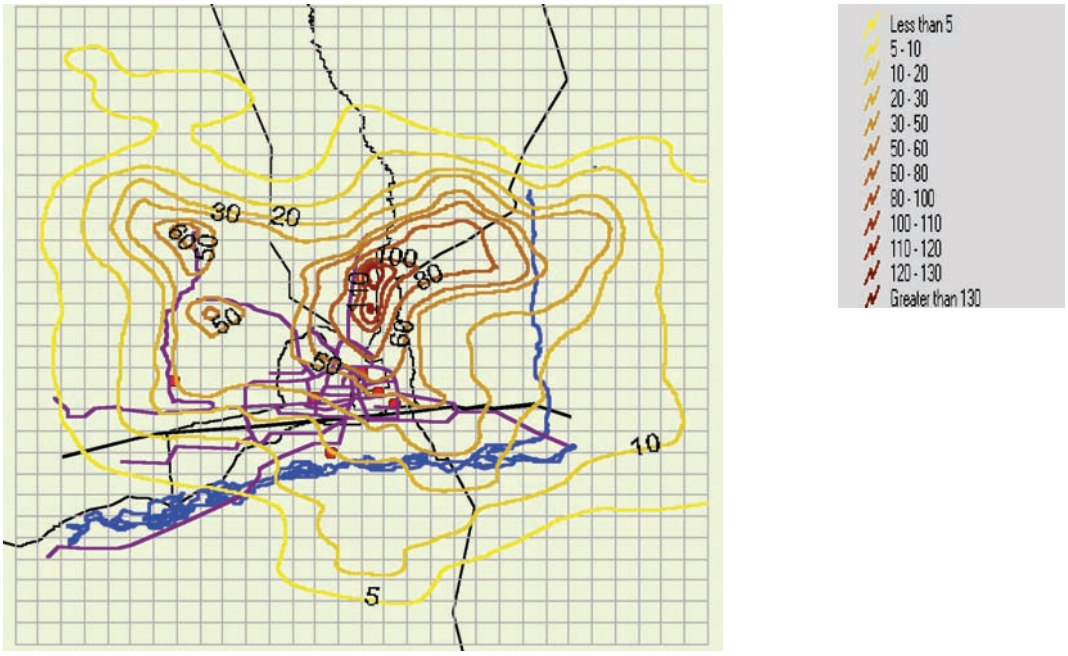
This mapping shows that i) the contribution from pollution sources to average concentrations of air pollution are significantly different and expose different areas to high concentrations; and ii) the effects of air pollution on the population are not distributed evenly and depend on the spatial distribution of ambient air pollution and the spatial distribution of the population.

$PM_{2.5}$

Isolines for calculated annual average $PM_{2.5}$ concentrations for 2007 are shown in Figure 31. Contributions from ger households, HOBs, CHPs and road traffic (exhaust particles and suspension of dry dust from paved and unpaved roads) have been included. The combined $PM_{2.5}$ spatial distribution differs from that of PM_{10}. The $PM_{2.5}$ exposure in the city centre is less than for PM_{10} mainly because the dry dust suspension contribution is less for $PM_{2.5}$ (only 15% of PM_{10}) The northern maximum shows up also for $PM_{2.5}$, as a result of a combination of ger household and HOB emissions as well as the traffic contribution.

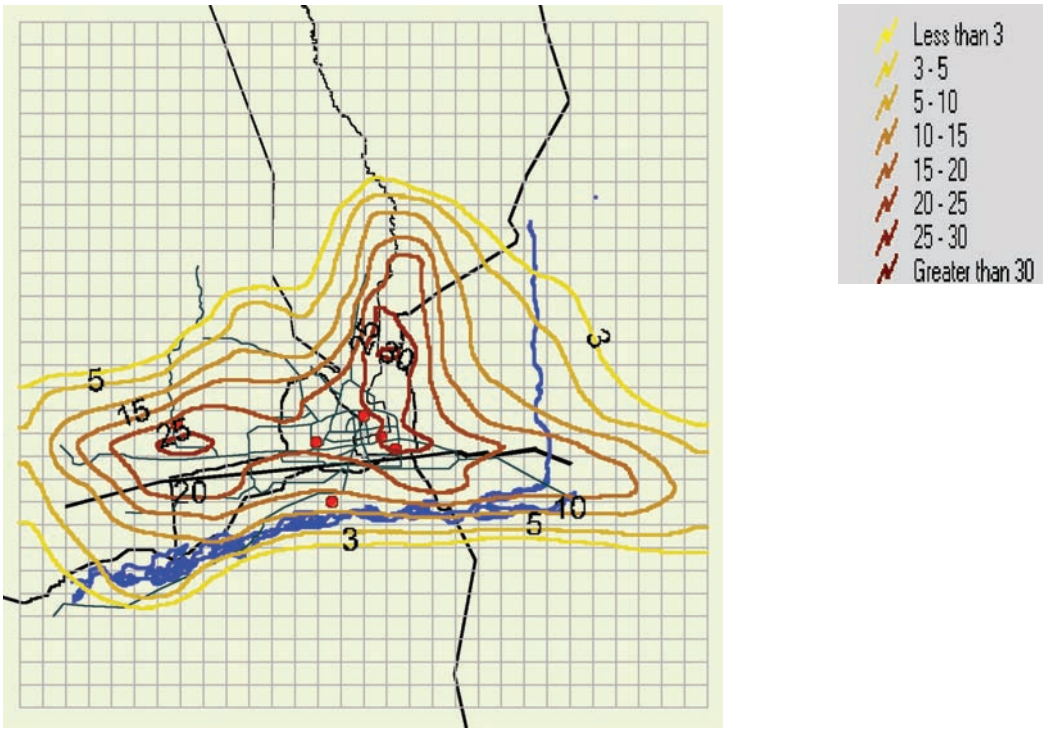
The $PM_{2.5}$ distribution is quite similar to the SO_2 distribution, although there are some differences because of the traffic contribution to PM. Maps showing source-wise contributions are shown in Figures 31–a to 31–f.

Figure 25: Modelled spatial distribution of PM_{10} in Ulaanbaatar, 2007



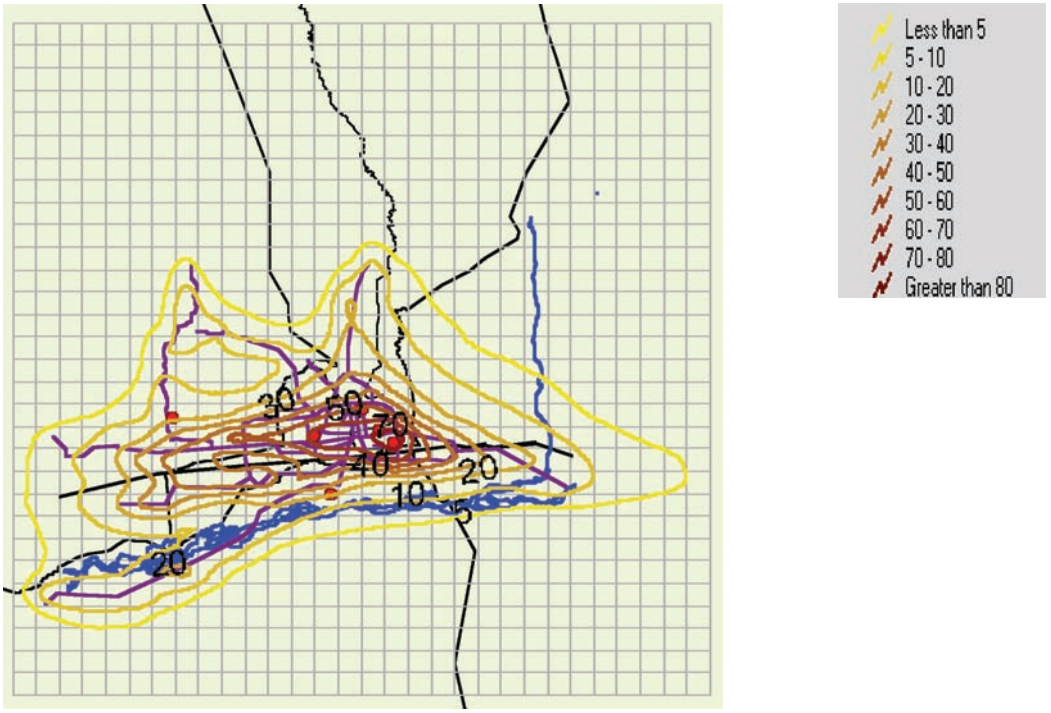
Contributions from each main source category (isolines of concentration (µg/m³) – ger households.

Figure 26: Modelled spatial distribution of PM_{10} in Ulaanbaatar, 2007



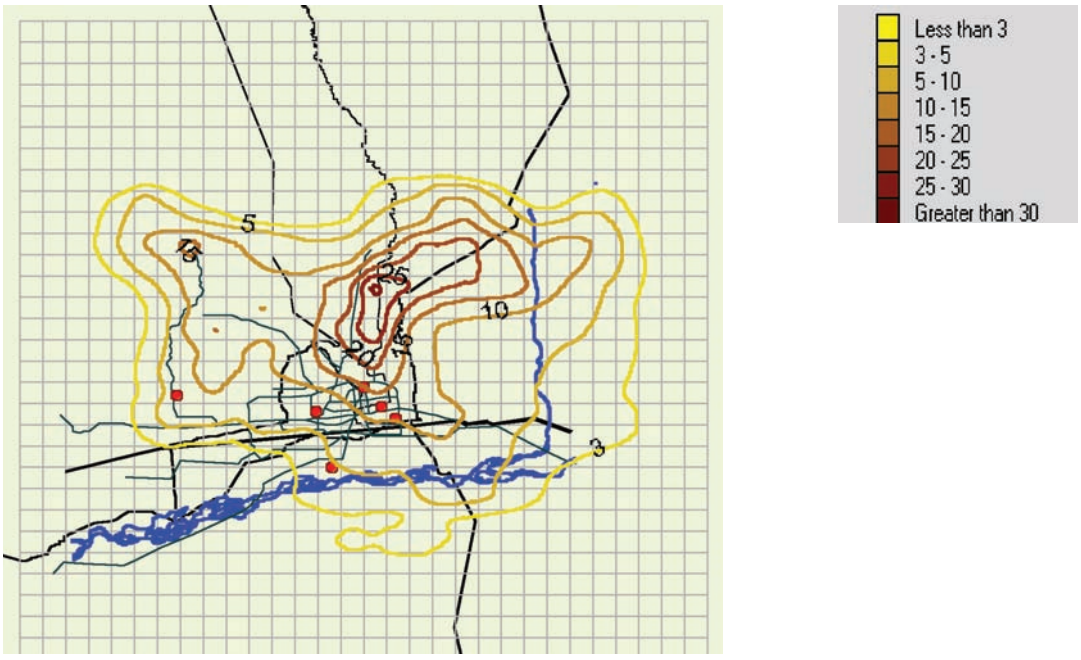
Contributions from each main source category (isolines of concentration (µg/m³) – heat only boilers.

Figure 27: Modelled spatial distribution of PM_{10} in Ulaanbaatar, 2007



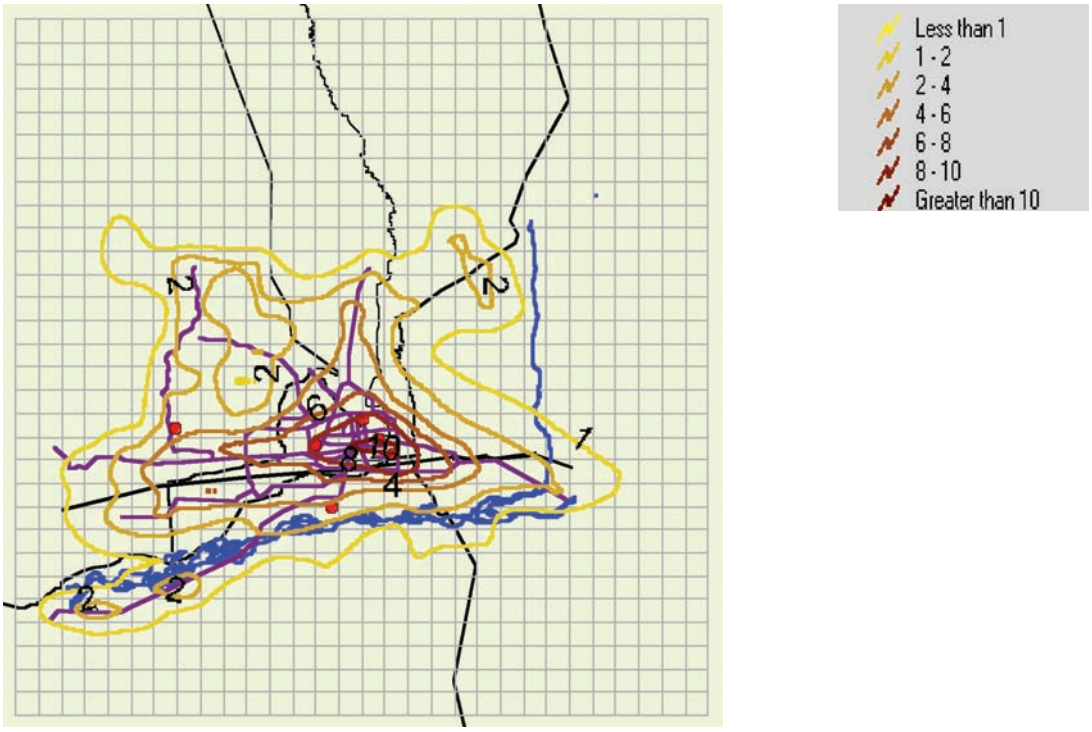
Contributions from each main source category (isolines of concentration (µg/m³) – dust suspension from paved roads.

Figure 28: Modelled spatial distribution of PM_{10} in Ulaanbaatar, 2007



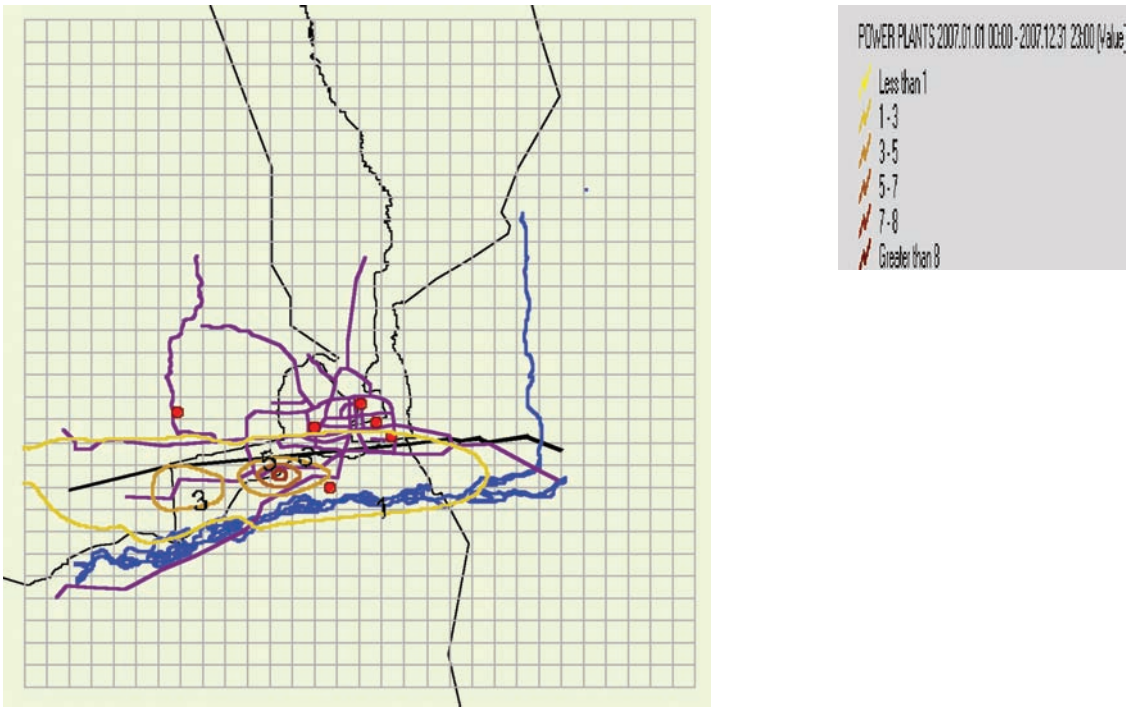
Contributions from each main source category (isolines of concentration (µg/m³) – dust suspension from unpaved roads.

Figure 29: Modelled spatial distribution of PM_{10} in Ulaanbaatar, 2007



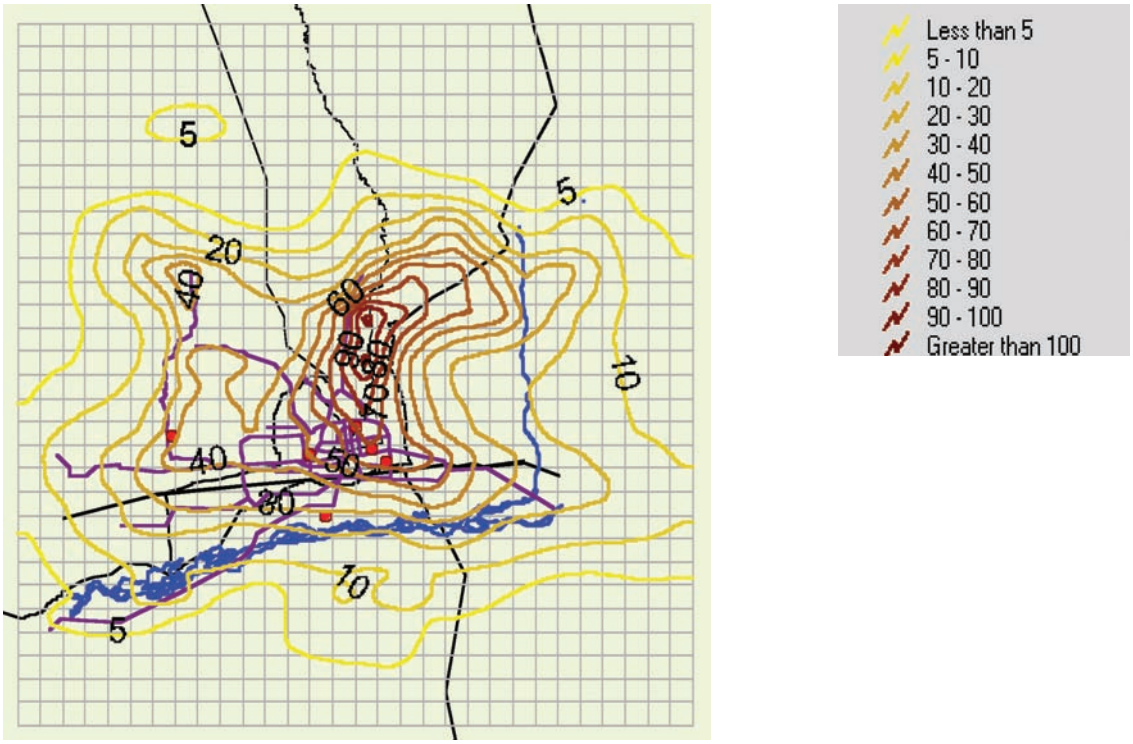
Contributions from each main source category (isolines of concentration (µg/m³) – vehicle exhaust particles.

Figure 30: Modelled spatial distribution of PM_{10} in Ulaanbaatar, 2007



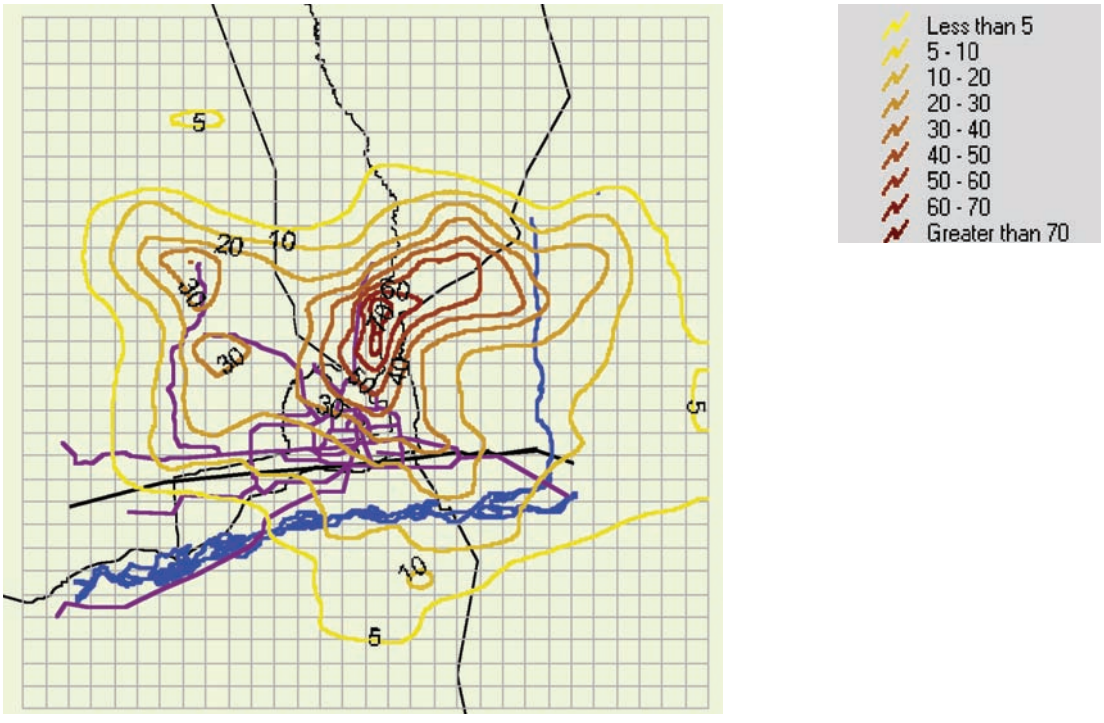
Contributions from each main source category (isolines of concentration (µg/m³) – CHPs.

Figure 31: Modelled spatial distribution of $PM_{2.5}$ in Ulaanbaatar, 2007



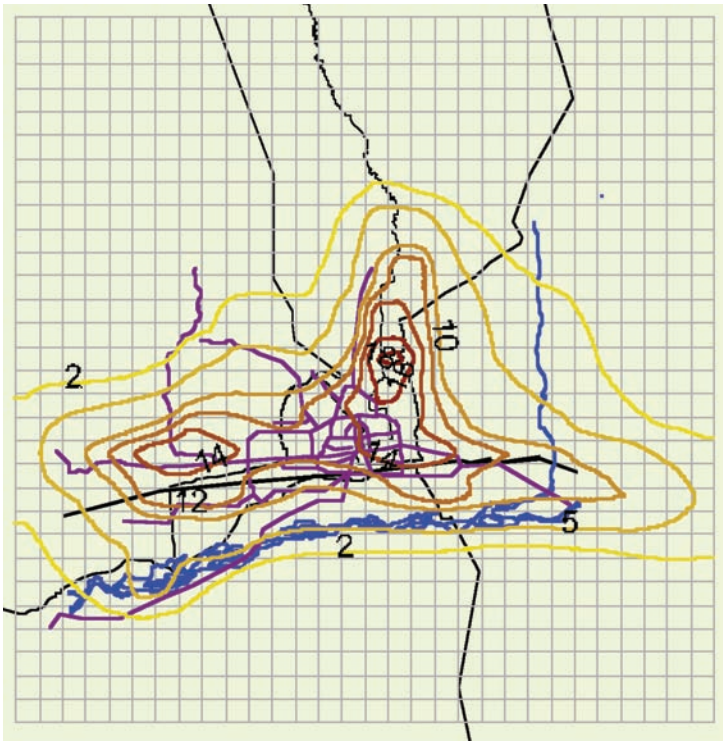
Isolines of concentration, µg/m³.

Figure 31-a: Modelled spatial distribution of $PM_{2.5}$ in Ulaanbaatar, 2007



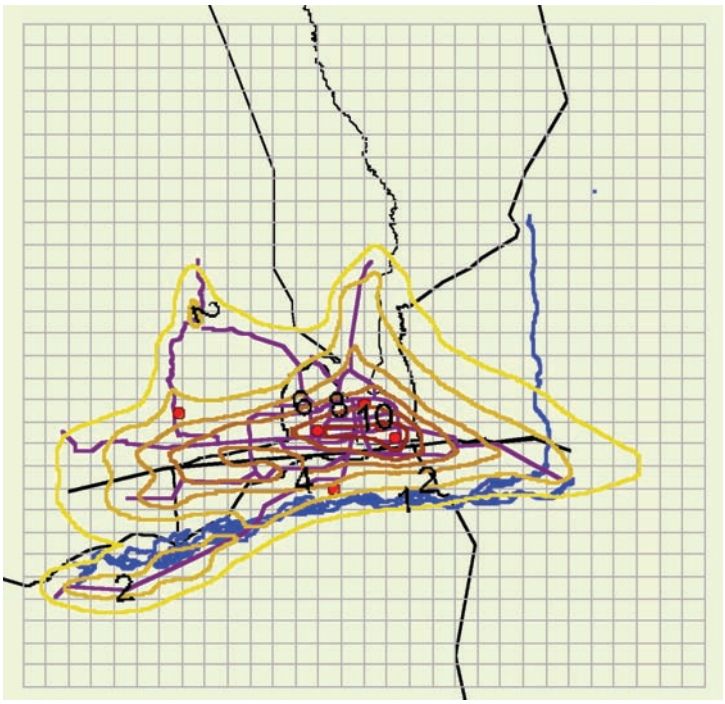
Contributions from each main source category (isolines of concentration (µg/m³) – ger households.

Figure 31-b: Modelled spatial distribution of $PM_{2.5}$ in Ulaanbaatar, 2007



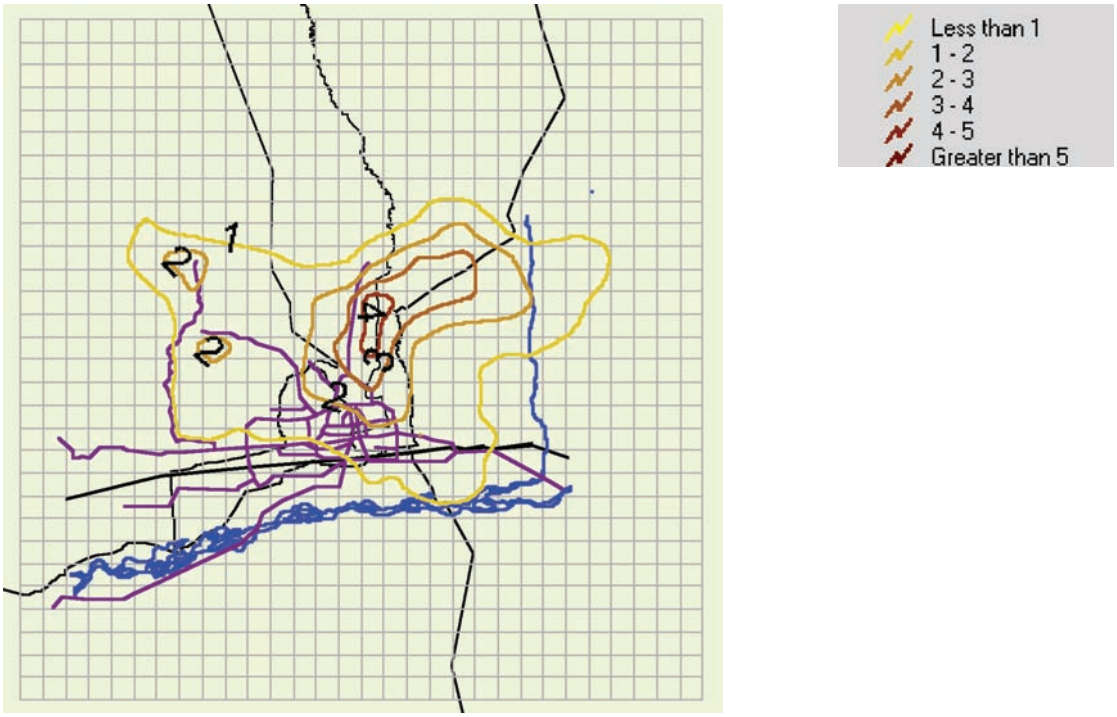
Contributions from each main source category (isolines of concentration (µg/m³) – HOBs.

Figure 31-c: Modelled spatial distribution of $PM_{2.5}$ in Ulaanbaatar, 2007



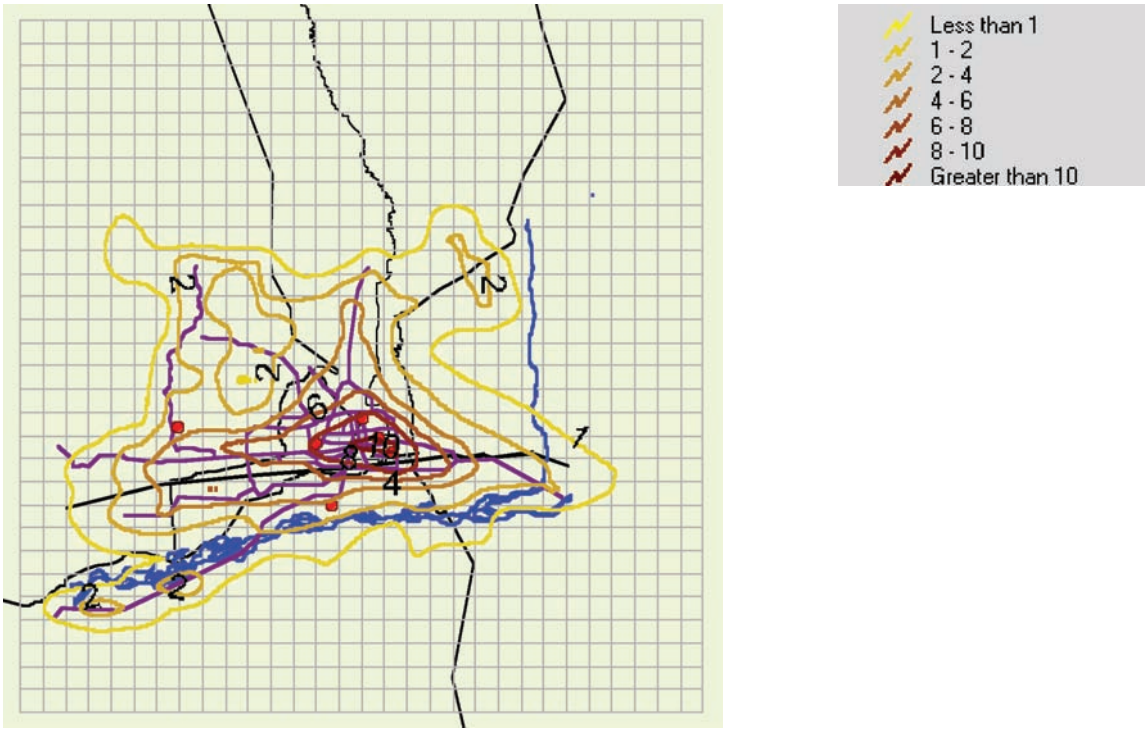
Contributions from each main source category (isolines of concentration (µg/m³) – dust suspension, paved roads.

Figure 31-d: Modelled spatial distribution of $PM_{2.5}$ in Ulaanbaatar, 2007



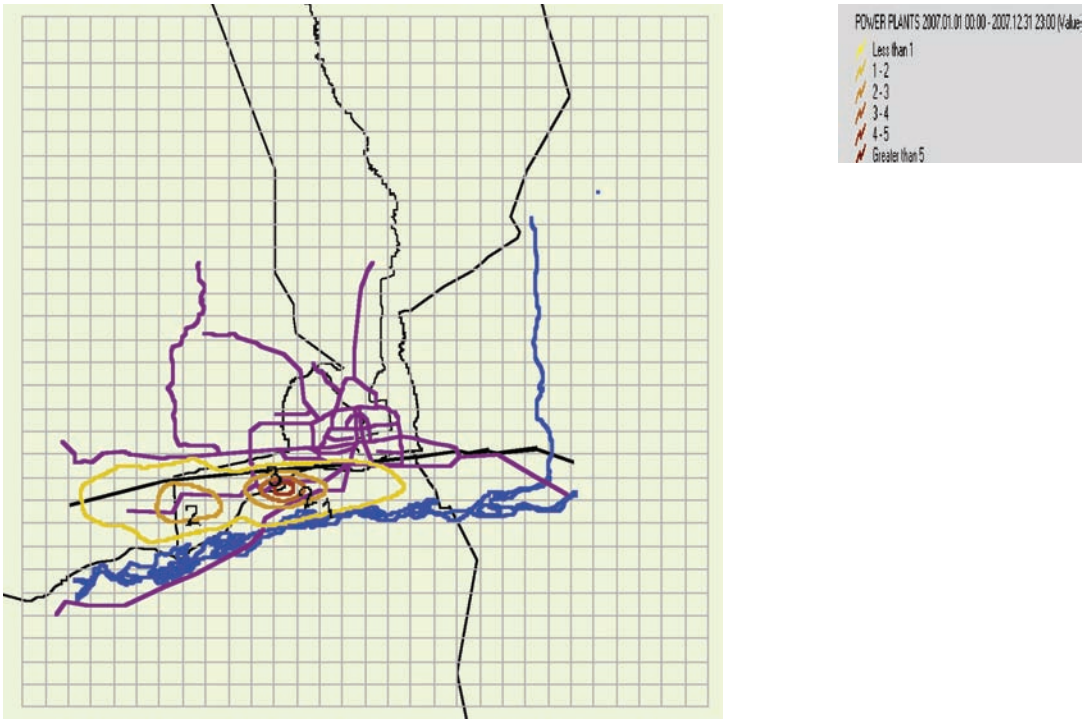
Contributions from each main source category (isolines of concentration (µg/m³) – dust suspension, paved roads.

Figure 31-e: Modelled spatial distribution of $PM_{2.5}$ in Ulaanbaatar, 2007



Contributions from each main source category (isolines of concentration (µg/m³) – vehicle exhaust particles.

Figure 31-f: Modelled spatial distribution of $PM_{2.5}$ in Ulaanbaatar, 2007



Contributions from each main source category (isolines of concentration (µg/m³) – combined heat and power plants.

The maps show significantly different patterns of PM_{10} and $PM_{2.5}$ concentrations for each main source across the city. PM contributed by ger households are distributed from east to west, in the ger areas, to the north, with maximum annual average contributions in parts of these areas of 120 µg/m³. The modelled PM_{10} contributions of unpaved roads are smaller than that of paved roads because traffic density on unpaved roads is much smaller than that of unpaved roads. Should traffic patterns change in the ger areas due to improved transport services or increased use of personal cars, without mitigation measures such as paving of roads, the contribution of dust suspension from unpaved roads could rise dramatically.

Based upon the spatial information in the Figures 23–30, the maximum impact areas for each of the main sources are listed in Tables 8 and 9 below:

Evaluation of the air pollution dispersion model

The dispersion model used, the EPISODE model, is evaluated against measurements carried out during 2007, the same period as for the modelling. The model, its input data and evaluation is described in Appendix H.

It is important to note that any comparison of an air pollution model with observations entails not just an evaluation of the model itself but also of the input data used to drive the model, i.e. emissions and meteorology. Unfortunately, errors in input data are difficult to separate from errors in the model. When there are sizable uncertainties in the input data then these will propogate through the model to the resulting concentration fields.

Table 8: Maximum PM_{10} concentrations by source and spatial distribution, 2007*

Source	Maximum	Impact Area (see Figures 24–30 above)
All sources	190	—
Ger households	120	Extended area from east to west in ger areas in north
Paved roads	70	UB centre area, smaller in the ger areas
Unpaved roads	30	Across the ger areas
HOBs	30	West and north of city centre
Vehicle exhaust	10	UB centre area, smaller in the ger areas
CHPs	8	Areas south of city centre

*The figures are maximum concentration contributions in different areas. Thus, the maximum concentration of the map where all the source contributions have been added, is lower than the sum of all the separate maximums, because they do not occur in the same point (grid cell).

Table 9: Maximum $PM_{2.5}$ concentrations by source and spatial distribution, 2007*

Source	Maximum	Impact Area (see Figure 31, sub a–f above)
All sources	90	
Ger households	70	Extended area from east to west in ger areas north
Paved roads	10	UB centre area, smaller in the ger areas
Unpaved roads	4	Across the ger areas
HOBs	18	West and north of city centre
Vehicle exhaust	10	UB centre area, smaller in the ger areas
CHPs	4	Areas south of city centre

*The figures are maximum concentration contributions in different areas. Thus, the maximum concentration of the map where all the source contributions have been added, is lower than the sum of all the separate maximums, because they do not occur in the same point (grid cell).

Sulfur Dioxide—SO_2

Emissions of sulphur dioxide, SO_2 from fossil fuel combustion can be relatively accurately assessed, when the amount of fuel burnt and its sulphur content is known, as well as the efficiency of any emissions cleaning equipment used. In UB, the sulphur in the coal combusted is the dominant sulphur source. Most of the sulphur in the coal is emitted as SO_2, only a few percent is converted to sulphate (SO_4) before being emitted to the atmosphere, or kept in the emitted coal particles or in the bottom ash. There is some sulphur also in diesel and gasoline combusted by road

Table 10: Measured and modelled annual average SO_2 (µg/m³) for stations UB 1–4, 2007

Mon. Station	Measured	Modelled	Comment
UB-1	14.2	19.2	1 Jan–10 Nov
UB-2	28.4	35.9	Entire year
UB-3	23.0	19.6	Entire year
UB-4	31.1	30.6	Entire year

vehicles, however, this source is much smaller. (Guttikunda, 2007) estimated the vehicles source of SO_2 to be about 6% of the sulphur from the coal combusted.

Since SO_2 is also rather stable in the urban atmosphere in smaller cities like UB where the residence time of the gas is short, typically a couple of hours, SO_2 is a suitable compound for validating atmospheric models.

Table 10 shows the comparison of modelled with measured SO_2 concentrations at the four CLEM monitoring stations (Stations UB 1–4, located as shown in Figure 7 on p. 15). The measured concentrations were adjusted according to the preliminary results of the comparative results described in section on SO_2 concentrations on p. 21 by multiplying with a factor 2. This obviously has to be confirmed through further quality checking. As a result, the uncertainty of the measured SO_2 concentrations are considered high until further quality control is carried out through a comparison study. The measured SO_2 levels vary considerably between the sites, with high winter concentration levels from as low as 50 µg/m³ at the UB-1 station to about 100 µg/m³ at the UB-2 station. The seasonal variation is similar at all stations (Figure 32), with very low concentrations in the summer, reflecting the low consumption of coal for ger heating and for HOBs then. The CHPs are also operating in the summer, and the low summer concentrations reflect the limited contribution from the CHPs to ground level concentrations, because of the tall stacks.

The emissions that are input to the model calculations, total emissions per source and its spatial distribution and time variation, are according to the section on emissions inventory from p. 29. The modelled concentrations follow the seasonal variation of the measurements well, and also reflect the different levels at the four stations, see Figure 32. There are some deviations from the measurements in some periods, such as for the UB-2 station, located a bit to the west of the UB centre area: overestimation during early January and in November–December, and in early March there is overestimation at 3 stations, UB-1,2 and 3, but not at UB-4. Apart from this, the correspondence between measured and modelled concentrations is quite good. Table 10 shows measured and modelled annual averages.

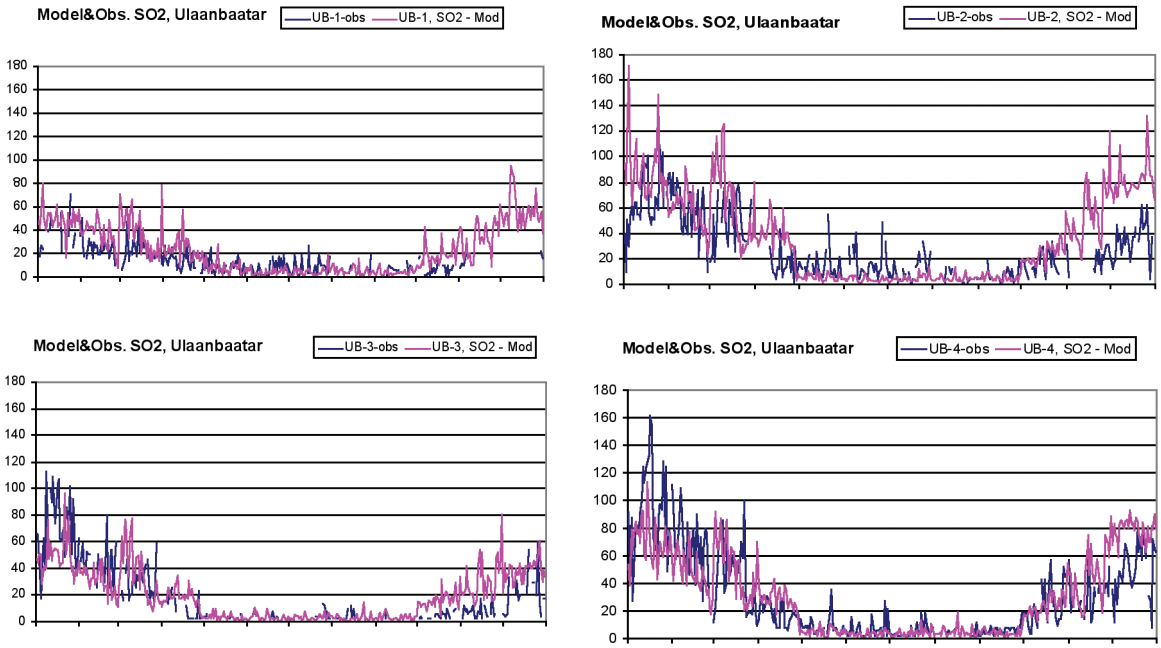
These results indicate that the model and emission data represent the observed seasonal trends and annual means of SO_2 to within the expected uncertainty. However, given the current uncertainty in the monitoring data, as well as the emissions, it is not possible to give a more conclusive assessment concerning the validity of the emissions.

PM_{10}

PM was in 2007 measured at only one station, the NUM station at the National University of Mongolia. As described above (section from p. 14), the NUM sampler gives reasonably good data for PM_{10}, while it underestimates the concentration of $PM_{2.5}$. Thus comparison of modelled concentrations with measured ones can only be done for PM_{10}.

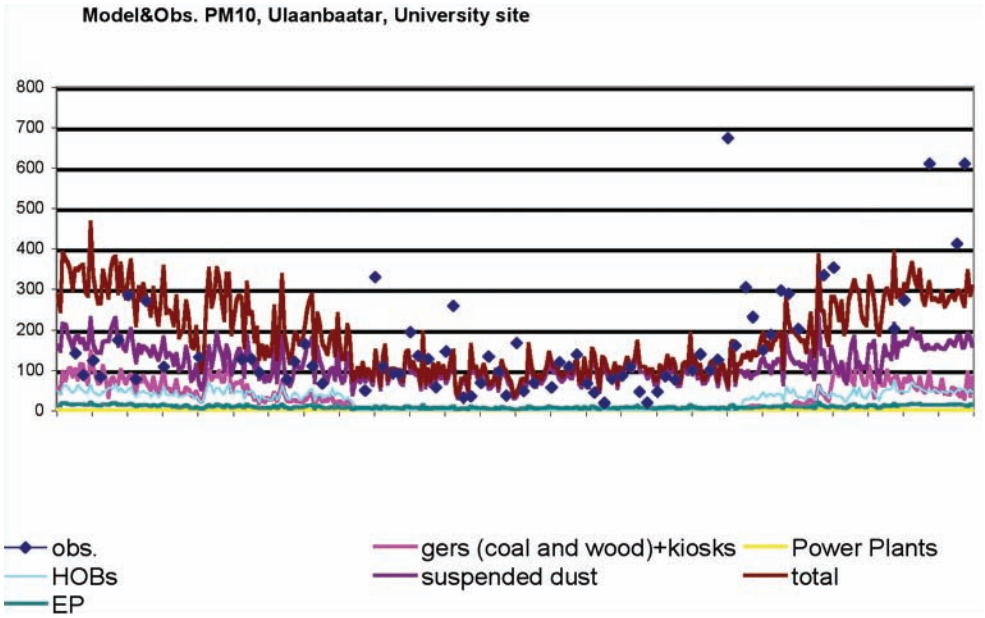
Figure 33 shows measured data and modelled contributions to PM_{10} from a number of sources.

Figure 32: SO_2 concentrations at stations UB 1–4



Measured and modelled daily average concentrations, 2007 (µg/m³).

Figure 33: Measured and modelled PM_{10} (daily average) at the NUM measurement site



Contributions from various sources.

The measurements are taken generally over 24 hours on two days per week. On days with very high $PM_{2.5}$ concentrations, the sampling period is shorter, down towards 6–8 hours from the starting time, due to sampler clogging. The brown line in Figure 33 shows the total modelled PM_{10} concentration, with contributions from Ger and kiosks coal and wood, HOBs, CHPs, vehicle exhaust particles and suspended dust from roads.

Note that Figure 33 represents the NUM site only. As we saw in the modelling section from p. 40, the contributions from the various PM sources to ground level concentrations varies substantially throughout the city: e.g. in ger areas the ger household emissions will dominate more, while in the city centre the road dust suspension and exhaust emissions will be more dominant.

The model overestimates the measurements early in the year (January–February) and underestimates at the end of the year (November–December) 2007. Inspection of the measurements as shown in section from p. 15 shows that the amount of suspension of dry dust (the coarse fraction of PM) was small in January–February and very large in November–December in that year. Suspension of dust from surfaces is naturally a very non-steady mechanism. Dust is building up on the surfaces during humid and low wind periods, and then released when exposed to turbulence when it is very dry. Data on dryness/freezing/wetness conditions on the roads have not been collected so far. Our model is presently run for constant dry conditions where the dust is always available for suspension, i.e. a steady suspension from the roads, hour-by-hour only dependent upon traffic amount. Thus, as the model is run presently, it does not necessarily reproduce the winter-time suspension dynamics day-by-day. It is possible to refine these model runs, if relevant information on road conditions day-by-day can be found. During the summer period, suspension is the completely dominating PM_{10} source.

Figure 33 shows that the model estimates the average summer-time PM_{10} reasonably well.

Correlation between the measured and the modelled PM_{10} concentrations is quite low, with a coefficient of determination (R^2), that represents how much of the observed variability is explained by the model, is quite low at 14%. This reflects the models inability to capture the day-to-day variations in the emissions. This is particularly important for resuspension, which is strongly dependent on surface conditions, though these are not described in the model. The fact that a much larger amount of the SO_2 variability is explained by the model, 37–55 %, indicates that the major part of the unknown variability does not come from the coal combustion sources but is, as indicated, the result of uncertainties in the emission of PM_{10} through resuspension.

Despite the strong variability, the model predicts an annual average PM_{10} of 163 $\mu g/m^3$, all source contributions added. The measurements give 157.7 $\mu g/m^3$ (see Table 11 below). Each of the modelled source contributions are based upon separate scientific considerations and upon the input in the emissions inventory section from p. 29. The estimated annual average concentration from the measurements is made up of data from only 2 days per week and thus has a considerable uncertainty, while the modelled annual average is based upon hourly data throughout the year. The uncertainty related to the 2-day-per-week sampling instead of all days in the year is estimated to about +/– 20%, assuming the variability of the about 73 samples is representative of the other 292 days when no samples were taken. This comes in addition to the the uncertainty in each of the sampled values, which can be estimated to be about +/– 15–20%, giving a composite uncertainty of about 26%. Another factor, which is discussed in Appendix C, is that the sampler used for these measurements operates, when the concentrations are high, only during part of the day, from 10 AM and then 6–8 hours. Due to the daily cycle of the concentrations (see Figures 11 and 12) this will introduce an extra uncertainty when comparing the daily mean values that are predicted in the model. On this basis, the agreement between the measured and modelled annual average is considered to be within the uncertainties of the measurements and the emissions.

Table 11: Measured PM_{10} and modelled source contributions at the NUM station, 2007 (µg/m³)

	Measured	Modelled
Concentration	157.7	163
Source contributions		
Coal and wood combustion	36%	44%
Suspended dust	58%	50%
Vehicle exhaust	6%	6%

The relative contributions of the different modelled sources to PM_{10} can also be compared to source apportionment studies made at the NUM station (Table 11). The modelled source contributions, on average, are very similar to those estimated from the monitoring data and well within the uncertainties related to the data. This further supports the model results for the total PM_{10} concentration, indicating that the model is producing realistic long-term average source contributions to PM_{10}, within the uncertainties related to both the monitoring and the emissions. This is important for the application of the model to assess the source contributions to population exposure and to provide useful information for abatement analysis.

The available data is very limited for making any solid conclusions concerning the performance of the model for PM_{10}. More information will be required for a thorough assessment of this and will be incorporated into the Final Report due in early 2010.

The dispersion modelled PM_{10} concentrations give the following contributions from the main source categories at the NUM station, as summarised in Table 11:

- Coal and wood combustion: 71 µg/m³ or 44%
- Suspended dust: 82 µg/m³ or 50%
- Vehicle exhaust: 10 µg/m³ or 6%

The statistical source apportionment from the NUM measurement data give a basis for estimating the following contributions to PM_{10}: 36% for combustion particles, 58% for the soil and construction particles and 6% for motor vehicle particles. Our model thus gives about 10% higher combustion particle contribution at the expense of the soil/suspension contribution, while the vehicle exhaust particle contribution is the same for the two methods. The dispersion modelling does not include construction particles.

As mentioned, the preliminary data from the AMHIB monitoring network for PM_{10} and $PM_{2.5}$, indicate that the PM concentrations in the ger areas could be considerably higher than has been modelled here. Further evaluation of the model can be made after improvements of the EI has been carried out and when quality assured AMHIB data are available.

4. Abatement Scenarios and Their Benefits in Terms of Reduced Health Costs

When faced with choices between proposed abatement measures, policymakers should use a basis for selection. The core of a local air pollution abatement program is its ability to reduce pollution and the harmful effects it has on the population. The selection criteria could be a) the degree to which the abatement measure, or package of measures, moves toward meeting Mongolian or International AQS across all of UB and/or b) the degree to which an abatement measure, or a package of measures, can reduce health costs, which may mean that, depending upon the health cost reduction target, not all of UB would meet air quality standards due to the spatial distribution of the population and pollution.

The types of assessments shown below provide policy makers with options regarding how to meet their targets, whether they are based on reaching concentration targets or on health effects reductions.

The indication from the first preliminary data from the AMHIB PM monitoring network is that the PM concentrations in the ger areas are underestimated. The main combustion source to PM in the ger areas is the ger stoves themselves, while suspension of dust from roads and surfaces is the main source to the coarse fraction. Both of these sources could be underestimated in the ger areas. The scenario analysis below shows that even if the ger stoves source strength is underestimated, it is still the main combustion source to the UB population exposure to PM, and the combustion source which is most important to control.

Improvements in the emissions inventory may result in an even increased importance of the ger stove and road/soil dust suspension sources for the average population exposure to PM.

Global Concerns. Considering global climate change concerns and that the nature of the problem in UB is the burning of carbon, reducing carbon emissions could also be considered as a selection criteria.

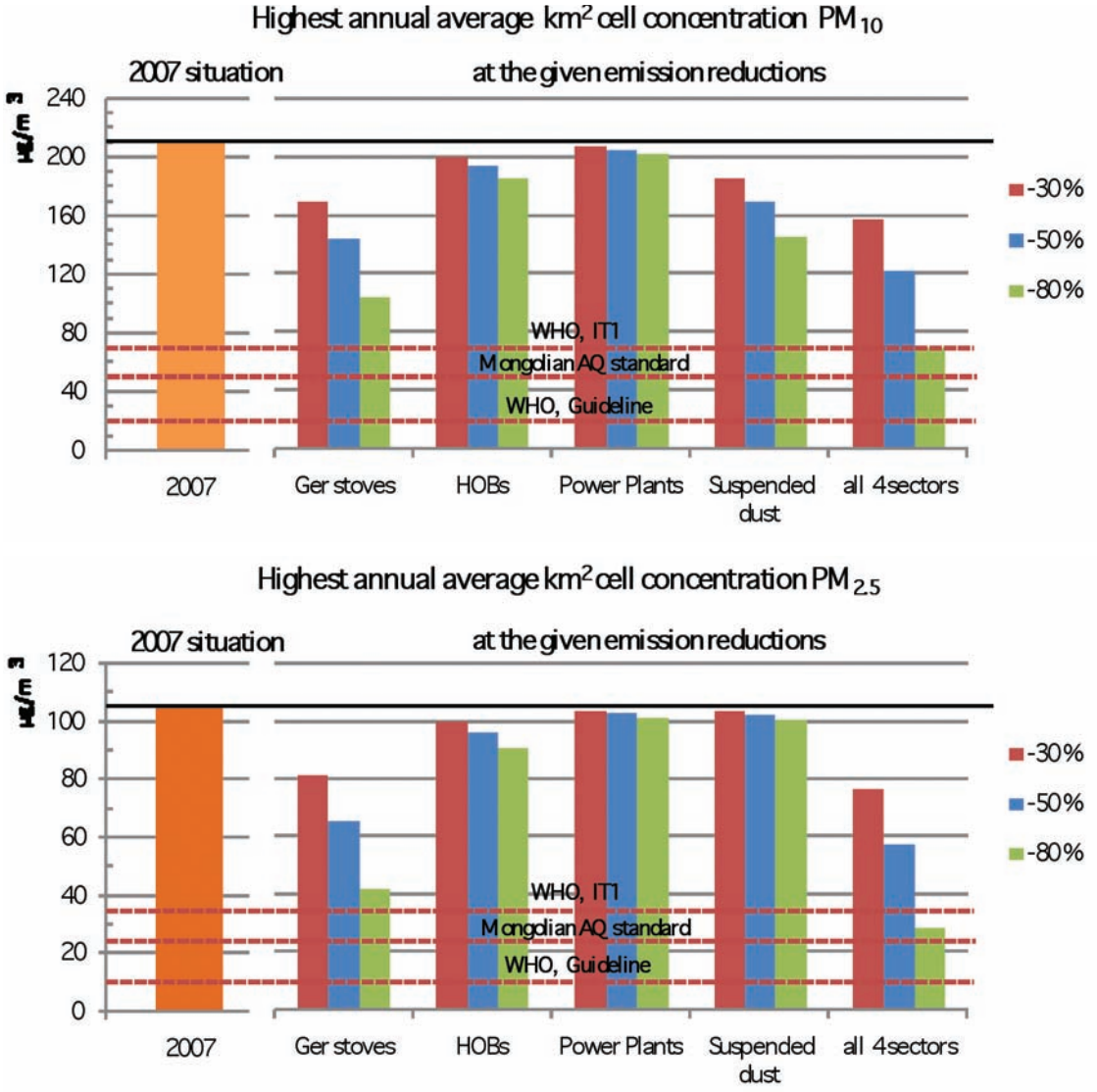
Abatement scenarios and reductions in PM pollution levels compared to Mongolian and International Air Quality Standards (AQS)

For the purpose of estimating the emission reductions needed to reach Mongolian and international standards for the entire UB population, Figure 34 shows the annual average concentration in the km^2 grid cell with the highest concentration, for the 2007 situation as the basis, and for the various reduction scenarios, which were:

- Impacts of reducing emissions by 30%, 50%, and 80%—irrespective of abatement method—from each of the main sources, respectively: ger heating systems, HOBs, CHPs and dust suspension from paved roads, and
- Impacts of reducing emissions in all four main sources by 30%, 50%, and 80%—irrespective of abatement method.

The highest modelled annual average grid cell concentration is 211 $\mu g/m^3$ for PM_{10} and 106 $\mu g/m^3$ for $PM_{2.5}$. The figure compares these

Figure 34: The highest annual average PM_{10} (top figure) and $PM_{2.5}$ (bottom figure) concentration in any grid cell in UB, 2007 and for various abatement scenarios (µg/m³)



annual average concentrations with various standards. On the basis of the available data used in the model, the ger stove abatement gives the largest effect to reduce the concentrations. The WHO IT-1 target can be met only with an 80% reduction in the emissions from all the four sources. To meet the Mongolian standard in the entire UB area, even larger reductions are needed.

Regarding the contributions from the CHPs, the analysis here is based upon the low emission estimate based upon assumed functioning PM cleaning equipment. The higher emission estimate based upon the JICA testing will increase the calculated reductions in concentrations resulting from percentage reductions in CHP emissions, by about a factor of 3. This should be taken into account in the consideration of the results below. The CHP contribution is important, although the mentioned correction will not change substantially the overall conclusions, since the CHP contribution to ground level concentrations is still limited.

Abatement scenarios, spatial impacts and reductions in health costs

Population weighted average exposures, PWE, (see Chapter 1) were calculated with the dispersion model to assess the health effects as a result of simulated emissions reductions.

The purpose of the simulations is to demonstrate the spatial impacts of interventions and health impacts.

The simulations are the same as in the section above and an additional simulation:

- *(To demonstrate spatial impacts)* Impacts of reducing emissions by 75% from ger households, 83% from heat only boilers and 50% from suspended dust on roads
- Impacts of reducing emissions by 30%, 50%, and 80%—irrespective of abatement method—from each of the main sources, respectively: ger heating systems, HOBs, CHPs and dust suspension from paved roads, and
- Impacts of reducing emissions in all four main sources by 30%, 50% and 80%—irrespective of abatement method.

Based on available data used in the model, the PWE in 2007 for PM_{10} is 76.7 µg/m³ and for $PM_{2.5}$ is 37.6 µg/m³, which are much lower numbers than the maximum grid average concentrations of 211 µg/m³ and 106 µg/m³, respectively, in section 4.1. The figures need to be treated separately because they are very different concepts. This is discussed below.

The maximum annual average concentration indicator is the highest cell in the grid and this is what the Mongolian standard should be compared with. The population weighted average is calculated by multiplying each grid PM value with the fraction of the population living in that grid. This weighted average is a good estimate for the exposure that the population as a whole experiences in UB. This indicator is used for estimating the resulting population-wide health effects of the reduced PM pollution (see below).

A 75%Ger/83%HOB/50% dust scenario—illustration of spatial impacts of abatement measures

The Discussion Paper simulates the impacts of reducing emissions by 75% from ger households, 83% from heat only boilers and 50% from dust suspension on paved roads. These are emission reductions based on technical options currently discussed in UB, including combined fuel and stove switching programs, replacing boilers, and cleaning roads.

The reduction resulting from each of the interventions is substantial, especially from interventions in the gers and HOBs. With all three interventions, the population weighted PM are reduced by 60–65%. The remaining PWE is 30.3 µg/m³ for PM_{10} and 12.4 µg/m³ for $PM_{2.5}$ (Table 12). This can be compared with the WHO Guidelines, which are 20 µg/m³ for PM_{10} and 10 µg/m³ for $PM_{2.5}$. The WHO Guidelines are set at the level where only minimal health effects should occur. The remaining PM pollution after these three interventions is still associated with some health effects on the UB population.

However, since PWE is a weighted average based on the distribution of the population, a significant part of UB will remain exposed to concentrations above the average with the highest modelled PM_{10} concentrations ranging between 70–80 µg/m³ and average PM_{10} concentrations in central UB ranging from 40–60 µg/m³.

Spatial distribution of PM_{10} under the 75%/83%/50% Scenario

Figure 35 shows the reductions in the PM_{10} concentrations in the grid resulting from the interventions, for each of the three interventions separately, as well as for all three combined. The ger stove/fuel improvements give the largest reduction, up to 90 µg/m³ in the most affected area, while the intervention to reduce dry dust suspension from roads gives the smallest reduction, concentrated in the central UB area where most of the traffic is.

Table 12: Population weighted average PM concentrations (PWE) in Ulaanbaatar, and reductions from the 75%Ger/83%HOB/50% dust intervention scenario (µg/m³)

	PM_{10}	$PM_{2.5}$
Population weighted average, PWE, 2007	**76.7**	**37.6**
Reductions in PWE from interventions:		
Ger stoves	32.7	19.6
HOB	8.7	5.2
Dust suspension	5.0	0.4
Total reduction	**46.4**	**25.2**
Remaining PWE	**30.3**	**12.4**

The total effect of the three interventions is to reduce the PM_{10} concentration by as much as 120 µg/m³ in the most affected area (north of UB centre). This corresponds to about 65% of the present PM_{10} concentrations.

Figure 36 shows the remaining PM_{10} concentrations after the three interventions. The highest concentrations then would be 70–80 µg/m³, while the average concentration in the UB central area would be about 40–60 µg/m³.

These concentrations are still high compared to the WHO and other guidelines. However, they approach the WHO Interim Target IT-2 of 50 µg/m³, and the EU Limit Value of 40 µg/m³. The Mongolian AQ standard of 50 µg/m³ would still be exceeded moderately in much of the central- northern of UB city area.

Spatial distribution of $PM_{2.5}$ under the 75%/83%/50% Scenario

Figure 37 shows the reductions in the $PM_{2.5}$ concentrations in the grid resulting from the interventions, for each of the three interventions separately, as well as for all three combined. As for PM_{10}, the ger stove/fuel improvements gives the largest reduction, up to 50 µg/m³ at the most affected area. The intervention to reduce dry dust suspension from roads gives only a very small reduction since only 15% of the suspended dust is in the $PM_{2.5}$ fraction.

The total effect of the three interventions is to reduce the $PM_{2.5}$ concentration by as much as 60 µg/m³ in the most affected area north of UB centre. As for PM_{10}, this corresponds to about 65% of the present $PM_{2.5}$ concentrations (see Chapter 3.8.2).

Figure 38 shows the remaining $PM_{2.5}$ concentrations after the three interventions. The highest concentrations then would be 30 µg/m³, while the average concentration in the UB central area would be about 20–30 µg/m³.

These concentrations are still high compared to the WHO and other guidelines. However, as is the case also for PM_{10}, they approach the WHO Interim Target IT-2 of 25 µg/m³, and the EU Limit Value of 20 µg/m³. The Mongolian AQ standard is exceeded only moderately.

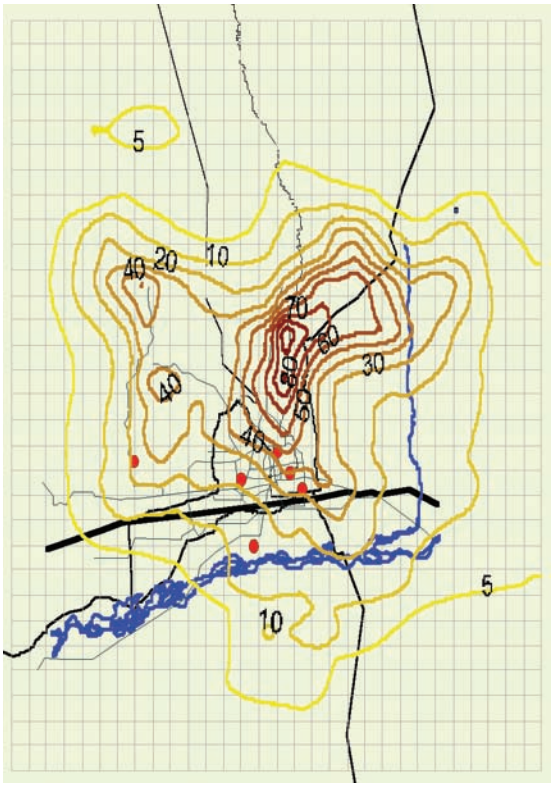
The 30%/50%/80% scenarios—illustration of health impacts of abatement measures

In order to make preliminary estimates of associated health costs, the Discussion Paper uses the *population weighted average PM concentration*, in short: PWE. Compared to annual average concentrations, the PWEs more accurately reflect exposure of UB's population to air pollution by adjusting for the spatial distributions of the pollution and the population.

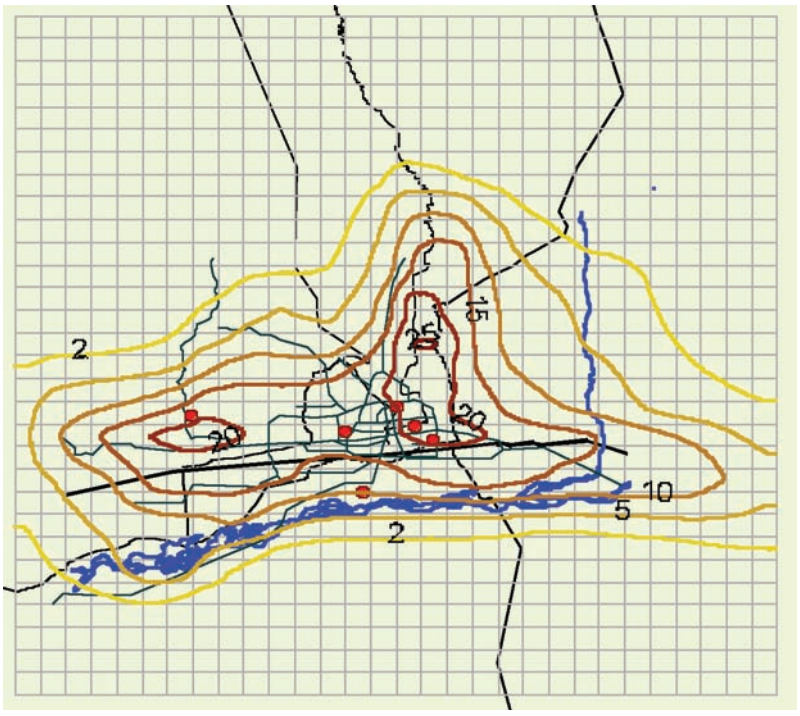
The PWE data in Table 13 are used to estimate health benefits of the reductions.

Figure 35: Calculated reduction in the PM_{10} grid resulting from the interventions (µg/m³)

Ger stoves emissions: —75%



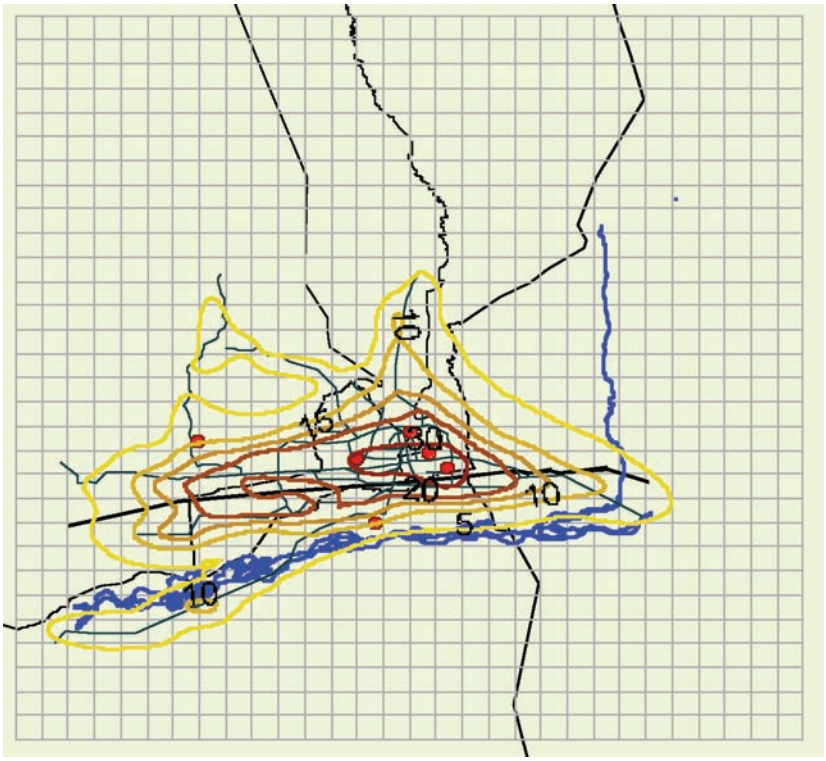
HOB emissions: —83%



Continued

Figure 35: Continued

Dust suspension from roads: —50%



PM_{10} reduction for all 3 interventions

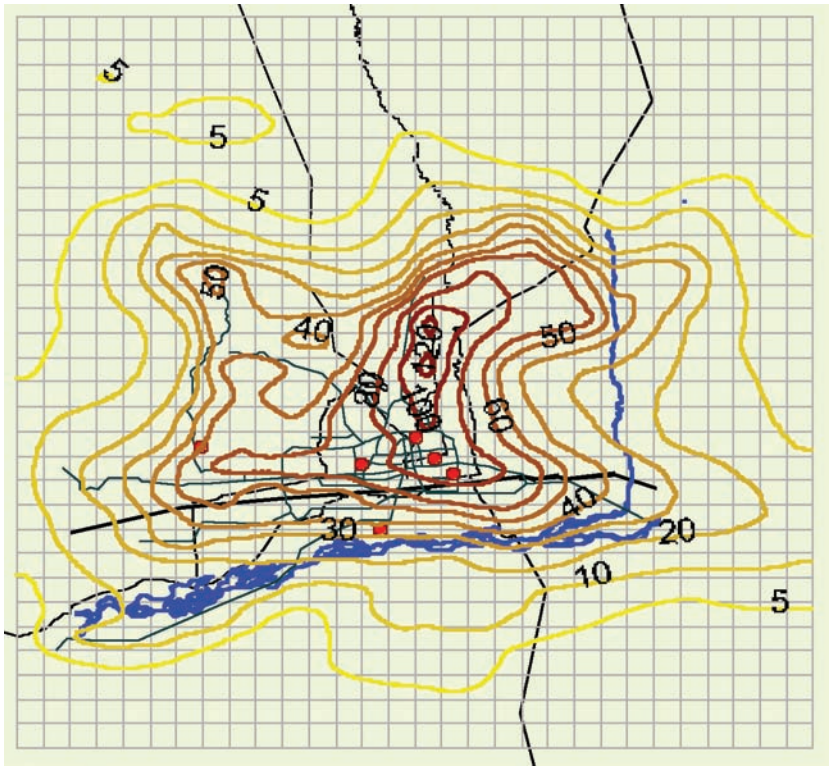
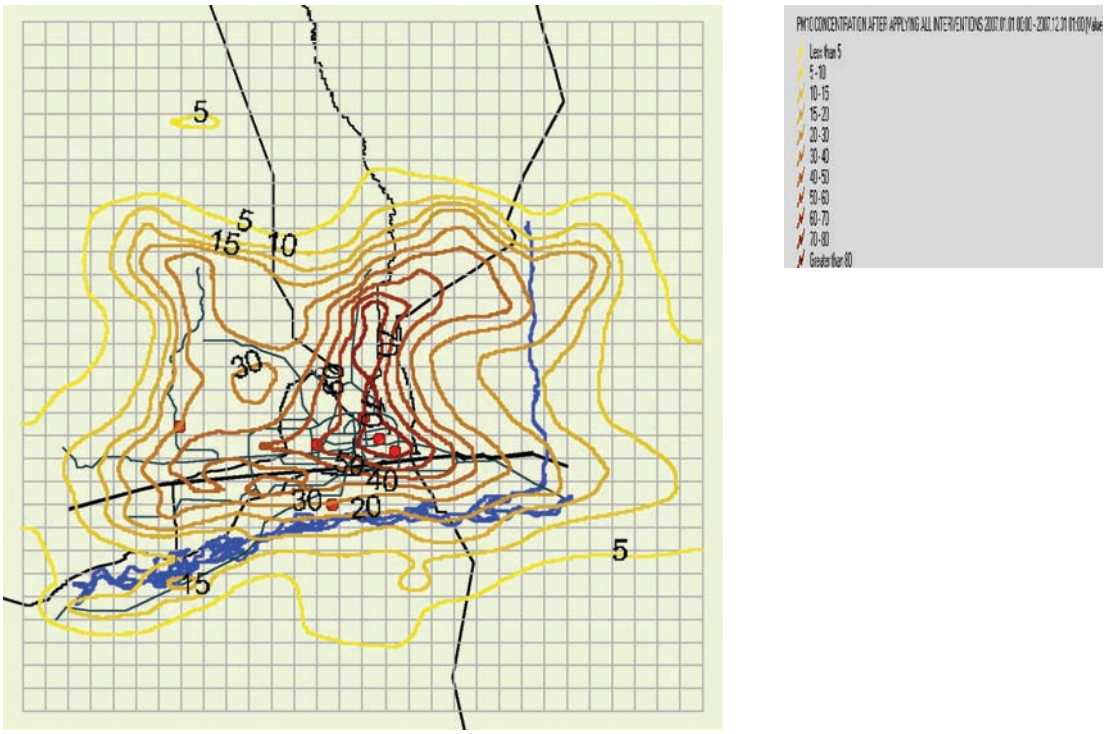


Figure 36: Calculated remaining PM_{10} concentrations in the grid after implementing all three interventions



The reduction in the PWE shows that while Ger interventions give the largest reduction, interventions in HOBs and dust suspension are also more important than their relative shares in average concentration contributions would initially suggest, especially for PM_{10}. This is because the central areas where the HOB and suspension sources have a larger PM contribution, have a larger population density than the ger areas.

Figure 39 should be interpreted carefully, especially when comparing it to average annual concentrations shown in Figure 34 above. It is not correct to compare directly Figure 35 with Mongolian AQ standards or international standards. Portions of the population still remain exposed above the standards even when the weighted average and the standard values are equal.

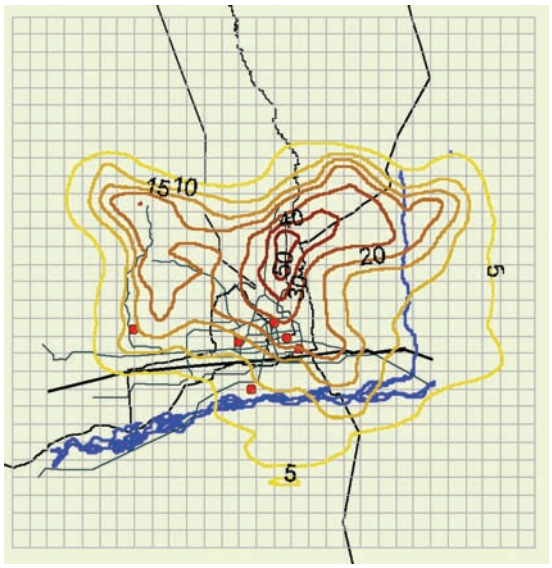
Figure 39 shows the population weighted average concentrations under different emission reduction scenarios. These reductions drive the health cost calculations given in the next section. However, Figure 39 could be used to give an indication of the relative health impacts of different interventions based on the spatial distribution of the population and the spatial distribution of PM and its sources. For example, a 30% reduction in ger emissions would result in a reduction in the population weighted exposure of PM_{10} by 17%, compared to a maximum average concentration reduction of 19% (Figure 34). This, however, does not correspond directly with a reduction in health costs because these also depend on a variety of factors. The 30% example reduction yields a 13% reduction in calculated health costs as shown in the next section.

Avoided premature deaths, cases of chronic bronchitis, and hospital admissions

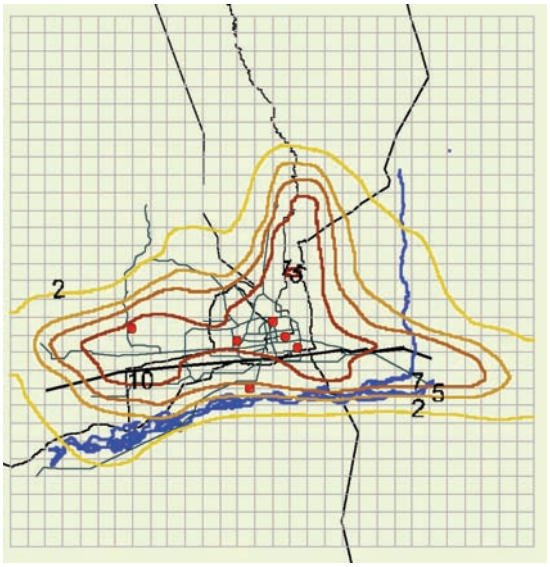
A large number of studies were conducted and are being conducted around the world to document a consistent association between elevated

Figure 37: Calculated reduction in the $PM_{2.5}$ grid resulting from the interventions (µg/m³)

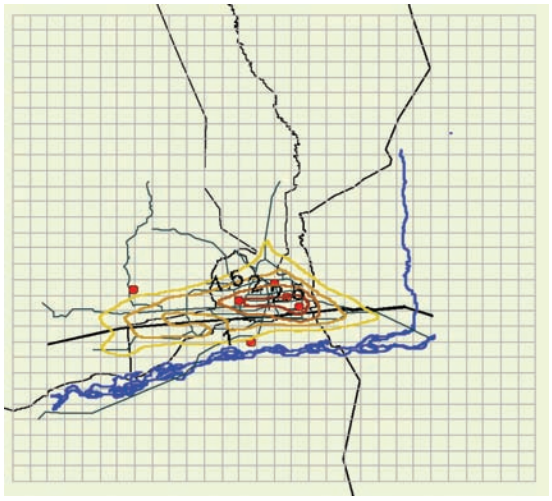
Ger stove emissions: —75%



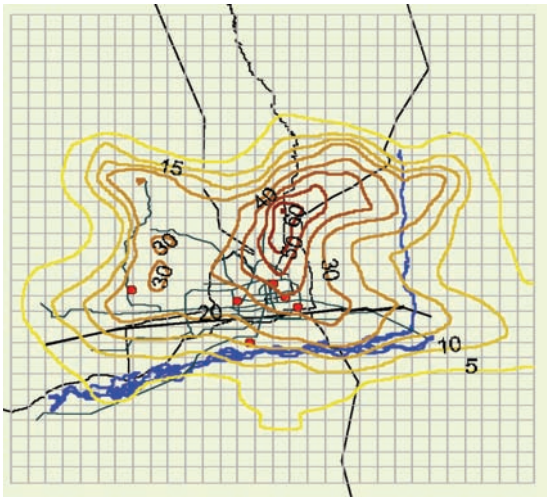
HOB emissions: —85%



Dust suspension from roads: —50%



$PM_{2.5}$ reduction for all 3 interventions

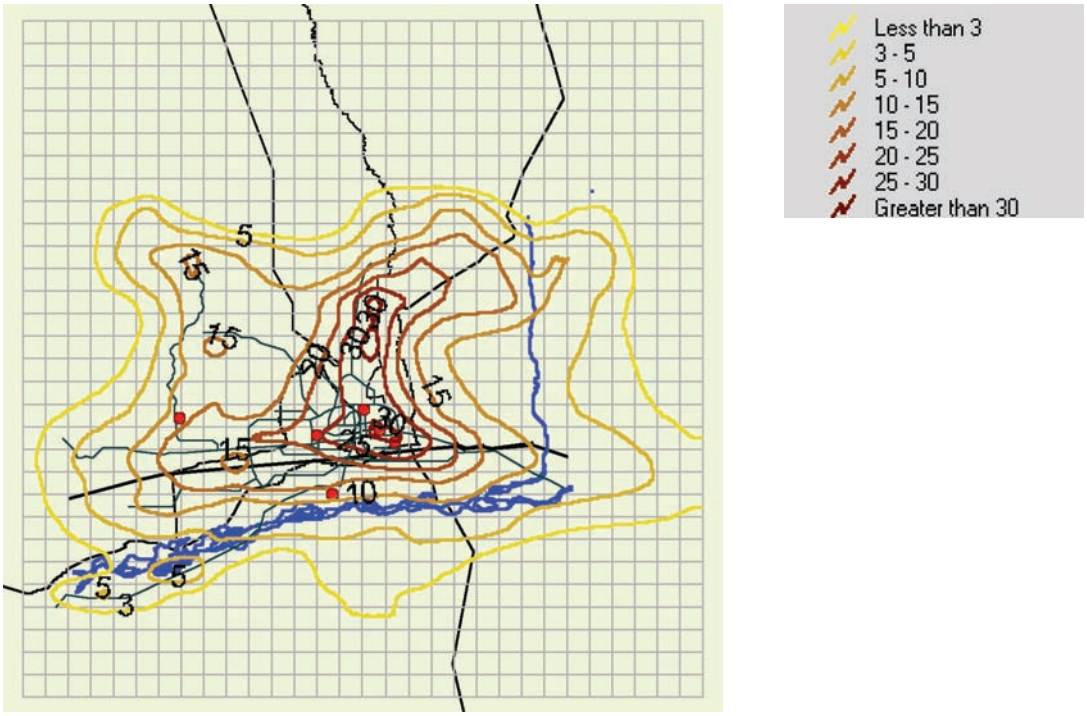


ambient PM_{10} and $PM_{2.5}$ levels to an increase in mortality rates, respiratory infections, number and severity of asthma attacks and the number of hospital admissions.[13] Actual health impacts of air pollution are determined by two factors, i.e., by sufficiently high concentrations of pollutants in the atmosphere and the presence of people in the region affected by these pollution levels. In UB, both are true, especially in the winter season, with high ambient PM concentrations and people in high density areas of Gers being constantly exposed to them.

This analysis applies the exposure-response functions applied in the assessment of costs of air pollution in China by the World Bank (2007) to calculate the number of premature deaths (i.e. deaths brought forward due to air pollution exposure), new cases of chronic bronchitis,

[13] OECD. 2000, 'Ancillary Benefits and Costs of Greenhouse Gas Mitigation', Proceedings of an IPCC co-sponsored workshop, Washington, DC, USA

Figure 38: Calculated remaining $PM_{2.5}$ concentrations in the grid after implementing all three interventions



and hospital admissions for respiratory and cardiovascular diseases, that can be avoided by implementing the interventions described above. Premature deaths and enhanced rates of chronic obstructive lung diseases (of which chronic bronchitis typically is the most prevalent) are two major health impacts associated with long-term exposure to PM pollution. In addition a range of other impacts, e.g., acute respiratory infections and more frequent asthma attacks, are found to be linked to air pollution exposure on a shorter time-scale. The different short-term and long-term symptoms and diseases can lead to school and work absenteeism, emergency room visits and hospitalization, which will have an economic impact on society. Using data for number of hospital admissions for cardiovascular and respiratory diseases in district level secondary hospitals, we include these end-points in the calculation below.

In this Discussion Paper, health impacts are estimated in the following way: First, the corresponding changes in ambient concentrations are estimated to establish a baseline value and then to determine what are considered "excessive" ambient concentrations. The excessive ambient concentrations are in some ways subjective because they determine the level of pollution concentrations that are deemed by society to be unacceptable. Proxies for this excessive level could be WHO or other international guideline values or local standards. WHO guideline values are typically determined by the level of pollution concentrations that are identified in epidemiological studies as 'threshold' levels for observable effects. Thus, they are a metric for the actual physical impacts rather than what may be defined as the target or acceptable level as defined in specific settings. This study uses 20 µg/m³ PM_{10} and 10 µg/m³ $PM_{2.5}$ as threshold levels for the effect (the WHO guideline values). Second, the excessive concentrations are combined with the population at risk of exposure and dose responses—the estimated health impacts of exposure to excessive levels of ambient concentrations of PM. The AMHIB is currently reviewing public health records

Table 13: Population weighted average PM concentrations in Ulaanbaatar, and reductions from abatement scenarios (µg/m³)

	PM_{10}	$PM_{2.5}$
Present situation (2007)	**76.7**	**37.6**
Reductions in population weighted average from interventions:		
30% reduction of Ger stoves	13.1	7.9
50% reduction of Ger stoves	21.8	13.1
80% reduction of Ger stoves	34.9	20.9
30% reduction of HOBs	3.1	1.9
50% reduction of HOBs	5.2	3.1
80% reduction of HOBs	8.3	5.0
30% reduction of power plants[14]	0.1	0.06
50% reduction of power plants	0.17	0.1
80% reduction of power plants	0.27	0.16
30% reduction of suspended dust	3.0	0.2
50% reduction of suspended dust	5.0	0.4
80% reduction of suspended dust	8.0	0.6
30% reduction of all 4 sectors	19.3	10.0
50% reduction of all 4 sectors	32.2	16.7
80% reduction of all 4 sectors	51.4	26.7
30% reduction of Ger stoves and 80% reduction of HOBS	21.4	12.8
80% reduction of Ger stoves and 30% reduction of HOBS	38.0	22.8

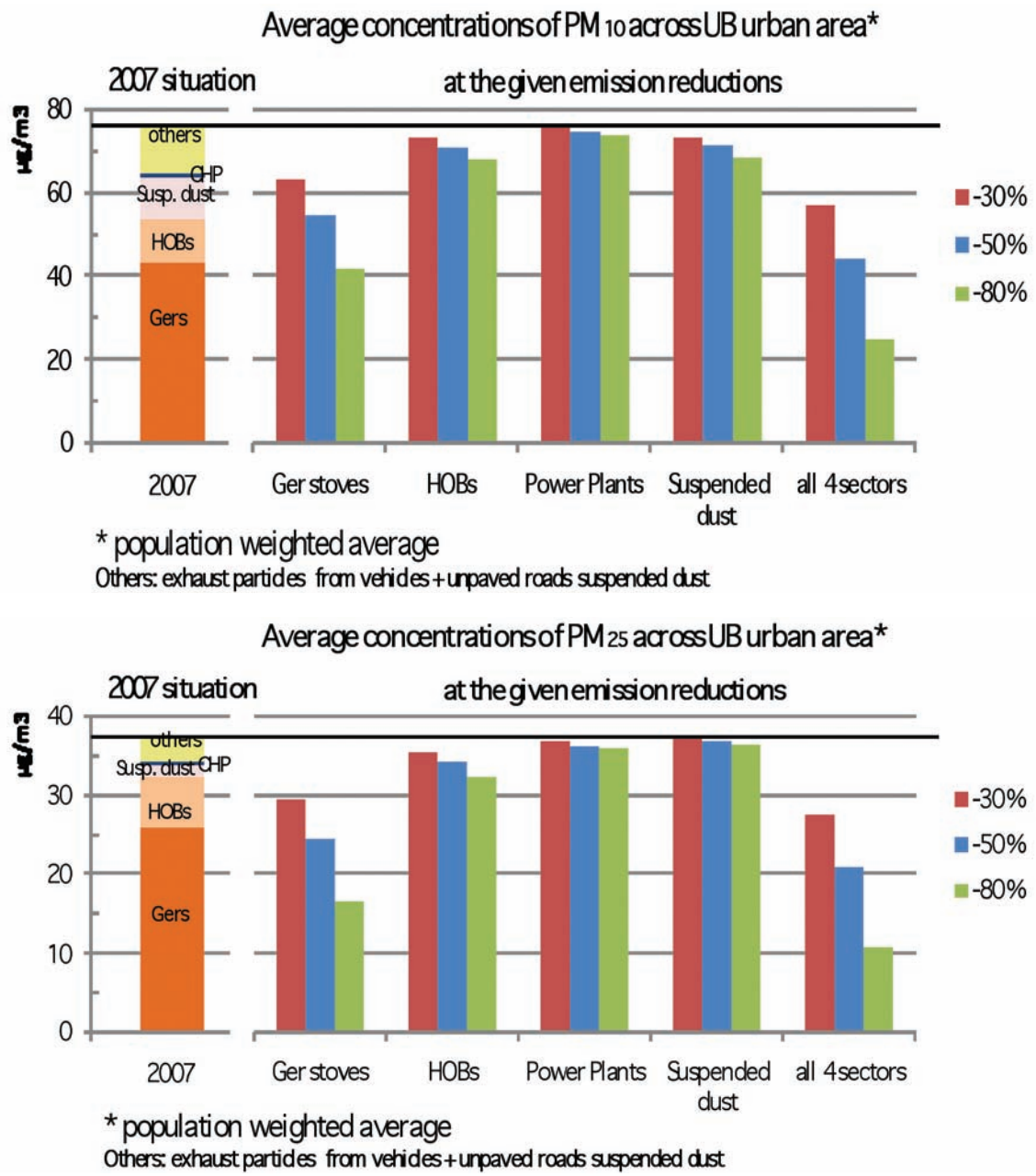
to evaluate correlations between incidences of hospital admittances for various respiratory illnesses and relatively high concentrations of PM—to provide more context to this analysis since epidemiological studies establishing local exposure-responses take years to complete. Third, a quantitative value is calculated on the health impacts using mathematical tools and generally accepted methodologies explained in more detail below. While not perfect, these exercises should help to understand better the orders of magnitude in the trade-offs between various costs of abatement options and their corresponding benefits.

The analysis presented in this Discussion Paper is restricted to the three major so-called "health end points"—premature deaths, chronic bronchitis and hospital admissions. Based on exposure-response functions[15] from the literature,

[14] Regarding the contributions from the CHPs, the analysis here is based upon the low emission estimate based upon well functioning PM cleaning equipment. The higher emission estimate based upon the JICA testing will increase the calculated reductions in PWE resulting from percentage reductions in CHP emissions, by about a factor of 3. This should be taken into account in the consideration of the results below. The CHP contribution is of importance, although the mentioned correction will not change substantially the overall conclusions, since the CHP contribution is still limited.

[15] Exposure-response functions measure the relationship between exposure to pollution as a cause and specific outcomes as an effect. They refer to damages/production losses incurred in a year, regardless of when the pollution occurs, per unit change in pollution levels. In this table, the function is defined as the percentage change in effects incurred per unit change in concentrations (µg/m³) per capita.

Figure 39: Population weighted PM_{10} (top figure) and $PM_{2.5}$ (bottom figure) reductions resulting from the 30%/50%/80% scenarios



health impacts are derived using the equation below.

$$E = ((RR - 1)/\ RR) * f_p * POP$$

where E is the number of cases of each health end point attributed to air pollution ('excess cases'), RR is the relative risk of health effect between two levels of pollution (here the current level and a lower level obtained from an intervention or the lower threshold level), f_p is the current incidence rate of the health effect, and POP is the exposed population considered (for hospital admissions we replace $f_p * POP$ with the annual number of

hospital admissions (see below)). Except for the mortality function, where we rely on WB (2007) (except we use 20 μg/m³ as a threshold level instead of 15), *RR* is given by:

$$RR = \exp(\beta*(C - C_t))$$

where β is the exposure-response coefficient (see Table 12 where betas are given as percentage values), C is the current pollution level and C_t is the target pollution level obtained from an intervention or from reaching the threshold value. We calculate the remaining number of cases attributable to air pollution after each intervention, and derive the number of cases that can be avoided by subtracting these figures from the calculated excess cases in the current situation (which is calculated by using the threshold levels described above). To determine costs of air pollution, this Paper uses a willingness-to-pay methodology (see, e.g., WB, 2007) to monetize health impacts and estimate the economic value of avoided health damage.

Due to the considerable attention these preliminary calculations may have when disseminated, it is necessary to provide some background in academic literature to disclose key assumptions so that others could use this work and improve it.

An important reason for limiting the number of health end points is the lack of background data in UB when it comes to prevalence rates for different diseases, hospitalization rates, etc. Nevertheless, assumptions are made in this Discussion Paper about the prevalence of chronic bronchitis in UB. According to Lopez et al. (2006) the prevalence rate in China and Mongolia is around 3% in adults above 30 years of age, with large uncertainties in the estimate. In WB (2007) a prevalence rate of 3.4% and a corresponding annual incidence rate (new cases per year) of 0.15% were used. This incidence rate was assumed in this Discussion Paper. As mentioned above, we used data for the number of hospital admissions for cardiovascular and respiratory diseases in district level secondary hospitals in UB in the calculation below. As the data were for 6 months (1 June 2008 till 15 December 2008), we multiplied with 2 to obtain an estimate of the annual number. Note that the hospital admissions estimates most likely represent only a fraction of the entire effect related to this end point since only district level secondary hospitals are included.

Since no long-term epidemiological cohort studies on mortality rates and air pollution have been carried out in Asia, the well-known, large study in the USA by Pope et al. (2002) is used by the WB (2007) to establish an exposure-response function. A direct application of the exposure-response function in Pope et al. may lead to implausibly high damage estimates in polluted regions in Asia, and the US results were therefore calibrated towards the few cross-sectional studies on mortality rates that were available for high pollution cities in China (see WB (2007) for details). The result is an exposure-response function that flattens towards higher PM_{10} levels. However, there are particularly large uncertainties related to this adjustment. New findings from short-term studies in Asia find that the pattern of the exposure-response functions appears linear over a fairly large range of ambient concentrations up to and sometimes exceeding 100 μg/m³. In addition to the estimated premature deaths resulting from the adjusted exposure-response function in WB (2007), this Discussion Paper provides an estimate of the health effect using the original (linear) exposure-response function from Pope et al. (2002). This indicates to some extent the sensitivity to the final results of the choice of function for the mortality impact. We use a cut-off of 20 μg/m³ PM_{10} when estimating mortality impacts (10 μg/m³ for $PM_{2.5}$ in the sensitivity test based on the approximate $PM_{2.5}/PM_{10}$ ratio) (see above).

The exposure-response functions for chronic bronchitis, hospital admissions for respiratory diseases, and hospital admissions for cardiovascular diseases (CVD) applied in WB (2007) are based on a meta-analysis of several Chinese studies (Aunan and Pan, 2004).

As done in previous applied studies (e.g. Mestl et al, 2004; Kan et al, 2004), the Discussion Paper uses as mentioned the PWE estimates for the whole region (i.e. the concentration times population in each grid averaged for the

Table 14: Exposure-response coefficients (% change in incidence of health effect per µg/m³ PM_{10}), baseline incidence rates, willingness-to-pay (WTP) for avoiding premature death (long-term effect) and chronic bronchitis, and Cost of Illness (COI) of hospital admissions

Health end point	Exp-resp coefficient (PM metric)	Baseline incidence rate	(USD per case)
Premature death (WB method)	See WB (2007)	0.0067	200,133 (WTP)
Premature death (Pope et al. (2002)	0.6 ($PM_{2.5}$)	0.0067	200,133 (WTP)
Chronic bronchitis	0.48 (PM_{10})	0.0148	64,042 (WTP)
Respiratory hospital admissions	0.12 (PM_{10})	See text	800 (COI)
CVD hospital admissions	0.07 (PM_{10})	See text	1300 (COI)

total population in all grids) as input to the health benefit analysis. Given that the exposure-response function for mortality (taken from WB, 2007) method) is non-linear, this Discussion Paper's results probably deviate slightly from the results that would have been obtained using geographically disaggregated PWE values. This uncertainty, however, is regarded by the team to be minor compared to other uncertainties in the analysis.

Monetized health benefits

This Discussion Paper relies also on WB (2007) to derive the unit costs of a premature death, new cases of chronic bronchitis, and hospitalization. Based on willingness-to-pay studies in China (WB, 2007) which derives a Value of Statistical Life (VSL) of 1.4 million Yuan, i.e. the value placed on avoiding premature death. We use the ratio between this value and the GDP/cap in China combined with the GDP/cap of Mongolia in 2007 to calculate the corresponding VSL for Mongolia.[16] In addition to this direct conversion, we in a sensitivity estimate assume an income elasticity of WTP of 0.5.[17] The VSL/GDP per capita ratio is 133 for China (2003 figures), while the nominal GDP/cap in Mongolia in 2007 was 1507 USD (WB database). This yields an estimated VSL of about 200,100 USD for Mongolia. As in WB (2007) we multiply this value with 0.32[18] to obtain an estimate of the WTP for avoiding a new case of chronic bronchitis (see Table 14). To obtain an estimate of the Cost of Illness related to hospitalization, we adjust the estimates from China (WB, 2007) in the same way as was done for VSL.

Table 15 shows the estimated number of cases attributable to PM pollution in the current situation and the number of cases that can be avoided from implementing the interventions described above. The current health damage corresponds to 8.0% of the GDP in UB[19] and 3.8% of GDP in Mongolia. In the sensitivity calculation using the linear exposure-response function from Pope et al (2002) directly, current damage corresponds to 12.2% of GDP in UB and 5.7% of GDP in Mongolia. The maximum achievable benefit (80% reduction in all 4 sectors) corresponds to 6.6% of GDP in UB in 2007 (3.1% of GDP in Mongolia). In the sensitivity

16 I.e. VSL (Mongolia) = [VSL(China)/GDP per cap (China)]*GDP per cap (Mongolia).

17 A range of studies indicate the income elasticity of WTO is below unit (see e.g. Pearce et al (eds), 2002. Valuing the environment in developing countries. Case studies. Edward Elgar Publishing. 567 pp.)

18 This factor is derived from a study indicating that people's choices imply that the utility of living with chronic bronchitis is about 0.68 of the utility of living in good health (Viscusi, W.K., W. Magat, and J. Huber. 1991. "Pricing environmental health risks: A survey assessment of risk-risk and risk-dollar tradeoffs for chronic bronchitis." Journal of Environmental Economics and Management 21:32–51.)

19 GDP in UB and Mongolia was 2.16 billion and 3.9 billion, respectively, in current USD (WB database, for 2007, available: http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/0,,menuPK:476823~pagePK:64165236~piPK:64165141~theSitePK:469372,00.html).

calculation this figure gets 11.6% of GDP in UB (5.4% of GDP in Mongolia). In the sensitivity calculation where we assume an income elasticity of WTP of 0.5, current damage corresponds to 4.1% of GDP in UB and 1.9 % of GDP in Mongolia. The maximum achievable benefit (80% reduction in all 4 sectors) corresponds to 3.3% of GDP in UB in 2007 (1.6% of GDP in Mongolia).

Table 15: Estimated current health damage due to PM pollution in Ulaanbaatar (base case), number of cases avoided due to interventions, and monetized current cost and benefit from interventions (in million USD)

	Annual number of cases				Monetized (million USD)					Share of GDP in Ulaanbaatar (2007)
	All-cause mortality (chronic)	Chronic bronchitis	Hospital admissions (respiratory disease)	Hospital admissions (CVD)	All-cause mortality (chronic)	Chronic bronchitis	Hospital admissions (respiratory disease)	Hospital admissions (CVD)	SUM	
2007 (current health damage)	614	379	735	448	123	24	0.59	0.58	148	8.0 %
30% reduction of Ger stoves	83	71	165	102	17	5	0.13	0.13	21	1.2 %
50% reduction of Ger stoves	149	121	277	170	30	8	0.22	0.22	38	2.1 %
80% reduction of Ger stoves	273	201	446	274	55	13	0.36	0.35	68	3.7 %
30% reduction of HOBs	18	16	39	24	4	1	0.03	0.03	5	0.3 %
50% reduction of HOBs	31	28	65	40	6	2	0.05	0.05	8	0.4 %
80% reduction of HOBs	51	45	104	65	10	3	0.08	0.08	13	0.7 %
30% reduction of power plants	1	1	1	1	0	0	0.00	0.00	0	0.0 %
50% reduction of power plants	1	1	2	1	0	0	0.00	0.00	0	0.0 %

Continued

Table 15: Continued

	Annual number of cases				Monetized (million USD)					Share of GDP in Ulaanbaatar (2007)
	All-cause mortality (chronic)	Chronic bronchitis	Hospital admissions (respiratory disease)	Hospital admissions (CVD)	All-cause mortality (chronic)	Chronic bronchitis	Hospital admissions (respiratory disease)	Hospital admissions (CVD)	SUM	
80% reduction of power plants	2	1	3	2	0	0	0.00	0.00	0	0.0 %
30% reduction of suspended dust	18	16	38	23	4	1	0.03	0.03	5	0.3 %
50% reduction of suspended dust	30	27	63	39	6	2	0.05	0.05	8	0.4 %
80% reduction of suspended dust	49	43	101	62	10	3	0.08	0.08	13	0.7 %
30% reduction of all 4 sectors	129	107	245	151	26	7	0.20	0.19	33	1.8 %
50% reduction of all 4 sectors	244	184	411	252	49	12	0.33	0.33	61	3.3 %
80% reduction of all 4 sectors	504	308	664	406	101	20	0.53	0.52	122	6.6 %
30% reduction of Ger stoves, and 80% reduction of HOBS	146	119	271	167	29	8	0.22	0.22	37	2.0 %
80% reduction of Ger stoves, and 30% reduction of HOBS	308	220	487	299	62	14	0.39	0.38	76	4.1 %

Conclusions

This Discussion Paper lays out a systematic approach that the AMHIB project will follow through to its conclusion in early Fall 2010. The World Bank and its AMHIB partners invite comments on this approach and analysis so that it can be as helpful as possible to action planning.

There is a need to set socially acceptable, technically feasible emission reduction targets to give a clear direction for action plans. Targets will be determined by technical options and the ability and willingness to pay for pollution reduction by civil society. The costs of air pollution are paid from the pocketbook, the budget and future health costs through higher incidences of pollution related illnesses. What and how to pay for air pollution is a choice to be made by civil society and its representatives. Due to the complex nature of air pollution, an open discussion of options and their estimated impacts based on an analytical framework using best available data is recommended. Cost effectiveness analysis (cost per unit emission reduced) and estimating avoided health costs of each policy option can, together with other factors considered important to UB's citizens, be considered in choosing clean air strategies. Setting targets that have been openly discussed helps build widespread support for pollution abatement activities that involve asking people to change environmentally damaging behaviors. Many in civil society, especially the poorest in UB, will be asked to change their behavior in some way to improve air quality. They should become active allies in the reduction of air pollution in UB.

When faced with choices between proposed abatement measures, policymakers should use a basis for selection. At the core of a local air pollution abatement program is its ability to reduce pollution and the harmful effects it has on the population. The selection criteria could be a) the degree to which the abatement measure, or package of measures, moves toward meeting Mongolian or International AQS across all of UB; b) the cost of abatement measures per unit of emission reduced; and/or c) the net benefits of abatement measures, or package of measures.

Due to the spatial distribution of the population and UB's pollution, short term strategies could achieve improvements in a significant share of the city even though all parts of the city might not meet air quality standards evenly.

Additionally, the high peaks in daily air pollution observed coincide with observed emission peaks from the ignition and reloading phases of the burn cycle in heating. Because these peaks comprise a significant share of PM average concentrations in wintertime, focusing on the ignition and reloading phase of the burn cycle in abatement design may be a good strategy. Additional testing is needed to confirm this indication.

Data quality needs improvement and this is reflected in the uncertainty in the modelling of this Discussion Paper, which will be improved in the Final Report, due in early 2010. This assessment of the air quality situation in UB

and of the effects of some selected abatement measures have been based upon a wide range of existing data, reports and information, as described in this Discussion Paper. The assessment followed the basic concept for doing air quality management work. This includes looking at monitoring data for air pollutants and meteorology, emissions inventorying, dispersion modelling and calculating pollutant concentrations and their distribution spatially and temporally, and the contributions from the various main source categories. Such calculations are done for the current situation (for which the year 2007 was used, the latest year with an extensive data base) as well as for the situation assuming some selected abatement measures are implemented. Calculations were also made of the reduction in population weighted exposure to PM for a number of abatement scenarios, and the corresponding benefits in terms of reduced health costs. There are shortcomings in the needed input data for this kind of assessment. The main shortcomings are related, critically, to air pollution monitoring data and emissions data. Therefore, while this assessment can be considered complete, this Discussion Paper provides what should be considered only preliminary estimates.

Given what is known, and based upon available data, the following preliminary conclusions can be drawn:

- UB is definitely one of the most polluted cities, and it might be THE most polluted city, in the world in terms of annual Particulate Matter concentrations and its severity is driven by arguably extreme wintertime PM concentrations.
- The needed effort to reduce air pollution is considerable. An 80% emissions reduction across all four main sources of air pollution could come close to reaching the Mongolian Air Quality Standards in most of the UB city area, which are equivalent to the middle interim targets set for developing countries by the WHO. To achieve WHO global guideline values, the emissions reductions would need to be over 80%.
- There is no magic bullet, no one solution that can reach Mongolian Air Quality Standards. A combination of measures is recommended.
- The cost of health damage attributable to current levels of air pollution in terms of particulate matter is estimated to be 8.0% of UB's GDP in 2007, or US$ 148 million (preliminary estimate). This is 3.8% of Mongolia's GDP. Using sensitivity analysis, this estimate could fall to 4.1% of UB's GDP or US$ 76 million, or about 1.9% of national GDP.
- The maximum achievable benefit from the described interventions (80% reduction in all 4 sectors) is estimated to be 6.6% of GDP in UB in 2007, or 122 million US$ (preliminary estimate). This is 3.1 % of Mongolia's GDP.

It is recommended that policy makers set targets such as the following and open a discussion with civil society on the costs and benefits. These targets can be adjusted as better data are obtained:

- set targets that would reach Mongolian Air Quality Standards as soon as possible and $PM_{2.5}$ targets by 2020.
- to achieve these targets, reductions of the emissions from the ger heating systems and the HOBs as well as dust suspension reduction from roads and near-road surfaces are all needed.
- recognizing socio-economic constraints in UB, it is further recommended that interim targets are set of a reduction in emissions of 50% across all four sectors resulting in $PM_{2.5}$ below 60 μg/m^3 and PM_{10} 120 μg/m^3 which would visibly improve smoke in UB. Currently calculated health costs (2007) of US$ 49 million equivalent would be saved.
- target the ger areas immediately, where pollution reduction benefits are greatest.
- target boilers also as they have a relatively larger impact on the population due to their distribution among population centers.
- install continuous emission monitoring systems in the power plants to ensure better operation of the flue gas cleaning systems.
- begin an open and candid discussion of actual costs and benefits of abatement measures by (i) ensuring the abatement measures are *technically feasible and their emissions reduction benefits are justified with sufficient evidence* (ii) appraising the full costs of abatement

measures so they can be compared to the health cost reductions and their contribution to overall improvements in ambient PM concentration reductions.
- Strengthen air quality monitoring and emissions inventories by providing sufficient operating budgets to key Mongolian air quality institutions.

The following is a summary of next steps in the AMHIB study based on the basic steps in the Air Quality Management (AQM) process introduced in this paper. The following list points to important points where an improved data base is needed. The AMHIB will attempt to address these either directly through its study or through recommendations that others can help address.

- Air Quality Assessment
  - Air pollution monitoring: monitoring with the use of state-of-the-art monitors at more stations in UB is needed. This monitoring should include at least $PM_{2.5}$ and PM_{10}, SO_2, NO_X and NO_2. This activity is already underway in UB, but data from this increased monitoring activity is only partially available. The AMHIB will set a baseline value for PM in 2008–2009 by the end of the study, but it is very important to establish a long-term program for training of monitoring network operators and a data quality control program to continually improve measurements and monitoring results.
  - Inventory of emissions: the existing emissions inventory needs to be improved. Main points needing improvement include: emission factors (EF) for the various sources; amount of fuel burned per source category; traffic data on main roads, study of the soil suspension source. There are programs and studies ongoing that are expected to improve EFs that will be used, if available, in AMHIB's final report.
  - Population: improved data for the spatial distribution of the population is needed.
- Environmental Damage Assessment
  - Improvements in air quality and health data will drive improved assessments
  - Studies of the health status of the population should continue. The final AMHIB report shall share results of its preliminary survey of air pollution related health issues.
  - Indications of the improved health status following abatement implementation should be studied.
- Abatement Options Assessment
  - Several technical assessments have been done over 2 years but remain largely at a proof of concept stage. Large scale demonstration projects need to be rolled out immediately to test proposed concepts especially in ger areas where success of abatement measures depends not only on technical effectiveness but also on socio-economic and strong cultural considerations. It is important to systematically move from demonstration projects to scale up as quickly as possible but only when concepts show promising impacts.
  - Some measures can be implemented over 1–2 years while others may take several years to implement.
- Cost Benefit Analysis or Cost Effectiveness Analysis
  - Cost-benefit analyses linking measures with results should continue. The AMHIB will continue to work with Mongolian counterparts to build capacity in this field.
- Abatement Measures Selection
  - The AMHIB and complementary activities by the World Bank and others should help to provide needed information to the government to develop and select abatement measures.
- Optimum Control Strategy
  - Set timetables and secure financing.
  - Establish a monitoring and evaluation system that continually reports on air quality improvements and assesses impacts of abatement measures.
  - Indications of improved health status following abatement implementation should be studied.

References

AirQUIS 2008: http://www.nilu.no/airquis/

Anfossi, D., D. Oettl, G. A. Degrazia, and A. Goulart (2005). An analysis of sonic anemometer observations in low wind speed conditions. Bound.-Layer Meteor., 114, 179–203.

Aunan, K. and Pan, X.-C. (2004). Exposure-response functions for health effects of ambient air pollution applicable for China—a meta-analysis. *Science of the Total Environment* 329 (1–3): 3–16.

Burmaa, B., Enkhtsetseg, Sh. (1996). Results of the study on correlation between morbidity among population and the children of Ulaanbaatar and air pollution, Healthy city-wonderful life, Ulaanbaatar, Mongolia MOH. 2004. *Health sector 2003,* Ulaanbaatar, Mongolia.

Burmaa, B. (2001). Child health with correlation of ecological factors of Mongolia, diagnostics and prevention, PhD thesis, Irkitsk, Russia.

Chow, J., Watson, J. G., Egami, R. T., Frazier, C. A. and Lu, Z. (1990). Evaluation of regenerative-air vacuum street sweeping on geological contributions to PM10. *J. Air Waste Manage. Assoc., 40,* 1134–1142.

Cowlin, S. C., Kaufmann, R. B., Edwards, R., Smith, K. R. (2005). Impact of Improved Stoves on Indoor Air Quality in Ulaanbaatar, Mongolia. ESMAP report 313/05. www .esmap.org (accessed May 20, 2009).

Enkhjargal, G., et al. (2004–2005). Indoor air quality assessment, Ulaanbaatar, Mongolia.

Enkhjargal, A. (2006). "Health impact assessment of ambient air pollution in two cities in Mongolia." Medical Faculty University Kebangsaan Malaysia, Research thesis in fulfilment for the degree of Masters of science, Kuala Lumpur Malaysia.

Enkhtsteteg, Sh. (2000). Hygienic assessment of influence of atmosphere air to indicators of immune factors of children who are living in living ecological condition of in Mongolia, PhD thesis, Irkitsk, Russia.

Guttikunda, S. (2007). Urban air pollution analysis for Ulaanbaatar. Consultant draft Report to World Bank.

Hurley, P. J., W. L. Physick, and A. K. Luhar (2005). TAPM: A practical approach to prognostic meteorological and air pollution modelling. Environ. Modelling and Software, 20, 737–752.

Haakonsen, G. and Kvingedal, E. (2001). Emissions to air from fuelwood use in Norway. Oslo, Statistics Norway (Reports 2001/36) (In Norwegian).

Jamal, H. H., Pillay M. S., Zaliha H., et al. (2004). *A study of Health Impact and Risk Assessment of Urban Air Pollution in the Klang Valley, Malaysia*, A Research Project Report, UKM.

Jaszczur, T., Lewandowski, M., Szewczyk, W., Zaczkowski, A., Butcher, T. (1994). Performance of Polish home stoves. U.S. Department of Energy Report (BNL–60367).

Kan, H., Chen, B., Chen, C., Fu, Q., Chen, M. An evaluation of public health impact of ambient air pollution under various energy scenarios in Shanghai, China. Atmospheric Environment 38:95–102.

Keil, C. (2005). *Air Quality* (online), http://www .cdc.gov/nceh/ehs/Docs/NALBOH%20Web/ NALBOH-2.pdf (15 March 2005).

Kukkonen, J., M. Pohjla, R. S. Sokhi, L. Luhana, N. Kitwiroon, and et al. (2005). Analysis and evaluation of selected local-scale PM_{10} air pollution episodes in four European cities: Helsinki, London, Milan and Oslo., Atmos. Environ., 39, 2759–2773.

Lodoysamba, S., Shagjjamba, D., Gerelmaa, G. (2008). Characterization of $PM_{2.5-0}$ and $PM_{10-2.5}$ air pollution of Ulaanbaatar city. Presented at the CAI-Asia Better Air Quality Conference, Bangkok, 12–14 November, 2008.

Lopez, A. D., Shibuya, K., Rao, C., Mathers, C. D., Hansell, A. L., Held, L. S., Schmid, V. and Buist, S. (2006). Chronic obstructive pulmonary disease: current burden and future projections. European Respiratory Journal 27: 397–412 DOI: 10.1183/09031936.06.00025805.

Mestl, H. E. S., Aunan, K., Fang, J., Seip, H. M., Skjelvik, J. M., Vennemo, H. (2004). Cleaner production as climate investment—Integrated assessment in Taiyuan City, China. Journal of Cleaner Production 13, 57–70.

Mestl, H. E. S., Aunan, K., and Seip, H. M. (2007). Health benefits from reducing indoor air pollution from household solid fuel use in China—three abatement scenarios. Environment International, 33, 831–840.

Ministry of Health, MOH, Health Sector Strategic Master Plan Initiative. 2004. Synthesis papers. Second revised reprint. Ulaanbaatar, Mongolia.

Pope, C. A. III, Burnett, R. T., Thun, M. J., Calle, E. E., Krewski, D., Ito, K., Thurston, G. D. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *J Am Med Assoc* 2002;287(9):1132–1141.

PREGA (2006). Energy efficiency study of thermal power plant #4 Ulaanbataar, Mongolia. A technical study report. Draft final report. Promotion of Renewable Energy, Energy Efficiency and Greenhouse Gas Abatement (PREGA) Report to the Asian Development Bank.

Saijaa, N., et al. (2004). Adverse health effect of air pollution, Ulaanbaatar.

Slørdal, L. H., Walker, S. E., Solberg, S. (2003). The urban air dispersion model EPISODE applied in AirQUIS2003. Technical description. Norwegian Institute for Air Research, Kjeller (NILU TR 12/03).

Slørdal, L. H., McInnes, H., Krognes, T. (2008). The Air Quality Information System AirQUIS. Information Technologies in Environmental Engineering 1, 40–47.

Smith, K. R., Mehta, S. and Maeusezahl-Feuz, M. (2005). Indoor Air Pollution from Household Use of Solid Fuels. Environmental and occupational risk factors, chapter 18, World Health Organization: 1435–1493. http://www.who.int/publications/cra/chapters/volume2/part2/en/index.html.

Spengler, J. (2005). Air pollution sources and human health effects, lecture, (online) http://courses.dce.harvard.edu/~environment/AP_Sources_Health_Effects_12_01_2004/sld001.htm (7 April 2005).

Spickett, J., Baker, A., Burma, B., Enkhtsetseg, Sh., et al. (2002). "Preliminary Health Risk Assessment of Environmental Pollution in Ulaanbaatar City, Mongolia." World Health Organization, Ministry of Health, and Public Health Institute, Ulaanbaatar.

Stansfield, S., Shepard, D. (1993). ACUTE RESPIRATORY INFECTION, Jameson, D., Mosley, W., Measham, A., Bobadilla, J. (eds.) *Disease control priorities in developing countries*, pp 67–90, Oxford.

Sunyer, J., Castellsague, J., Saez, M., et al. (1996). Air pollution and mortality in Barcelona. *J Epidemiol Community Health*. 50 Suppl 1:s76–80.

Tseregmaa, Ts. (2003). Study of respiratory system morbidity of elders living in Ulaanbaatar city in connection with some influencing factors. Ulaanbaatar, Mongolia, National University of Medical Science.

U.S. EPA (1995). Compilation of air pollutant emission factors. AP-42, Fifth edition. Research Triangle Park, U.S. Environmental Protection Agency.

U.S. EPA (1998). Residential wood combustion technology review. Volume 2. Appendices. Research Triangle Park, U.S. Environmental Protection Agency (EPA-600/R-98-174b).

World Bank (2007). Cost of Pollution in China. World Bank: Washington, DC. http://siteresources.worldbank.org/

INTEAPREGTOPENVIRONMENT/Resources/China_Cost_of_Pollution.pdf (conference version).(accessed May 20, 2009).

World Bank (2008a). Mongolia energy efficient and cleaner heating in poor, peri-urban areas of Ulaanbaatar. Summary report on activities. Asia Sustainable and Alternative Energy Program (ASTAE).

World Bank (2008b). Small boiler improvement in Ulaan Bataar consultant report. Part of the UB Clean Air Program mission Clean air action plan for Ulaan Bataar Mongolia. World Bank Consultant Mission Report.

World Bank (2009). Mongolia—Enhancing Policies and Practices for Ger Area Development in Ulaanbaatar. Urban Development Sector Unit, East Asia and Pacific Region.

WHO (2002). *Health impact assessment of air pollution in the eight major Italian cities*. World Health Organization Regional Office for Europe, Martuzzi, M., Galassi, C. 2002. (online) http://www.euro.who.int/document/E75492.pdf. (12 March 2005).

Appendix A: Air Quality Standards and Guidelines for PM and SO_2

Air quality standards, limit values and guidelines for PM and SO_2

Particulate Matter—PM

The tables below summarize Mongolian air quality standards (AQS) as well as WHO guidelines, USEPA standards and EU limit values (LV) for PM_{10} and $PM_{2.5}$ and international standards for SO_2[20].

WHO Guidelines are the lowest. They represent the levels where effects are very small, and should be considered as goals for the future. WHO has established Interim Targets (IT-1-3), realising that in many developing countries, the WHO guideline cannot be met in the short term.

Table A1: Various guidelines, standards and limit values for $PM_{2.5}$ and PM_{10}

Guidelines, standards, limit values (all numbers in µg/m³)				
	$PM_{2.5}$		PM_{10}	
	Annual average	24 hour average (daily)	Annual average	24 hour average (daily)
Mongolian Standards, 2007	25	50	50	100
WHO Guidelines, 2005	10	25	20	50
WHO Interim Targets (IT)				
IT-1	35	75	70	150
IT-2	25	50	50	100
IT-3	15	37.5	30	75
USEPA AQS, 2006	15	35 [1]	—	150
EU LV	25[3] 20[4]	—	40	50[2]

[1] 7 days above 35 per year is allowed (98th percentile)
[2] 35 days above 50 per year is allowed (90th percentile)
[3] To be met by 2010
[4] To be met by 2020

[20] World health organization: Air Quality Guidelines for particulate matter, ozone, nitrogen oxides and sulphur dioxide. Global update 2005. Summary of risk assessment. http://www.epa.gov/air/criteria.html http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0447:FIN:EN:PDF

Table A2: Basis for WHO Air Quality Guidelines (AQG) and Interim Targets

Basis for WHO Air Quality Guidelines (AQG) and Interim Targets	Basis for selected level
Interim Target – 1 (IT-1)	These levels are associated with about 15% higher long-term mortality risk relative to the AQG level
IT-2	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% (2–11%) relative to the IT-1 level
IT-3	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% (2–11%) relative to the IT-2 level.
Air Quality Guideline	These are the lowest levels at which total, cardiopulmonary, and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to $PM_{2.5}$.

Source: WHO, Krzyanowski, *Update of WHO Air Quality Guidelines,* February 22, 2008.

Table A3: Various SO_2 guidelines, standards and limit values, SO_2 guidelines, standards, limit values (all numbers in µg/m³)

	Annual average	24 hour average (daily)	10 minute average
WHO Guidelines, 2005	—	20	500
WHO Interim Targets (IT)			
IT-1		125	—
IT-2		50	—
USEPA AQS, 2006	78	365	—
EU LV	—	125	—

USEPA standards and EU limit values differ. The EU LV is stricter than the US AQS for PM_{10}, while it is more lax for $PM_{2.5}$.

They represent to some extent what is politically and technically feasible to meet presently.

Appendix B: Criteria and Suggestions for an Improved Monitoring Network for Air Pollution in UB

Criteria and suggestions for an improved monitoring network for air pollution in UB

The following criteria can be listed as a basis for designing an improved air quality monitoring network for UB:

1. The long term monitoring network in UB should be based upon the automatic monitors, as presently installed in some NAMHEM/CLEM stations as well as in new stations provided by donors.
2. In addition, the two Gent filter sampler equipments of NUM should be part of the network, for PM_{10} measurements, not for $PM_{2.5}$.
3. The locations of the AMHIB project (Locations 1–8) will be operated until mid 2009, and those locations are considered fixed.
4. In order to establish a link between the baseline monitoring done at the AMHIB network until mid 2009 and the continuing, long-term monitoring with the new NAMHEM/CLEM and donor equipment, such new equipment should be co-located at some of the stations used for the AMHIB study (the "AMHIB stations").
   It is suggested to locate this new automatic equipment at at least 2–3 of the AMHIB stations no. 1, 3, 4, 6 and 7. (AMHIB station no. 5, which is same as CLEM station UB-1, will already be equipped with automatic monitors).
5. 1–2 stations should be established within the most polluted area in UB.
6. 2–3 stations should be located in the vicinity of streets in residential/city centre areas.
7. 1–2 unpaved roads should also be covered, within the ger areas.
8. Pollutants:
   As the main source of air pollution in UB is coal combustion, SO_2 and PM are the most important pollutants to cover extensively. $PM_{2.5}$ and PM_{10} should be covered at all or most stations.
   The car exhaust source should be covered by measuring NO_X and NO_2 at traffic related stations and at 1–2 urban stations. CO could be measured at the traffic stations. Benzene should be measured at 1–2 traffic stations. Ozone is most probably not an important pollutant in UB, being a relatively small city for away from other urbanised areas. It could be measured at one urban station.
9. Topography considerations:
   UB is located in a wide valley, with hills to the North and South of the valley, and heights up to several hundred meters. Winds are predominantly along the valley axis during autumn and winter, when the air pollution is highest, while during spring and summer it is turned more from the northerly direction. Due to this topography/wind patterns, the wide UB valley is to a large extent separated from the parallel valleys behind the hills during the high pollution periods, and the emissions flow mostly along the valley axis.

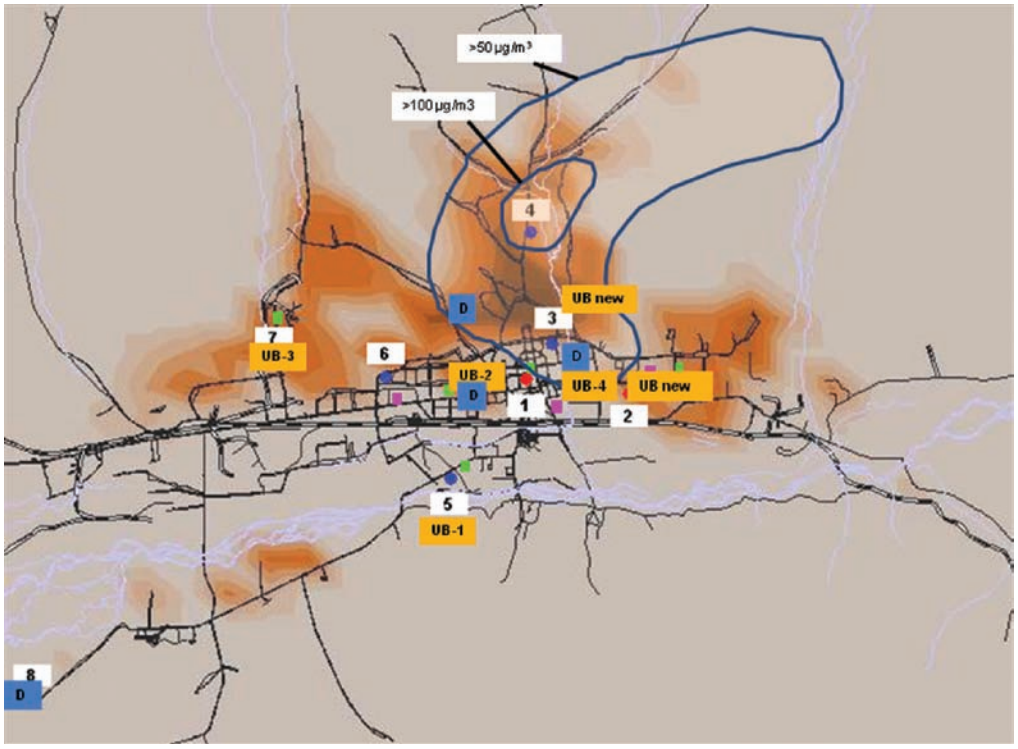
The ger areas which are growing behind the hills are thus to a large extent separated pollution-wise from the main valley. Those ger areas thus have to some extent their own air pollution domain.
With more monitoring equipment available, it is suggested to check on the air pollution concentrations also in those areas.

10. Indoor air pollution considerations
The air pollution inside the gers have been studied to some extent in UB. One report has found extremely high concentrations, using passive samplers, while the report from the Public Health Institute found moderate PM concentrations, using active samplers (the NUM samplers).
More work is needed to establish the extent of indoor air pollution.
Such work should be carried out in parallel with the monitoring network discussed in this note. In such work, it would be important to monitor indoor and outdoor pollution simultaneously.

Suggested further improvements of the monitoring network

Figure B1 shows the locations of the stations now operating in UB. They include the CLEM stations UB 1–4 and two new CLEM stations, the AMHIB stations (marked 1–8) and newly installed or soon to be installed donor-supported stations (marked D). The locations are approximate. All stations except UB-3, UB-4 and the new UB station measure PM concentrations ($PM_{2.5}$, PM_{10} or both). The areas with the highest PM concentrations, according to the modelling, are marked on the map.

Figure B1: Locations of currently operating air quality monitoring stations in UB, approximate locations



Yellow: CLEM stations.
White: AMHIB stations.
Blue: Donor-supported stations.

The monitoring stations are of two types:

- UB: urban background station: location is not dominated by any particular nearby source.
- T: traffic station, located close to street/road or crossing.

Except for station UB-2 and the nearby D station, which are traffic (T) stations, the stations are all urban background (UB) stations.

Based on the above-listed criteria, stations at the following locations are suggested:

1. One more automatic station should be established in the most polluted residential area. A station at or near AMHIB station 4 is suggested. New equipment should be run in parallel with the AMHIB equipment, to establish the connection with AMHIB baseline.
2. One more station located near a heavily trafficked street is recommended. It could be in the area around AMHIB station 3.
3. The pollution situation near unpaved roads should be covered, by placing a station in a ger area near an unpaved road relatively large traffic.

Appendix C: AMHIB Data Quality Assessment

AMHIB data quality assessment

The PM measurement equipment of the AMHIB network is provided by the various institutions, and differs between the various stations. The instruments utilize different measurement principles and are in different operating conditions, which affects data quality. The following is a comparison of the PM concentration data provided by these instruments.

The comparison has been made through co-located comparison sampling that has been carried out three times in 2008, each of 4–5 days duration: 4–5 and 17–20 April, 1–6 July and 18–22 November 2008. The two first campaigns were carried out at the NAMHEM monitoring station at the roof of the NAMHEM building, while the last one in November was carried out at the meteorology station UB3 located in a Ger area to the west of UB centre. During the last campaign, NILU provided a GRIMM 107 PM monitor.

The AMHIB team carried out calibration of the air flow through the instruments used, and of the filter weighing procedure at NUM, where all the filters are weighed. The uncertainty of the air flow and particle weight determinations were generally on the order of 10%. These uncertainties are acceptable, and cannot explain the larger instrument discrepancies. However, larger weighing errors have been detected occasionally; therefore, there can be larger discrepancies for individual data.

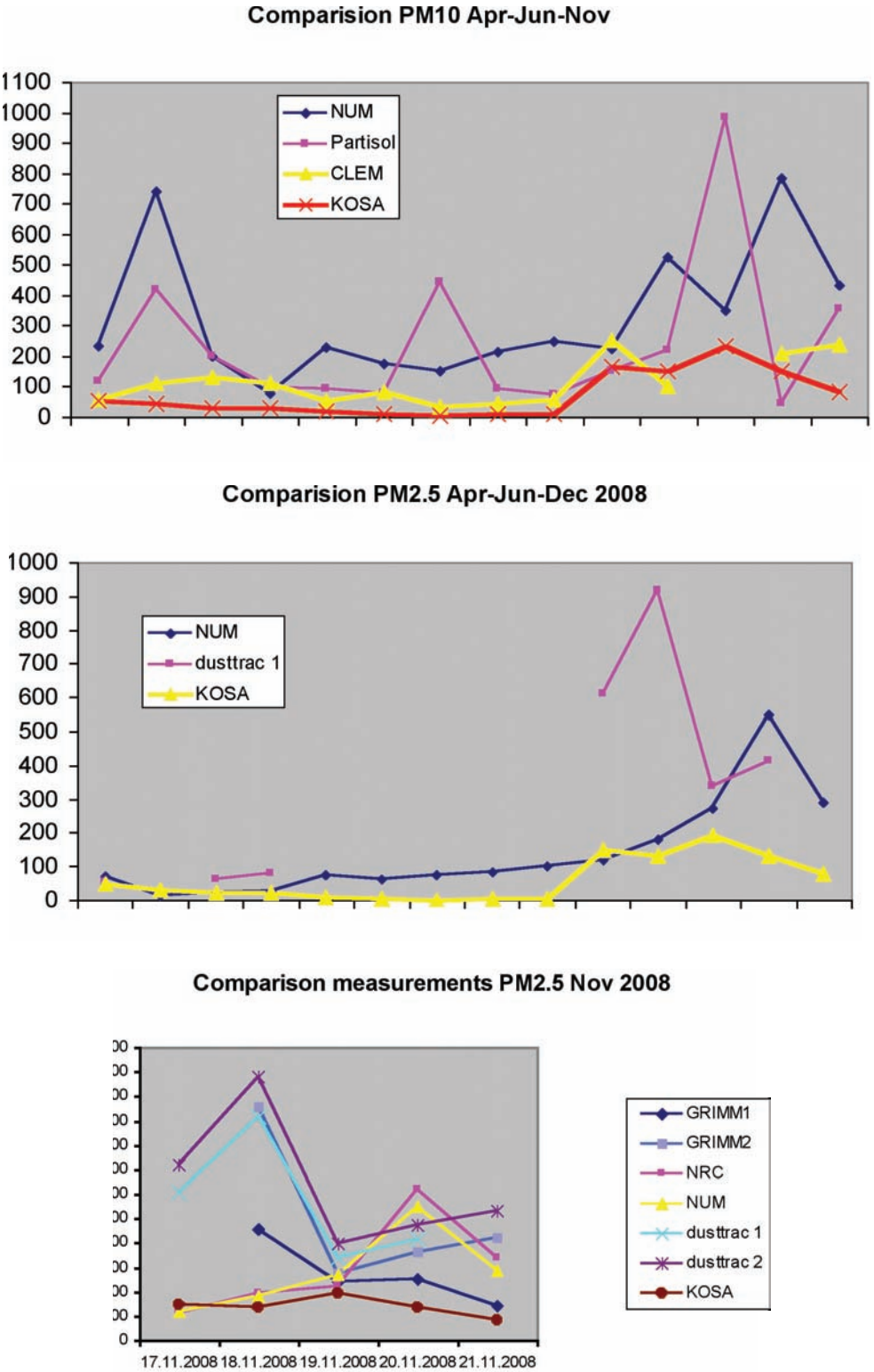
None of the instruments can be considered reference instruments. However, under the prevailing instrument operating conditions of the institutions in UB, it is fair to consider the Ghent (NUM and NRC) sampler and the GRIMM monitor (under low RH conditions) as the better instruments against which the other ones can be compared, on the condition (for $PM_{2.5}$) that the Ghent sampler operates throughout the sampling period without getting clogged.

Figure C1 shows the results of the comparisons. There are at times discrepancies, some large, occur between many of the samplers. Some of the discrepancies are partly the result of the characteristics of the instruments described in Table C1, e.g. that the Ghent (NUM) sampler does not operate throughout the day (has to be shut off due to clogging that reduces the air flow significantly), and that the Dustrac and GRIMM monitors are affected by hygroscopic particle[21] growth at high humidity (such as on the 17th, 18th, and 21st November). However, many discrepancies are not easily explained, e.g. the low concentrations measured by the C-20 (CLEM) sampler and by the KOSA instrument, although the KOSA has increased response during the November comparison.

Table C1 provides observed characteristics of the instruments in the AMHIB network.

[21] Hygroscopic particles are particles which readily take in and retain moisture under certain conditions of humidity and temperature.

Figure C1: Results from PM sampler and monitor comparisons in Ulaanbaatar, for PM_{10} and $PM_{2.5}$, 2008



Comment to Figure:
– GRIMM1 to be compared with NRC and NUM.
– GRIMM2 to be compared with Dusttrac 1 and 2.
– due to different operation times of the instruments.

Table C1: Characteristics of the instruments in the AMHIB network

Instrument/ Institution	Measurement principle	Characteristics
Ghent sampler w/10 µm PM inlet. NUM. Stations 2 and 3 (Sampler is denoted NUM and NRC at stations 2 and 3 respectively)	Filtering. Gravimetric analysis	The sampler separates the particles in 2 size fractions: Fine ($PM_{2.5}$) and coarse ($PM_{10-2.5}$). The first (coarse fraction) filter clogs easily. This has 2 effects: 1) The coarse fraction filter will then collect also some of the fine fraction particles, resulting in too large coarse fraction and too small fine fraction. 2) During days with high pollution, the sampler cannot operate for longer than a few hours before clogging.
C-20 sampler w/ special inlet. CLEM. Station 1	Filtering. Gravimetric analysis	The inlet to the sampler is designed to cut particles larger than 10 µm. There is a question whether the inlet cuts away smaller particles. The performance of the inlet is not tested.
Partisol 2000. NAMHEM. Station 6	Filtering. Gravimetric analysis	State-of-the-art PM sampler, USA. PM_{10}
KOSA NAMHEM. Station 1	Beta absorption	Japanese instrument. Measures $PM_{2.5}$ and PM_{10}.
Dustrac 8520 Stations 1,4,7,8	Light scattering	State-of-the-art monitor, USA. Measures $PM_{2.5}$ or PM_{10}. The response of the sampler, in UB conditions, increases significantly during high relative humidity (RH) conditions, when hygroscopic particles (containing sulphate) grow in size.
GRIMM 107	Light scattering	State-of-the-art monitor, Germany. The same problem as above with increased response during high RH.

Main observations:

- The Ghent (NUM) sampler agrees fairly well with the GRIMM sampler when the relative humidity is below about 70%.
- The Partisol 2000 sampler varies widely compared to the Ghent sampler. Most often it gives lower PM, but sometimes much higher. This is surprising because the Partisol is a state-of-the-art instrument.
- The Dustrac and GRIMM instruments agree rather well. They utilise the same measurement principle. They both give readings that are too high at high relative humidity conditions, especially during the winter period.
- The KOSA instrument gives very low readings compared to the Ghent, Dustrac and GRIMM instruments.
- The C-20 sampler generally gives much lower concentrations than the Ghent, Dustrac and GRIMM instruments.

In conclusion, the Ghent (NUM) samplers, the Partisol and the Dustrac instruments give data of reasonable quality, given the shortcomings listed in Table C1, while the Kosa (station 1) and the C-20 instruments (station 5) somehow give PM concentrations that are too low.

Appendix D: Examples of PM Concentrations in Cities Worldwide

Examples of PM concentrations in cities worldwide

PM_{10} concentrations in Ulaanbaatar

The PM concentrations in UB are very high. There is a very strong seasonal variation with very high winter concentrations and much lower summer concentrations. The annual average PM_{10} concentrations measured at the NUM monitoring station since 2006 where 141, 157 and 279 µg/m³ for 2006, 2007 and 2008 respectively. The real concentration is somewhat higher, since the samplers used underestimate the concentration (Chapter 3 and Appendix C). The increase in measured concentration may indicate that the PM concentrations in UB have been increasing over the later years, although it is possible that the apparent increase might be explained by factors such as meteorology. The measurements carried out under the AMHIB study at several new stations since June 2008 give similarly high concentration levels, confirming the very high PM_{10} concentration level in UB.

The extremely episodic nature of UB PM pollution, which is caused by the combination of ger heating practices and the meteorological situation, causes extremely high short-term PM concentrations. The extremely high hourly and daily concentrations may represent the highest urban scale PM levels anywhere, with hourly PM_{10} concentrations approaching 2,500 µg/m³ and daily averages approaching 700–800 µg/m³ over areas covering much of the city.

These concentrations, with *annual average* PM_{10} up to 279 µg/m³, and maximum *daily average* up to 700–800 µg/m³ can be compared with concentrations in other cities in the world, see below. The overview below is rather complete for cities in the US and in Europe, while for the other regions data availability is incomplete.

Some cities in China have *annual average* PM_{10} approaching and exceeding somewhat 200 µg/m³, and some other cities, such as Karachi and Cairo have similar levels. The levels are much lower in the US and in Europe, where most cities have PM_{10} below 40–50 µg/m³, with a few cities above 100 µg/m³ and up to 180 µg/m³ in dry regions in the US (Arizona and California). Here, the PM is dominated by dry surface dust particles. As for maximum daily PM_{10} averages, US and European cities have mostly below 200 µg/m³, while some industrial cities in the Eastern part of Europe still have high maximums, a few cities in the range 400–700 µg/m³. These maximum daily averages approach those experienced in UB.

PM_{10} in recent years in Chinese cities

The table below lists cities with highest PM_{10} concentrations in 2004–05 and 2006–07 respectively. In 2004–05, 9 of the cities had annual average PM_{10} over 150 µg/m³ (i.e. higher than class 3 classification in China that illustrates the worst/lowest air quality classification for PM_{10}). In 2006–07, these were reduced to 2 cities (Lanzhou and Beijing). The current target set by the government in China, is that all Chinese cities

Table D1: Cities with highest air pollution (average PM_{10} concentrations 2004–05 and 2006–07) in China

	PM_{10} concentrations			PM_{10} concentrations	
Northern cities	**2004–05**	**2006–07**	**Southern cities**	**2004–05**	**2006–07**
Linfen (Shanxi)	0.202	0.141	Panzhihua (Yunnan)	0.256	0.112
Datong (Shanxi)	0.171	0.133	Xiangtan (Hunan)	0.138	0.128
Weinan (Shaanxi)	0.171	0.131	Yueyang (Hunan)	0.138	0.125
Baotou (Neimeng)	0.165	0.141	Zhuzhou (Hunan)	0.136	0.105
Lanzhou (Gansu)	0.165	0.161	Changsha (Hunan)	0.131	0.108
Kaifeng (Henan)	0.163	0.110	Chongqing	0.131	0.110
Pingdingshan (Henan)	0.162	0.129	Zigong (Sichuan)	0.125	0.88
Taiyuan (Shanxi)	0.157	0.133	Wuhan (Hubei)	0.125	0.122
Changzhi (Shanxi)	0.148	0.117	Chengdu (Sichuan)	0.120	0.117
Luoyang (Henan)	0.147	0.116	Luzhou (Sichuan)	…	0.123
Fushun (Liaoning)	0.145	0.113			
Beijing	0.145	0.155			
Yangquan (Shanxi)	0.144	0.098			
Tongchuan (Shaanxi)	0.139	0.112			
Jinan (Shandong)	0.139	0.116			
Urumqi (Xinjiang)	0.114	0.144			

Note: Concentrations in the table are in mg/m3. Multiply by 1000 to convert to µg/m³ (0.1 mg/m³ corresponds to 100 µg/m³).
Source: World Bank staff estimates based upon China Environmental Yearbooks 2005–08.

should reach at least a class 2 level (i.e. < 100 µg/m³ within the ongoing 11th Five Year Plan period (i.e. 2006–2010). However, the target may be too challenging to achieve and a more realistic target may be through the 12th Five Year Plan period (i.e. 2011–2015).

PM_{10} data for 11 cities in Shanxi province for 2004–2007 were as follows (µg/m³, approximate data):

	Average	Highest
2004	163	220
2005	140	200
2006	147	200
2007	108	120

It is clear that the annual average PM_{10} concentration in China cities is above 100 µg/m³ in a large number of cities, (i.e. above China's Class 2 standards). The example from Shanxi province indicates that control measures during the later years are being effective in reducing the PM_{10} level in many cities.

Comparison of PM_{10} levels in cities worldwide

Collection of data from highly polluted cities worldwide have been collected from various assessments and given in the figures below. The two figures below are examples. The first one is from the preparatory work for the WHO AP

Figure D1: PM_{10} in selected cities, 2000–2004

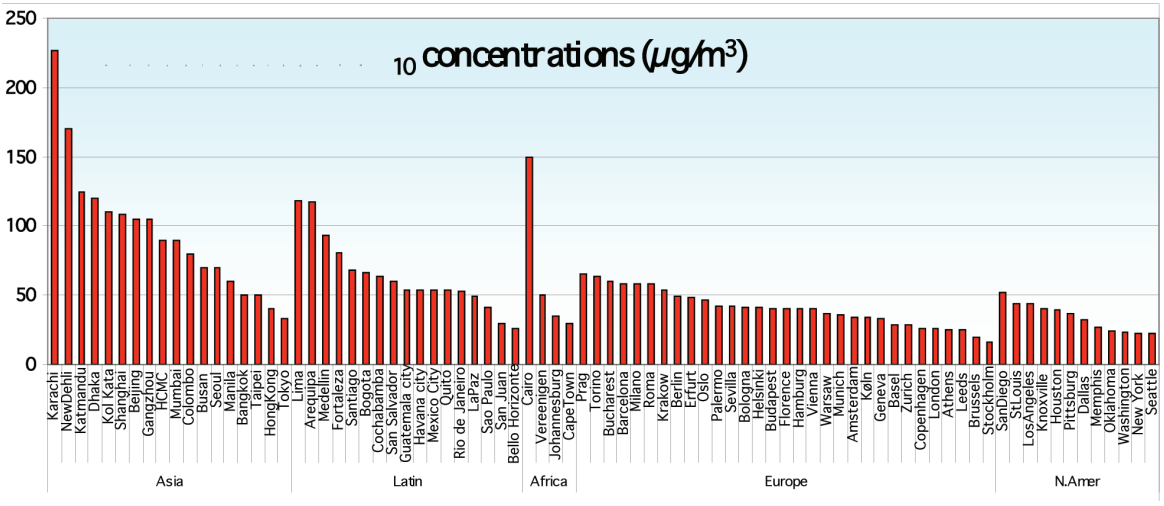
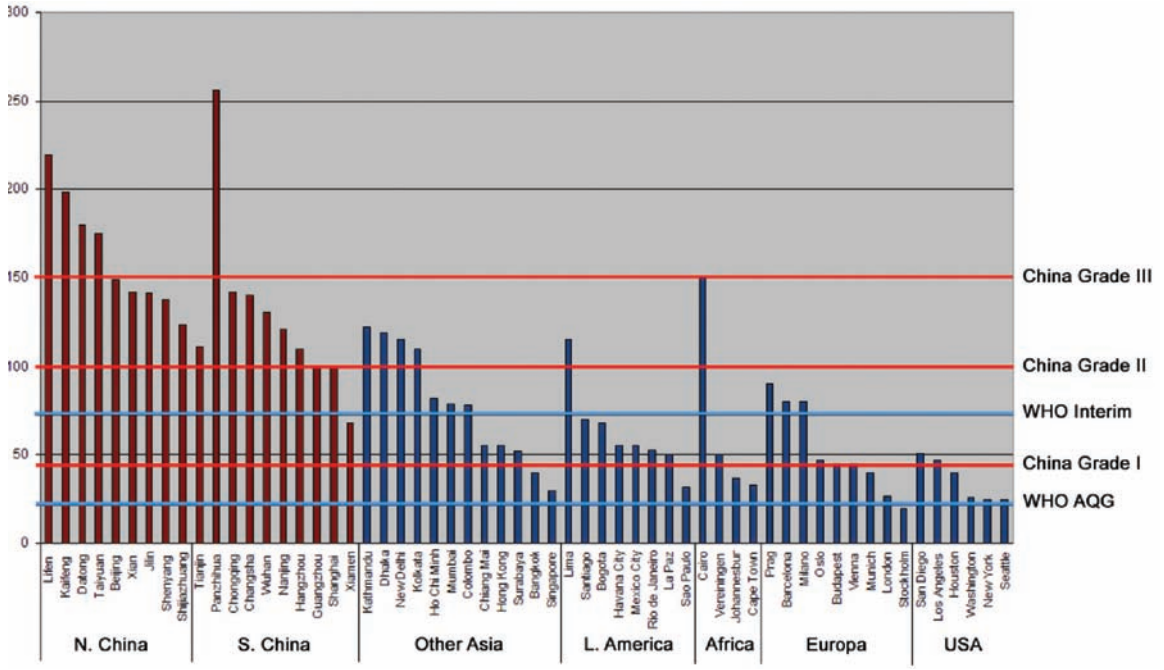


Figure D2: PM_{10} in selected cities, 2005



guideline update 2005. The data are from the period 2000–2004, different for the different cities. The second one is from a similar collection of 2005 data.

For Europe and USA, see more recent data overview below.

PM_{10} in USA

The following summarizes *PM_{10} collected at 1115 stations in the US, 2007*[22]

[22] http://www.epa.gov/oar/data/

Table D2: PM_{10} in 340 cities in the US, 2004

	PM_{10} concentrations (µg/m³)	
	Average 340 cities	Range 340 cities
Annual average	25.8	14–63
24 h average	33.8	24–268

- Highest annual average:
  - 4 stations has annual average PM_{10} over 100 µg/m³
  - the 3 highest annual average concentrations: 181, 168, 137 µg/m³
  - these high concentrations occur in Arizona and California, in very dry locations exposed to dusty conditions
- Highest daily (24-hour average) concentrations:
  - highest measured daily concentrations: 10,000, and some stations around 2,500 µg/m³
- these occur in the same dry locations as above, and are probably associated with dust storms
- 13 stations have max daily concentrations above 500 µg/m³, and 37 stations have max daily concentrations above 300 µg/m³

PM_{10} levels in most population centers in the US are much lower than these maximum levels, with annual averages mostly below 40 µg/m³ and max daily values mostly below 200 µg/m³.

The following summarizes measurements of *$PM_{2.5}$ at 1136 stations in the US, 2007*[23]

- Highest annual average was 22.5 µg/m³, and most stations had less than 15 µg/m³.
- Highest daily (24-hour average) was 172 µg/m³, while most stations had less than 100 µg/m³.

PM levels in Europe

In 2007 PM_{10} was monitored continuously at more than 2000 stations in some 700 cities plus rural areas in Europe. $PM_{2.5}$ was monitored at 308 stations in about 210 cities. Data are reported to the central data base Airbase, and data can be searched there.[24]

PM_{10}

In most of the cities, the *annual average* PM_{10} level is below, and mostly well below, 50 µg/m³. However, levels are high in a few industrial cities in some countries in eastern Europe. Annual average PM_{10} concentration in the 60–100 µg/m³ range were found in some 10 cities or industrial areas in Macedonia, Bulgaria and Poland, including a few areas in Italy and Spain. The highest *daily averages* measured were 864 and 674 µg/m³ in Tetovo city, Macedonia, and in Pernik city, Bulgaria respectively. About 15 cities and areas have maximum daily concentrations above 400 µg/m³.

$PM_{2.5}$

In most European cities, the *annual average* $PM_{2.5}$ level is less than 30 µg/m³. A few cities, including also in Macedonia, Bulgaria and Romania, have concentrations in the range 30–50 µg/m³. The highest daily averages measured in those areas was 366 µg/m³, while 16 cities in all Europe had highest daily average above 150 µg/m³.

[23] US Environment Protection Agency: PM Standards Revision–2006. http://www.epa.gov/oar/particlepollution/naaqsrev2006.html

[24] http://air-climate.eionet.europa.eu/databases/airbase/index_html

Appendix E: Preliminary Emissions Inventory for Ulaanbaatar

Introduction to development of the emissions inventory

The main objectives of the emissions inventory are:

- To calculate the total emissions per source category and type, as a basis for a preliminary assessment of the importance of each of them to the air pollution situation in the city
- To provide input to air pollution (dispersion) modeling of the air pollution concentrations in the city, which determines the actual importance of each source.

Total emissions versus emission height and location

The first objective listed above relates to calculating total emissions (e.g. tonnes per year), irrespective of the locations and time variations of the emissions. To meet the second objective, it is necessary to specify the locations/spatial distribution of the emission sources, the time variation of the emissions (seasonal/monthly as well as hourly) as well as the emission conditions of each source: height above ground, temperature, etc.

The first step, the per-source total emission assessment, identifies the main sources based on amount of emissions. The second step, assesses the relative importance of each source by introducing spatial distribution, timing, and emission heights. For example, the importance of pollution sources at locations away from population centers or tall stacks (as is often the case with power plants and large industries) is less significant than what may be smaller total gross emitters that are located throughout the population centres and emit at low heights. The latter is the situation for small scale domestic heating by coal combustion, as well as for road traffic.

Pollutants

In line with the assessment of PM and SO_2 as the main pollution problems of UB, the emission inventory in this Discussion Paper is limited to PM and SO_2.

Methods

The basic method for emissions inventorying is utilized in this paper:

- Emissions are the product of an activity (e.g. amount of fuel burnt, kms driven) and an emission factor (EF) (e.g. amount per fuel used or km driven).
- Emission cleaning is either accounted for in the EF, or by reducing the emissions above by a factor (1-cleaning efficiency).
- The EF depends upon many factors that needs to be taken into account: e.g. type of process (such as boiler/stove type), fuel specifications, process technology (such as engine and exhaust cleaning technology of a vehicle) etc.

For each source category/type, the emissions can be assessed by top-down or bottom-up methodologies.

Example of top-down method: First,the total emissions can be calculated after the total fuel consumption for small scale combustion for space heating has been estimated (e.g. from fuel sales statistics), and the total emissions has been estimated by applying an emissions factor (EF) established through testing for stove-fuel combinations. The resultant emissions are distributed spatially over the area where the fuel is burned as a function of the distribution of the population/density of households. A time variation function can be overlaid—daily variation, based upon daily heating practices and seasonal variation, based upon temperature statistics.

Example of bottom-up method: First, for the total vehicle exhaust emissions can be calculated for each road link when the road traffic amount (vehicles per day) and vehicle type distribution is known/estimated for each road link of the total urban road network and the EF is applied to each type of vehicle in the traffic flow. The spatial distribution of the emissions in then known from the locations of the road links, and thus specified in the input to the model. The time variation is also often known from traffic counting, or it is estimated from the general activity patterns for the city.

Background material of emissions inventory in this Discussion Paper

The main background sources for the inventory are:

- Air Pollution Sources Inventory of UB City. Ministry of Environment, National Agency for Hydrology Meteorology and Environmental Monitoring, 2007. (Referred to as "NAMHEM, 2007").
- Urban air pollution analysis report. Draft Consultant Report to World Bank (Guttikunda, 2007).
- Mongolia: Energy Efficient and Cleaner Heating in Poor, Peri-urban Areas of UB. Summary Report on Activities (World Bank, 2008a). (Referred to below as "The heating report, 2008").
- Report "Small boiler improvement in UB". (World Bank 2008b) (Referred to below as "HOB report, 2008").

Inventory

Below each of the main air pollution sources is treated separately. For each source the basis for the emissions inventory is described:

- Description of the source
- Calculation method
- Emission factor(s)
- Total emissions
- Spatial distribution
- Time variation
- Uncertainties

Emissions per source

Ger area households

References: World bank, 2008a;. NAMHEM, 2007.

Calculation method

Top-down: This type of source category, a large number of small and rather similar stoves without specific knowledge of their location and characteristics, is treated as an 'area source'. Total emissions are calculated as the product of fuel consumption and emission factors, then spatially distributed according to population distribution.

Description of source and its fuel consumption

Number of households

The Heating report gives 100,941 households (2007) in the 6 ger districts nearest to UB. The NAMHEM, 2007 statistics gives 119,210 households (2007). In addition to the 6 khoroos included in the Heating report, there are a few districts in town that also have ger household in addition to apartments. When these areas are included, the number of households was estimated to about 130,000.

Our model area covers much of the 6 districts of the Heating report, but not all of its districts. However, the number of ger households in the areas that are outside our model grid is limited, although there are some populated ger areas north of our grid area (stated based upon careful inspection of Google earth map), but still within the districts. The number of households inside our grid area is thus somewhat less than the about 130,000 of the Heating report. Considering the uncertainty of this number, we still use 130,000 ger households as a best estimate for the number within our model area.

Fuel consumption per type of household/stove

The Heating report gives the average consumption of coal and wood per ger area household as 4.19 tons and 4.68 m^3 (3.18 tons), for the winter season 2006/7. This is based upon statistics on types of households: gers, houses with and without heating wall and houses with low pressure boilers, LPB). Gers have the lowest average consumption (3.97 tons) and LPBs the highest (6.17 tons), while for wood the differences between the households types are less.

Total fuel consumption

The Heating report gives its estimate of total ger area household consumption as 546,000 tons of coal and 415,000 tons of wood for the 2006/7 heating season. No estimate is given for the summer consumption, while it is clear it is much less than the winter consumption.

The "NAMHEM, 2007" statistics for 2007 gives the consumption as 403,459 tons of coal and 237,196 tons of wood, quite a bit lower than the heating report gives. We put emphasis on the data from the heating report.

Emission factors and total emissions from ger area households

Appendix F describes the available sources of information on emission factors for small stoves. Based upon this, the following EFs are used in the calculations, resulting in the following total emissions for the winter season 2006/7:

Pollutant	Emission factor		Total emissions
	Coal	Wood	
PM_{10}	16 kg/ton	18.5 kg/ton	16,363 tons
$PM_{2.5}$	9.6 kg/ton	16.7 kg/ton	12,133 tons
SO_2	6.5 kg/ton	….	3,542 tons

The basis in measurements for setting EFs for ger stoves is very weak.

Spatial distribution

The emissions are distributed over the ger areas the same way as done by Guttikunda (2007), based upon information about the distribution of households across the areas. The distribution is shown in Figure E1 . This spatial household distribution has not been quality assured, and the uncertainty is not known. E.g., from field observations about household densities, it seems like the estimated density in the central-western part of the ger areas is too low.

Time variation

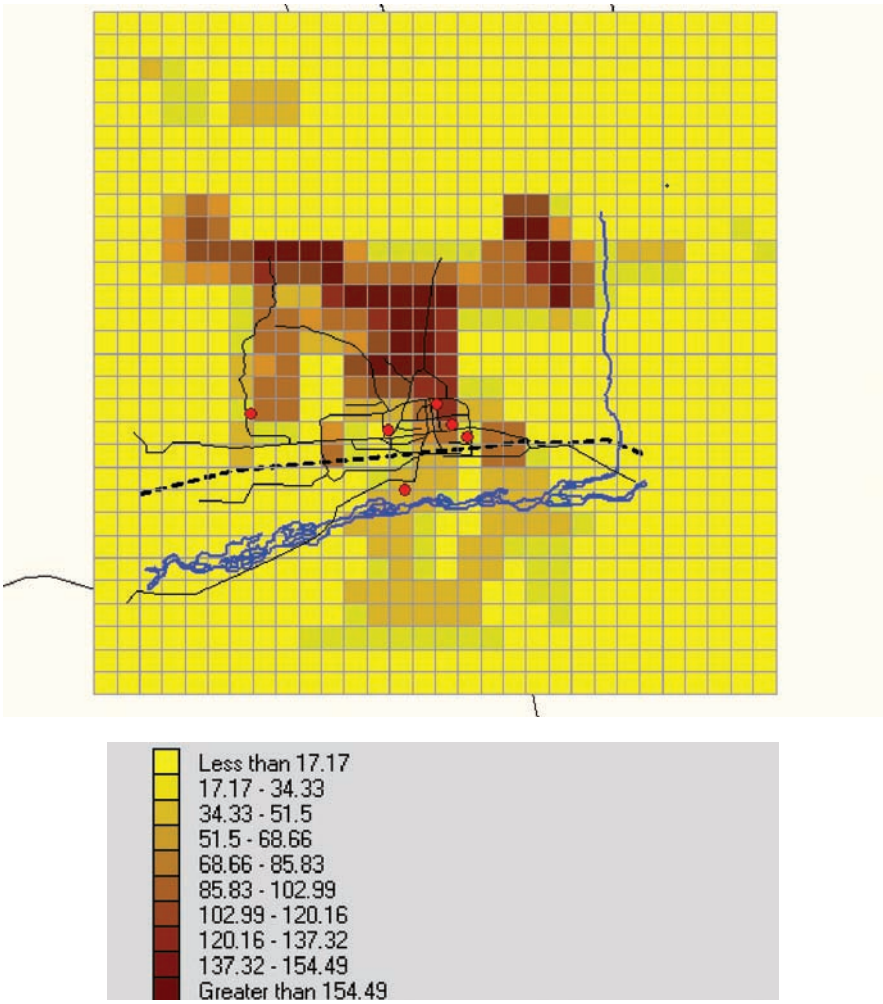
The emissions are distributed with time as follows:

- Seasonal: 95% of the consumption is used in the 8 winter months October–April. Within this period, the consumption is distributed between the days dependent upon the daily average actual temperature for each day. The rest 5% is evenly distributed over the summer season. The resulting time variation of the ger household emissions across the year is shown in Figure E2.
- Daily: the variation follows the typical heating and cooking schedule of the households, as shown in Figure E3.

Uncertainties

The main uncertainties in the total emissions from this source is associated with the average emission factors, as discussed in Appendix F. There is not enough information available to assess the uncertainty statistically.

Figure E1: Spatial distribution of ger household emissions in km² grid cells, PM_{10}, 2007 (tons/year)



Heat only boilers

Reference: World Bank, 2008a.

Calculation method

Top-down: The number of HOBs is limited, about 267, but not enough information is available on the location, size and characteristics of each HOB. The emissions are calculated from an estimate of the total fuel consumed in the HOBs and multiplied by an average emission factor. The emissions are then distributed spatially evenly over the areas where most of them are located.

Description of source and its fuel consumption

Number and types of boilers

According to the 'HOB report', the UB municipality has identified 145 boiler houses in UB with 267 boilers (list from March 2007). This list does not include industries and commercial owners. Most of the 'old' industries are supplied from the CHP plants, while some new industries (the Coca Cola plant is mentioned as an example) are equipped with new efficient boilers.

Boiler types are mainly: Russian BZUI 100, improved Russian type named DTH, boilers

Figure E2: Time variation (from day to day) of ger emissions, based upon temperature variations

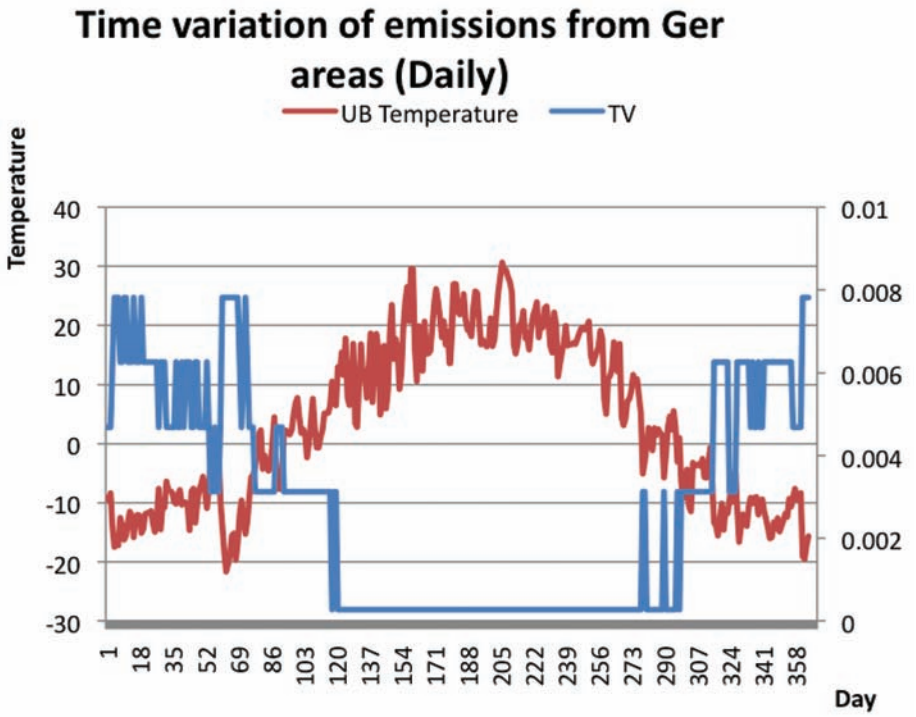
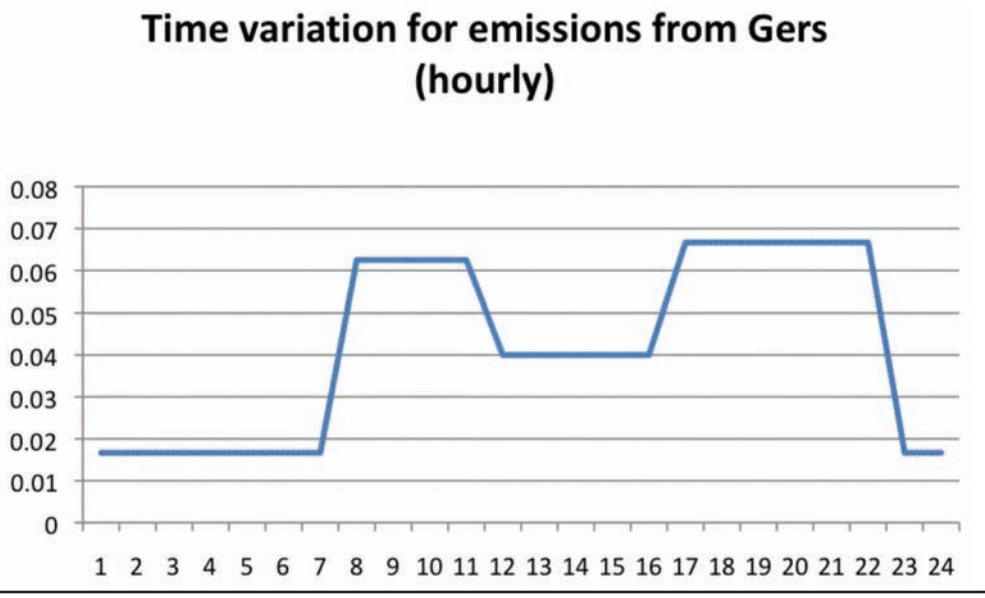


Figure E3: Time variation across the day of ger emissions, based upon heating and cooking practices



of Chinese type, and locally available improved boilers. The efficiency of the boiler types is listed as 34%, 71%, 63% and 85% for the old Russian, DTH, Chinese and improved boiler respectively, based upon limited testing. There also exist a number of other types, and the East European type CARBOROBOT is mentioned specifically, apparently with good efficiency and low emissions.

A clear inventory of numbers of each type is not available presently. It appears that most are of the old Russian type, with a certain number of the others, e.g. it is mentioned that about 10% of the boilers are of the Chinese type.

Total fuel consumption

The total fuel consumed by the HOBs is not well known. The following is cited from the 'HOB write-up': *"The total annual coal consumption is assessed at 150.000 tonnes and a conservative multiplication factor of 2 (when assessing the effects on air pollution) gives an annual consumption of 300.000 tonnes of lignite. (…) Allowing for other industrial and commercial consumers another 200.000 tonnes may be added to the HOB consumption"*.

This adds up to 500,000 tons annually consumed by HOBs in UB. The uncertainty of this estimate is apparent.

Using the fuel consumption data from the HOB testing in the HOB-2008 report (300 kg/hr for the Russian type and 220–286 for the other types), 5000 operating hours per year and 267 boilers, we arrive at an annual consumption of about 380,000 tons per year. This assumes that the hourly fuel consumption used in the tests is representative for all hours during the whole winter. Then, there are a few more than 267 boilers. The fairly new Coca Cola boiler, using 20,000 tons per year, is mentioned as an example.

In conclusion, we use 400,000 tons as annual coal consumption, stating that there is a fairly large uncertainty to this number.

Emission factors and total emissions from HOBs

Based upon limited testing, the EF for TSP (total suspended particles) is given as 29.1, 26.8, 28.4 and 4.4 kg/ton for the old Russian, DTH, Chinese and improved boilers respectively. The improved boiler thus appears to have substantially less emissions, while the 3 other types are remarkably similar, although their designs and efficiencies differ. It seems fair to use 28 kg/ton for the 3 types and 4.4 for the improved boiler.

The average EF to use and combine with the total fuel consumption depends on the fraction of improved boilers among the boilers presently (see Appendix C). A 1%/5%/10%/20% fraction gives an average EF of 27.8/26.8/25.6/23.3 kg/ton respectively, and the variation from the average of these numbers is about +–9%, i.e. a limited uncertainty. It seems like the fraction of improved boilers is still low, probably less than 5%. If so, an average HOB EF is about 27 kg/ton.

Total annual HOB TSP emissions are then 400,000 tons × 27 kg/ton, giving 10,800 tons. Using the fractions of PM_{10} and $PM_{2.5}$ of TSP from Appendix F, 0.6 and 0.36 respectively, the resulting emissions of PM_{10} and $PM_{2.5}$ are 6,480 tons and 3,888 tons respectively.

Spatial distribution

We use the information collected by Guttikunda (2007) as a basis for distributing the HOB emissions spatially. Figure E4 shows locations of HOBs according to his data. The resulting spatial distribution of HOB emissions is as shown in Figure E5, where the total emissions have been distributed rather evenly in the grids corresponding to the green dots in Figure E4. There is no specific information yet on the actual distribution of the emissions. It is possible that the distribution used overestimates the HOB emissions in the central urban areas.

Figure E4: Location of a number of HOBs in Ulaanbaatar (Guttikunda, 2007)

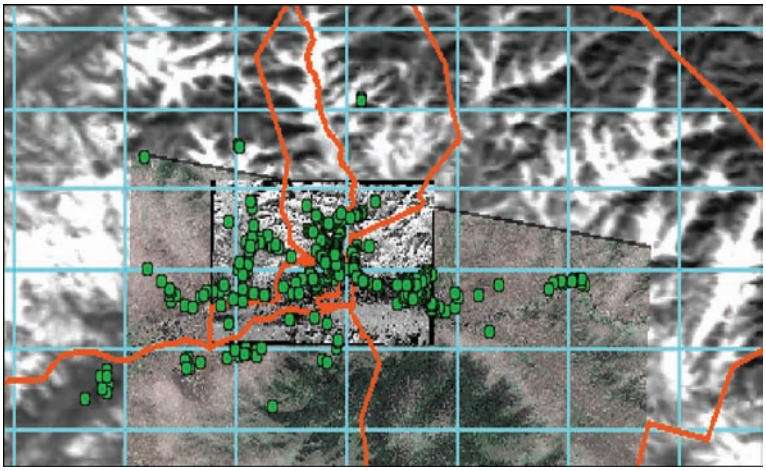
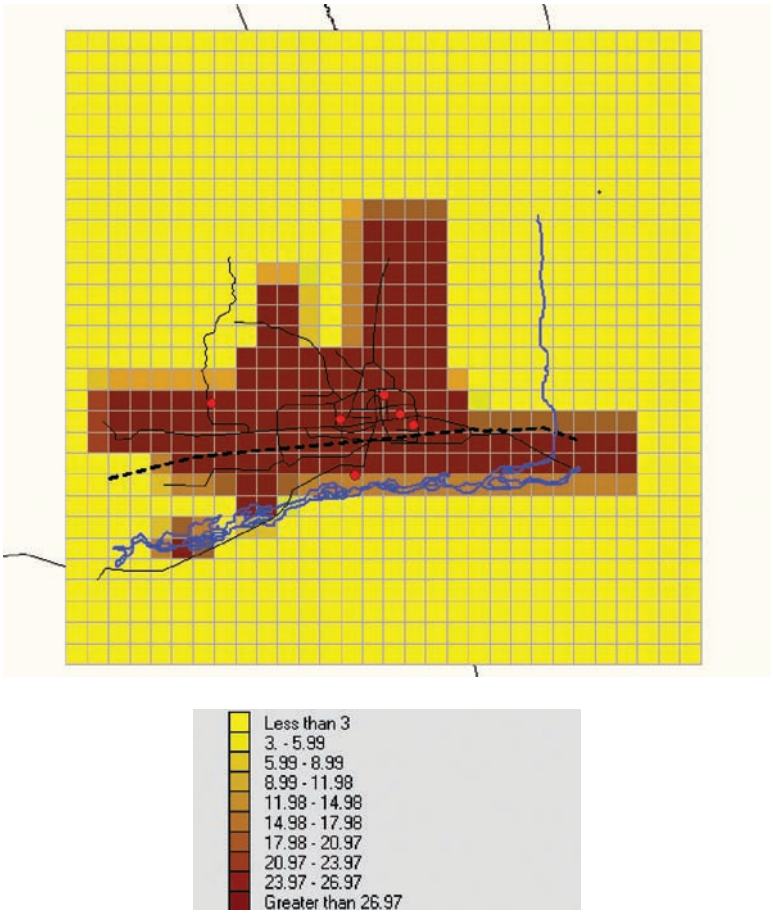


Figure E5: Spatial distribution of HOB emissions, 2007 (tons/year)



Time variation

The working hours of HOBs in UB is assessed to be 5,000 annually (HOB write-up), distributed across the winter season. We distribute the emissions evenly over all hours from early October to late April.

Uncertainties

The main uncertainty in the estimate of HOB emissions lies with the total fuel consumption. The uncertainty may well be of the order of 30%. A better estimate is needed here. The uncertainty of the EF is not known, but based upon the limited testing done (see above), it seems to be not very large. The spatial distribution and time variation estimates do not appear to introduce major uncertainties in the calculation of the contribution from HOBs to PM concentrations.

Combined heat and power (CHP) plants

Calculation method

Bottom-up: The locations are known, and the specific fuel consumption per plant is known. Emissions are calculated per plant, and inserted in the dispersion model at their respective location. Emissions are calculated as a product of fuel consumption and EF, modified by efficiency of the cleaning equipment.

Description of the source and its fuel consumption

There are three CHP plants located as shown in Figure E6.

Characteristics of the CHP plants:

	CHP2	CHP3	CHP4	Reference
Capacity, MWe	21.5	148	540	PREGA study, 2006
No. of boilers	5	12	8	PREGA study, 2006
Power produced, 2004, GWh	106	565	2150	PREGA study, 2006
Coal consumption, 2006, million tons	0.182	0.888	2.42	Guttikunda, 2007
Height of stacks, m	100	120&150	250	

Figure E6: Locations of the three CHP plants in Ulaanbaatar (Guttikunda, 2007)

Total coal consumption in 2006 was 3.49 million tons (Guttikunda, 2007) and in 2007 it was 3.36 million tons. It seems power production and coal consumption for the CHP plants vary little between years.

Emission factors and total emissions from the CHP plants (see Appendix F)

PM_{10}: 19.5 kg/ton
$PM_{2.5}$: 7.8 kg/ton

On top of this: Flue gas cleaning efficiency: 80% for CHP 2 and 3, and 95% for CHP 4.

Time variation

The total load of the three CHPs is rather constant during the period from 8 AM to 10 PM every day, while the lowest load during night time is about 25% lower, lowest at 3–5 AM. Seasonally the day-load varies from about 410 MW in December–January and down to 250 MW in July, that +– 30% from a yearly average load (PREGA, 2006).

In our model calculations, we enter the CHP emissions as constant over all hours of the year. This introduces an overestimation for the summer months and underestimation for the winter months. This introduces only a small error in the annual average concentration contributions from CHPs.

Vehicle exhaust

Calculation method

Bottom-up: The locations of the road nodes between road sections are known for a large part of the main road network. Traffic amounts and distribution between vehicle types has been estimated for about 100 road sections (links), and emission factors have been estimated for each vehicle type. The emissions from each road link are added in the km^2 grid, and treated as area source.

Description of the source

Vehicle data

The number of vehicles has grown steadily and sharply over the later years, see Figure E8, while the length of improved roads (i.e. paved roads) has increased little since 1992. This has lead to increased traffic loads on the roads and frequent and widespread traffic jams. As of 2005, passenger cars made up about 75% of the vehicles population. Old cars (>11 years) dominate, and made up about 50% of the passenger cars in 2006. Although public transport by micro-buses and taxis has increased substantially since about 1998, private passenger vehicles dominate the transport and traffic sector in UB.

Vehicle data for 2007 (NAMHEM, 2007):

Total number of registered vehicles:		**92,706**
Of which:		
Passenger cars:	69,502	74.9%
Trucks	14,205	15.3%
Public transport (buses)	6,440	7.0%
Special vehicles	2,559	2.8%
Number of vehicles using:		
Gasoline		ca 64%
Diesel		ca 34%
Gas		ca 2%

Traffic data

Data for the traffic flow in streets are needed in order to model and assess the contribution from vehicular traffic to the spatially distributed concentrations of air pollutants. Since no traffic flow data were available previous to this work, an effort was made to provide such data. As part of the AMHIB study team, NILU provided a note for how to count traffic in sections in a simplified manner as a basis for assessing the flow of traffic, its variation across the day and its vehicle composition. As part of the AMHIB study team, the NUM team was asked to carry out a limited counting effort, which they did successfully using students. Traffic was counted and vehicles classified at 9 selected street sections. The results of this counting, and of subsequent further flow

estimation at a number of other sections, are given in Appendix G.

A summary of the results:

- The traffic flow at the 9 sections varied between about 14,000 and 57,000 vehicles per day (ADT). Light duty vehicles dominated the traffic flow at all sections.
- The diesel fuelled share of the light duty vehicles varied within 10–15%. Diesel fuelled vehicles have much larger exhaust PM emissions than the gasoline fuelled ones.
- The heavy duty share of the traffic flow varied between about 3% and 12% at the 9 sections.
- Buses dominated the heavy duty share at some sections, while light duty trucks dominated at others.
- While most heavy duty vehicles in Europe are diesel fuelled, with relatively large exhaust PM emissions, the situation in UB is different: most heavy vehicles are gasoline fuelled, with relatively small exhaust particle emissions.
- Rough estimates of the traffic flow, in 4 broad classes from <20,000 to >60,000 ADT was provided for 48 additional street sections within and around UB centre area.

Figure E7 shows the part of the main street network in UB with the traffic flow indicated by color coding. On each section the composition of the traffic in terms of vehicle class contribution is also estimated, based upon the vehicle classifying countings.

This traffic flow counting and estimating activity provides input data for including emissions from the vehicular traffic to air pollution modeling for UB.

Emission factors

The vehicle exhaust emission factors depend upon type of vehicle, their technology (engine and exhaust cleaning) and fuel used, their age and technical condition, as well as the driving speed and road inclination.

For UB, classes of vehicles and fuel used were defined as in the Table below. Their correspondence with the vehicle types classified in the counting exercise (Appendix G) is also given there.

The existing vehicle exhaust regulations in UB does not limit the types of vehicles allowed

Figure E7: Traffic flow on the main road network in Ulaanbaatar, classified inbroad ADT classes: <20,000 (yellow), 20,000–40,000 (green), 40,000–60,000 (red), >60,000 (purple)

on the roads. As Mongolian gasoline still contains some lead, the catalysts on new or secondhand vehicles will not function after a short time when driving on local gasoline. No specific information is available on the exhaust emission levels of the vehicles on UB roads, old or new. As about 50% of the cars were older than 11 years in 2006 (still older now), it is fair to assume that they are of medium-to-low technical standard. Most of the trucks are also old (mostly Russian), while the bus fleet has a wide spread in ages, some fairly new. Based upon this limited information, EFs for the UB vehicle fleet cannot be set with high accuracy. The basic EFs in the Table below are used in this work, for the vehicle classes defined above.

Vehicle class, fuel	Correspondence to vehicle types classified in the countings, Table G1	Emission factor g/km
Light duty vehicles, gasoline	Private car, taxi, micro bus, 40% of jeeps	0.1
Light duty, diesel	60% of jeeps	2
Buses, diesel	'Big passenger bus'	2
Light heavy duty vehicles, diesel	Trucks up to 2.5 tons	2
Medium heavy duty vehicles, diesel	70% of trucks above 2.5 tons	2
Medium heavy duty vehicles, gasoline	30% of trucks above 2.5 tons	0.4

Regarding traffic speed, we use 30 km/h in central area, 50 km/h on ring roads, etc, and 70 km/h on main roads out from UB.

Spatial distribution

The road traffic in UB is considered in two parts:

a. The traffic on the main road network, as shown in Figure E7.
b. It is clear that the road network defined in Figure E7 is not complete. There is traffic on more large roads, as well as on numerous small roads, mainly unpaved, linking between the main roads, especially in the ger areas.

As a gross estimate (e.g. based upon similar experiences in Oslo), we add small road traffic corresponding to 30% of total vehicle-km of traffic under a) above. These vehicle-kms are distributed across the km^2 grid cells in the ger areas in the same manner as the household heating emissions are distributed, i.e. largely proportional to the population density distribution.

The resulting spatial distribution of the exhaust particle emissions is shown in Figure E9.

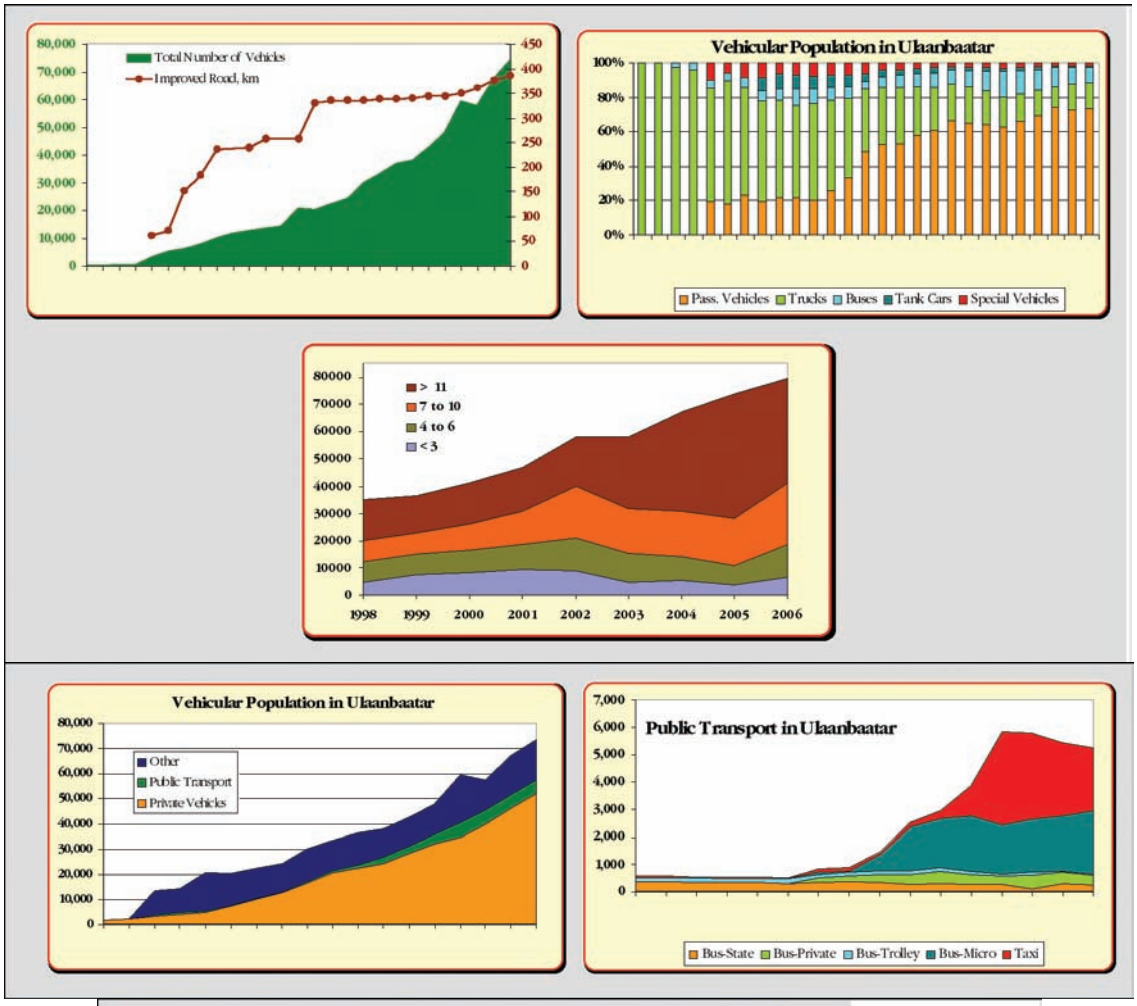
Total emissions

The total vehicle exhaust emissions are calculated by multiplying the traffic amounts on each road section with its length and the EFs for each of the vehicle classes, and summing up over all road sections. The 30% additional small road traffic is then added. For this traffic, the average vehicle composition of the main road traffic is used.

Time variation

Based upon the counting described in Appendix G, the traffic varies during the day for the different roads counted. The variation in the daytime hours is generally not large. In this work, the hourly traffic is taken as constant from 7 AM till 7 PM, and

Figure E8: Vehicle and road data for Ulaanbaatar (Guttikunda, 2007)



Type of Vehicle	Average Vehicle KM Traveled
Car/Van/Jeep	40
Bus (regular)	200
Bus (micro)	275
Taxi	140
Truck	150

Source: City Transport Department of Ulaanbaatar

Centre figure: Age distribution of passenger cars.

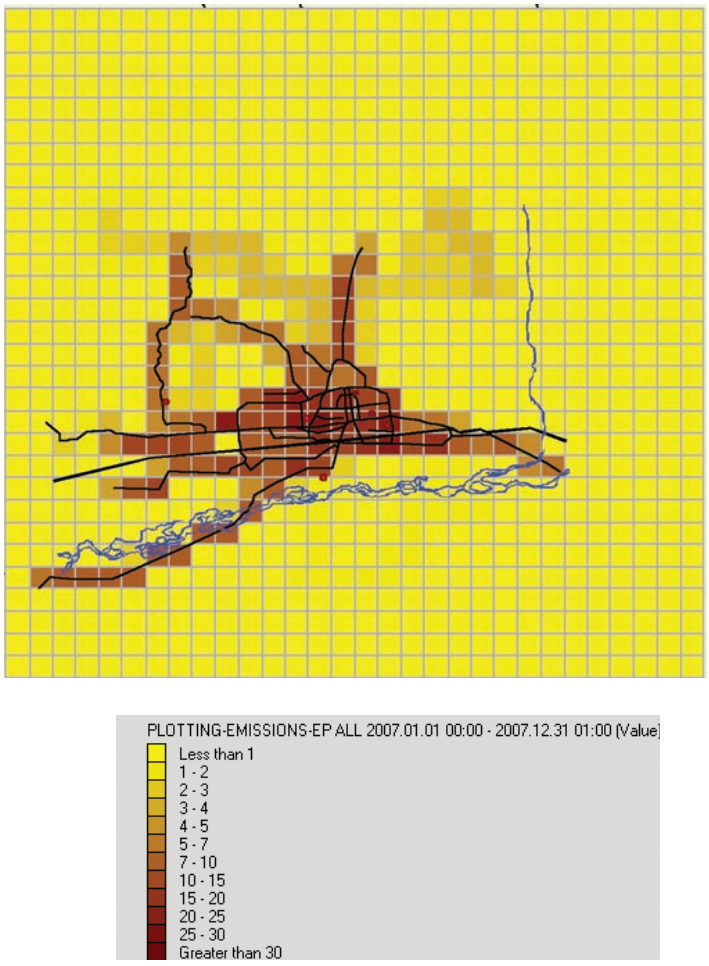
close to zero from 7 PM to 7 AM. This is an obvious simplification, but does not introduce significant error for the present analysis. This variation is used for all days of the year, although it is known that the variation is different on weekends and holidays. It is considered that the error introduced by this simplification is quite small.

Suspension of dust from roads

Calculation method

Bottom-up: Calculated similarly as vehicle exhaust emissions, based upon the same data for traffic and roads.

Figure E9: Spatial distribution of the PM emissions from exhaust particles from the road traffic in UB, 2007 (tons/year)



Description of the source

Dry dust on road surfaces is whipped up, suspended to the air, from vehicle turbulence as they travel the road. The extent of suspension increases with the speed of the traffic by about the square of the speed. Suspension takes place obviously only when the surface is dry, which is most often the case in UB. Large vehicles, trucks and buses, suspend much larger amounts of dust than small vehicles. The dust suspension is very much larger from unpaved than from paved roads. The dust suspension problem is more substantial in the *ger* areas with the unpaved roads than in UB central areas, although there is substantial suspension also from paved roads in the centre, since there is always a depot of dust on the road surfaces.

Most of the mass of the suspended dust is on particles larger than 10 micrometers, thus larger than those affecting humans by breathing. However, a substantial amount is also below 10 micrometers (PM_{10}), as well as below 2.5 micrometers $PM_{2.5}$).

The source emits parallel with the exhaust emissions from the traffic. However, it has a different spatial distribution and time variation, mainly because suspension only takes place when it is dry, and because of the importance of surface conditions (paved/unpaved).

Emission calculation

The emissions are calculated based upon the same traffic and road data as used for vehicle exhaust, with the addition of some parameters:

- state of dryness on the roads
- paved/unpaved road surface.

The dust suspension is translated into emissions of PM into the air by using a method that takes into account the variation of suspension as a function of vehicle speed and vehicle types (heavy duty vehicles suspend much more particles than light duty vehicles because of the more intense turbulence around the larger vehicles). The following theoretical/empirical algorithm is used, which was developed based upon PM measurements in Oslo and Stockholm as a function of traffic parameters:

$$Q_{PMC} = C * (A * TT + B) * (VD / VDref)^2 * (0.98 * ST + 0.02)$$

in which Q_{PMC} is the average PM coarse particle suspension emission per vehicle in the traffic flow; C is emission of exhaust particles at the reference site; TT is the percentage of heavy vehicles; A and B are the constants in the function relating suspension to the share of heavy duty vehicles; VD is the driving speed and VDref is the driving speed at the reference site; ST is the share of vehicles using studded tires. The parameters A, B and C are empirical constants, these parameters are dependent on the local road and traffic conditions. In this work, the values used are 0.62, 3.32, and 0.54 respectively, values taken from previous experiments both in Oslo and Stockholm. The algorithm is developed for sites where a share of the vehicles use studded tires, which is normal in Scandinavian cities for increased friction on icy roads. The wear of the road surface due to the studs in the tires create a depot of dust particles that are suspended due to the turbulence created by the vehicles in traffic. The depot of dust on the road surfaces in UB come from other sources, mainly dry particles from open surfaces nearby. Thus, while the mechanisms behind the creation of the dust depot are different from Scandinavia, the suspension mechanism is largely the same. It was estimated, as a first attempt, that the dust depot on the UB paved road surfaces is similar to the roads with a rather moderate share of studded tires in Scandinavia, and we use the formula as if 10% of the vehicles had studded tires, i.e. ST=0.1. On unpaved roads, the suspension is very much higher, and there we used, as a first attempt, ST=1.0, i.e. as if all vehicles had studded tires.

Traffic induced suspension also gives a contribution to fine particles in air. The suspension of fine fraction particles, Q_{PMF}, was set to 15% of the coarse fraction, Q_{PMC}, based upon experience from Oslo.

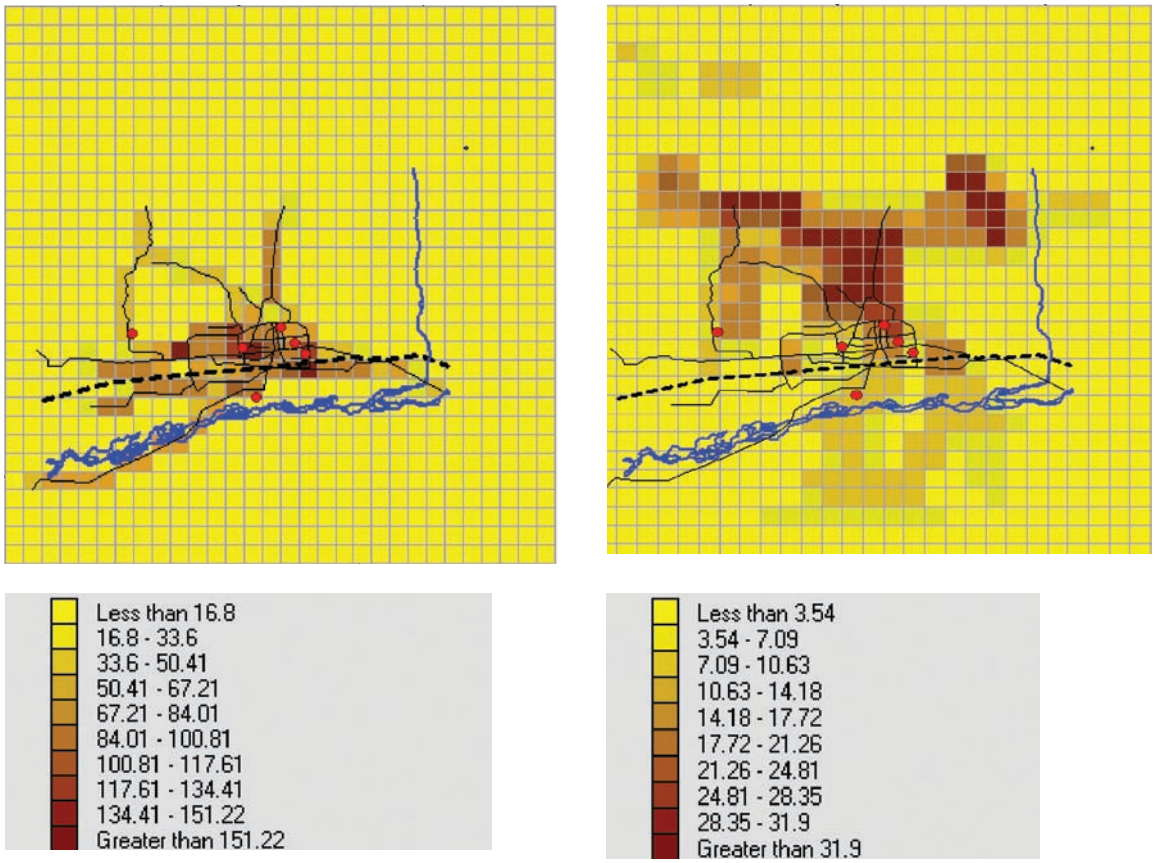
The suspension emissions were calculated in a similar way as for exhaust particles, using Q_{PMF} and Q_{PMC} as average emission factors per vehicle. For the paved roads, the spatial distribution is given by the traffic distribution, using the same distribution as when calculating exhaust particle emissions. For the unpaved roads, the spatial distribution follows the population distribution, the same way as the distribution of exhaust particles is calculated for the small road traffic (see spatial distribution under the vehicle exhaust section on p. 105). The resulting spatial distribution of the emissions from paved and unpaved roads is shown in Figure E10.

This estimate of suspension of PM from roads was used in this work in the first attempt to account for road dust suspension in UB. The representativeness of the formulas have not been tested for UB conditions, although the resulting modelled PM concentrations, with all sources included, correspond well with the measured concentrations at the NUM site, the only site with data available at the time when the modelling work was carried out. The spatial distribution of the unpaved road emissions is determined by the ger area population distribution, and thus depends on the correctness of that distribution.

Stoves in kiosks and shops

There are some 4500 kiosks and shops in UB which are heated by the same type of stoves as used by the ger households. This is a less important source, and we do not have its spatial distribution across UB. We use Guttikunda's (2007) estimate and distribution of this source: we allocate 5% of the ger household emissions to this source, and distribute it as the household emissions.

Figure E10: Spatial distribution of suspended PM_{10} from road traffic in UB. Left: paved roads. Right: unpaved roads.



Note the different scales.

Appendix F: Emission Factors for Coal and Wood Combustion in Small Stoves and Boilers

Coal combustion

PM emission factors for coal combustion can roughly be based upon ash contents in the coal, fraction of the ash emitted as TSP, and then ratios between TSP and PM_{10} or $PM_{2.5}$. Significant improvements are necessary through field and laboratory testing of stove-fuel combinations to accurately adjust these emissions factors.

The table below gives the actual fractions used by Guttikunda (2007) for UB.

Updating the emission factors

Ger stoves

For the ash contents and consumption of coals used in UB, we have the following data:

Coal mine	Ash contents	Fraction of households using the coal
Nalaikh	16.5 %	about 75 %
Baganuur	13.1 %	about 25 %

This gives an average ash contents in Ger stoves of 15.65%, and thus a PM_{10} EF of about 16 kg/ton.

We have searched the open literature for data PM emissions from small stoves like those in gers. We have found data from Polish ceramic stoves, they are quite a bit larger than ger stoves, and smaller than the HOBs we are looking at in UB. Their measurements gave TSP emissions of 14–17 kg/ton (Jaszczur, 1994). A Chinese study gives, for bituminous coal in improved stove types ('high efficiency household coal stoves') a PM

Table F1: Emission factors for coal and wood, used by Guttikunda (2007)

Source	Ash %	TSP/Ash ratio	PM_{10}/TSP ratio	$PM_{2.5}$/PM_{10} ratio	EF PM_{10} kg/ton	EF $PM_{2.5}$ kg/ton
CHP, coal	15	0.2	0.65	0.4	19.5	7.8
Ger stove, coal	25	0.2	0.5	0.6	25	15
Ger stove, wood					3.8	2.3
HOB, coal	15	0.2	0.6	0.6	18	10.8

(TSP) emission factor of 14.8 kg/ton (Zhi et al, 2008). There are no data in AP 42 for small scale coal stoves. With a ratio between PM_{10} and TSP of 0.5, the Polish and Chinese stoves have a PM_{10} EF of about 7–8 kg/ton.

The old ger stoves in UB should have larger emissions than the larger Polish stoves and the more efficient Chinese stoves above.

It is apparent that the basis in measurements for setting EFs for ger stoves is weak, and that the EFs for both PM_{10} and $PM_{2.5}$ are very uncertain, including the $PM_{2.5}/PM_{10}$ ratio of 0.6.

HOB

The WB Consultant's 'HOB report' also gives data from measurements of TSP emissions from three 'old' and one new boiler type. TSP emissions from the 'old' ones are 27–29 kg/ton. The EF measured for the newer improved HOB type was much lower, 4.4 kg/ton. Estimating the number of improved boilers at 5% of the total HOBs in UB, the average TSP EF from the UB measurements is about 27 kg/ton. This agrees favourably with the HOB EF in Table F1 above, when it is converted to PM_{10} emissions by multiplying with 0.6, which gives 16.2 kg/ton.

Wood in gers

The emission factor used by Guttikunda is 3.8 kg/ton.

The PM emissions from small scale wood stoves have been studied in Norway, where the use of such stoves is wide spread. Haakonsen and Kvingedal (2001) have summarised EFs for such stoves. The EF for PM from stoves varies significantly with the feed rate. At the typical feed rate used Norway, 1–1.5 kg/hour, the emission factor for PM_{10} is as large as 40 kg/ton. US EPA AP 42 gives a factor of 15.3 kg/ton (US EPA, 1995) , and 18.5 kg/ton in a more recent publication (US EPA, 1998). Thus, there is a wide range of EFs for wood burning in small stoves.

In the lack of EF data for UB stoves, we suggest to use the most recent US EPA factor, 18.5 kg/ton.

Appendix G: Ulaanbaatar Traffic Data

Ulaanbaatar traffic counting

Results from traffic countings

Traffic was counted at 9 street sections in UB during the period, at the request of the NILU part of the AMHIB team. The counting activity was organised by the AMHIB team, executed by NUM, based upon a note developed by NILU. The traffic was counted for 3 15-minute periods during one day at each of the 9 streets, separately in each traffic direction. The 3 15-minute periods were in morning rush hour (period between 9 and 10 AM), midday traffic (period between 1 and 2 PM) and during evening rush hour (between 6 and 7 PM). The vehicles were classified and counted in 7 different vehicle classes. See details in Table G1.

Based upon information provided by NUM about the gasoline/diesel fuel mix within each of the counted classes, the 7 classes were distributed across 6 vehicle/fuel classes suitable for input to emission factor assessment and input to air pollution modelling, as described in section below.

In the right-most sections in Table G1, the average daily traffic has been estimated, based upon the counting and the 6-class classification. The average count in the 3 15-minute periods was considered to represent the average traffic count over the entire day (ADT). It was considered that this traffic lasted for 13 hours, between 7 AM and 8 PM, and that the total evening-nighttime traffic was about 10% of this daytime traffic. This method provides for a rough estimate of the ADT at each of the streets, with a limited accuracy roughly estimated to be within +/–20%.

The estimated ADT varied between about 33,000 and 57,000 at 8 of the 9 street sections, while the 9th section was relatively low traffic, with an ADT of about 14,000.

The traffic flow was dominated by light duty vehicles at all counted sections. The heavy duty fraction varied between about 3% (at the no. 1 section: Bayangol Hotel and the no. 4 section: Library Gorki) to about 12% (at the no. 8 section: Traffic Police). Buses dominated the heavy duty fraction at some sections, and light duty trucks at other sections.

The diesel fuelled share of the light duty vehicles varied within 10–15%.

While the heavy duty share of vehicles in Europe is generally dominated by diesel fuelled vehicles with large emissions of exhaust PM, the situation in UB is quite different, where almost all buses and light and medium heavy trucks are gasoline fuelled, with comparatively low exhaust PM emissions.

Ulaanbaatar vehicle classes and emission factors for exhaust PM

The following vehicle/fuel classes are defined for UB, based upon information provided by NUM about the fuel mix within each of the vehicle classes counted, see section above:

Table G1: Results from traffic countings at selected street sections in Ulaanbaatar

No1.Bayangol Hotel — Road 3

?	Vehicle Class	9-10 öää To Center	9-10 öää from Cente	13-14 öää To Center	13-14 öää from Cente	18-19 öää To Center	18-19 öää from Cente	Total	ADT
1	Motor car, taxi	329	436	258	239	285	262	1809	36059
2	Jeep	110	98	91	118	86	127	630	12558
3	Micro Bus	15	34	15	10	11	80	165	3289
4	Big passenger Bus	18	15	8	14	5	18	78	1555
5	Truck to 2,5t	4	9	1	1	1	0	16	319
6	Truck above 2,5t	0	1	0	1	0	0	2	40
7	Motocycle	2	0	0	2	0	0	4	80
							Total		53900

No1.Bayangol Hotel		ADT
1	Light Duty Vehicles, Gasoline	44372
2	Light Duty Vehicles, Diesel	7535
3	Buses, Gasoline	1555
4	Light Heavy Duty Vehicles, Gasoline	319
5	Medium Heavy Duty Vehicles, Diesel	28
6	Medium Heavy Duty Vehicles, Gasoline	12
	Total	53820

No2.Ö?í ñí èè 20-ð ä?ë Center Point

?	Vehicle Class	9-10 öää From Cent	9-10 öää To Center	13-14 öää From Cent	13-14 öää To Center	18-19 öää From Cent	18-19 öää To Center	Total	ADT
1	Motor car, taxi	290	357	344	309	379	373	2052	40903
2	Jeep	71	91	72	91	93	98	516	10286
3	Micro Bus	8	3	15	12	21	18	77	1535
4	Big passenger Bus	30	28	21	18	16	16	129	2571
5	Truck to 2,5t	1	3	4	2	10	2	22	439
6	Truck above 2,5t	0	0	0	0	0	0	0	0
7	Motocycle		2	1	1	0	3	7	140
							Total		55873

No2.Ö?í ñí èè 20-ð ä?ëä??ð		ADT
1	Light Duty Vehicles, Gasoline	46552
2	Light Duty Vehicles, Diesel	6171
3	Buses, Gasoline	2571
4	Light Heavy Duty Vehicles, Gasoline	439
5	Medium Heavy Duty Vehicles, Diesel	0
6	Medium Heavy Duty Vehicles, Gasoline	0
	Total	55734

No6.Televiz

?	Vehicle Class	9-10 öää From Cent	9-10 öää To Center	13-14 öää From Cent	13-14 öää To Center	18-19 öää From Cent	18-19 öää To Center	Total	ADT
1	Motor car, taxi	147	263	117	188	151	205	1071	21349
2	Jeep	20	54	25	38	65	54	256	5103
3	Micro Bus	18	35	17	23	31	31	155	3090
4	Big passenger Bus	6	4	3	3	5	3	24	478
5	Truck to 2,5t	14	20	24	17	22	22	119	2372
6	Truck above 2,5t	0	1	1	2	4	1	9	179
7	Motocycle	0	1	1	0	0	0	2	40
							Total	1636	32611

No6.Televiz		ADT
1	Light Duty Vehicles, Gasoline	26479
2	Light Duty Vehicles, Diesel	3062
3	Buses, Gasoline	478
4	Light Heavy Duty Vehicles, Gasoline	2372
5	Medium Heavy Duty Vehicles, Diesel	126
6	Medium Heavy Duty Vehicles, Gasoline	54
	Total	32571

No8.Traffic Police

?	Vehicle Class	9-10 öää To center	9-10 öää From Center	13-14 öää To center	13-14 öää From Center	18-19 öää To center	18-19 öää From Center	Total	ADT
1	Motor car, taxi	200	218	253	245	250	263	1429	28485
2	Jeep	60	64	70	64	79	87	424	8452
3	Micro Bus	31	78	42	37	45	28	261	5203
4	Big passenger Bus	0	2	6	0	1	2	11	219
5	Truck to 2,5t	28	38	43	45	33	36	223	4445
6	Truck above 2,5t	11	7	23	5	15	11	72	1435
7	Motocycle	2	2		1		0	5	100
							Total		48338

No8.Traffic Police		ADT
1	Light Duty Vehicles, Gasoline	37068
2	Light Duty Vehicles, Diesel	5071
3	Buses, Gasoline	219
4	Light Heavy Duty Vehicles, Gasoline	4445
5	Medium Heavy Duty Vehicles, Diesel	1005
6	Medium Heavy Duty Vehicles, Gasoline	431
	Total	48239

No9.School 17

?	Vehicle Class	9-10 öää From Center	9-10 öää To Center	13-14 öää From Center	13-14 öää To Center	18-19 öää From Center	18-19 öää To Center	Total	ADT
1	Motor car, taxi	219	262	166	160	247	169	1223	24378
2	Jeep	28	28	54	50	72	46	278	5541
3	Micro Bus	32	48	30	19	54	47	230	4585
4	Big passenger Bus	12	8	3	6	5	9	43	857
5	Truck to 2,5t	23	26	28	30	32	25	164	3269
6	Truck above 2,5t	5	2	7	3	0	1	18	359
7	Motocycle	0	0	0	0	1	0	1	20
							Total		39010

No9.School 17		ADT
1	Light Duty Vehicles, Gasoline	31180
2	Light Duty Vehicles, Diesel	3325
3	Buses, Gasoline	857
4	Light Heavy Duty Vehicles, Gasoline	3269
5	Medium Heavy Duty Vehicles, Diesel	251
6	Medium Heavy Duty Vehicles, Gasoline	108
	Total	38990

No3.Super market 1

?	Vehicle Class	9-10 öää From Center	9-10 öää To Center	13-14 öää From Center	13-14 öää To Center	18-19 öää From Center	18-19 öää To Center	Total	ADT
1	Motor car, taxi	238	282	268	232	291	249	1560	31096
2	Jeep	58	42	79	52	83	46	360	7176
3	Micro Bus	6	8	8	21	8	6	57	1136
4	Big passenger Bus	11	9	10	12	7	12	61	1216
5	Truck to 2,5t	3	4	4	5	2	4	22	439
6	Truck above 2,5t	0	0	0	0	0	1	1	20
7	Motocycle	0	0	1	0	0	1	2	40
							Total		41122

No3.Super market 1		ADT
1	Light Duty Vehicles, Gasoline	35103
2	Light Duty Vehicles, Diesel	4306
3	Buses, Gasoline	1216
4	Light Heavy Duty Vehicles, Gasoline	439
5	Medium Heavy Duty Vehicles, Diesel	14
6	Medium Heavy Duty Vehicles, Gasoline	6
	Total	41083

No4.Library GorKi

?	Vehicle Class	9-10 öää From Cent	9-10 öää To Center	13-14 öää From Cent	13-14 öää To Center	18-19 öää From Cent	18-19 öää To Center	Total	ADT
1	Motor car, taxi	41	143	44	113	96	63	500	9967
2	Jeep	18	45	14	52	26	27	182	3628
3	Micro Bus			3	4		1	8	159
4	Big passenger Bus	0	0	0	0	8	0	8	159
5	Truck to 2,5t	2	1	2	6	0	1	12	239
6	Truck above 2,5t							0	0
7	Motocycle							0	0
							Total		14153

No4.Library GorKi		ADT
1	Light Duty Vehicles, Gasoline	11577
2	Light Duty Vehicles, Diesel	2177
3	Buses, Gasoline	159
4	Light Heavy Duty Vehicles, Gasoline	239
5	Medium Heavy Duty Vehicles, Diesel	0
6	Medium Heavy Duty Vehicles, Gasoline	0
	Total	14153

No5.Dulgeen Nuur

?	Vehicle Class	9-10 öää From Cent	9-10 öää To Center	13-14 öää From Cent	13-14 öää To Center	18-19 öää From Cent	18-19 öää To Center	Total	ADT
1	Motor car, taxi	224	253	211	274	385	373	1720	34285
2	Jeep	59	98	47	66	73	84	427	8512
3	Micro Bus	81	95	46	61	95	98	476	9488
4	Big passenger Bus	8	8	4	6	7	7	40	797
5	Truck to 2,5t	17	27	30	25	34	28	161	3209
6	Truck above 2,5t	2	2	5	3	5	7	24	478
7	Motocycle	0	0	1	1	1	0	3	60
							Total		56830

No5.Dulgeen Nuur		ADT
1	Light Duty Vehicles, Gasoline	47178
2	Light Duty Vehicles, Diesel	5107
3	Buses, Gasoline	797
4	Light Heavy Duty Vehicles, Gasoline	3209
5	Medium Heavy Duty Vehicles, Diesel	335
6	Medium Heavy Duty Vehicles, Gasoline	144
	Total	56770

No7.Sansar

?	Vehicle Class	9-10 öää From Cent	9-10 öää To Center	13-14 öää From Cent	13-14 öää To Center	18-19 öää From Cent	18-19 öää To Center	Total	ADT
1	Motor car, taxi	156	191	181	201	211	231	1171	23342
2	Jeep	48	49	66	64	88	93	408	8133
3	Micro Bus	45	58	39	39	47	36	264	5262
4	Big passenger Bus	6	7	5	4	3	3	28	558
5	Truck to 2,5t	15	29	22	20	23	15	124	2472
6	Truck above 2,5t	0	0	1	1	1	1	4	80
7	Motocycle	0	0	0	2	0	0	2	40
							Total		39887

No7.Sansar		ADT
1	Light Duty Vehicles, Gasoline	31857
2	Light Duty Vehicles, Diesel	4880
3	Buses, Gasoline	558
4	Light Heavy Duty Vehicles, Gasoline	2472
5	Medium Heavy Duty Vehicles, Diesel	56
6	Medium Heavy Duty Vehicles, Gasoline	24
	Total	39847

i. Classes / fuel:
   1. Light duty vehicles, gasoline: 'Motor car', taxi, micro bus, 40% of jeeps
   2. Light duty, diesel: 60% of jeeps
   3. Buses, diesel: 'big passenger bus'
   4. Light heavy duty vehicles, diesel: 'Truck up to 2.5 tons' (might be added to class 1).
   5. Medium heavy duty vehicles, diesel: 70% of 'Truck above 2.5 tons'
   6. Medium heavy duty vehicles, gasoline: 30% of 'Truck above 2.5 tons'

ii. Emission factors, PM, basic factors (at 60 km/h):
   —Vehicle class:
   1. 0.10 g/km
   2. 2 g/km
   3. 2 g/km
   4. 2 g/km
   5. 2 g/km
   6. 0.4 g/km

   —Traffic speed
   Use 30 km/h in central area, 50 km/h on ring roads, etc, and 70 km/h on main roads out from UB.

Further traffic volume estimations for UB street sections

Based upon the counting described above, the NUM team was asked to classify the traffic flow in a number of other street sections in UB, the objective being to provide rough estimates that could be used as a basis for traffic and emissions input to the air pollution modelling.

The team was asked to classify the traffic flow as follows:

Code	Estimated traffic flow, ADT
1	< 20,000
2	20,000 – 40,000
3	40,000 – 60,000
4	> 60,000

The results of this classification are shown in Table G2. Figure E7 in Appendix E shows the results of the traffic flow classification.

Table G2: Traffic volume in streets in Ulaanbaatar

No	Name of points	Number of points	Traffic volume code
1	100 ailiin toiruu	10	1
2	Baraan zakh	11	2
3	Denjiin myanga	12	3
4	III surguul	13	3
5	Tasganii Ovoo	14	3
6	Ekh nyalkhasiin emneleg	15	3
7	Geseriin zuun tald	16	2
8	Narnii titem	17	3
9	Bombogor	18	3–4
10	Bombogoroos 4 zam khurtel	19	3
11	ETN Ordon	20	3
12	Durslekh urlagiin muzei	21	2–3
13	Y surguuli	22	2
14	Germany Elchin	23	1
15	EZD Surguuli	24	2

(*continued on next page*)

Table G2: Continued

No	Name of points	Number of points	Traffic volume code
16	Khogjimiin colloge	25	3
17	SHUTI Surguuli	26	3
18	Bagshiin ikh surguuli	27	3–4
19	Lenin club	28	3–4
20	Ikh tengeriin zam	29	2
21	Shine pioneriin ordon	30	3
22	Parkiin urd	31	3–4
23	Emiin zavod	32	3–4
24	Teeveriin tovchoo	33	4
25	YII guanz	34	2–3
26	Bars zakh	35	4
27	25 aptek	36	4
28	Od kinoteatr	37	3–4
29	Moskva restoran	38	4
30	28-r surguuli	39	2
31	Emkh taivnii guuriin urd	40	3
32	Zaisan	41	<1
33	18-r surguuli	42	3
34	Tunnel	43	3
35	Bokhiin orgoo	44	3–4
36	Khavdar sudlal	45	4
37	13-iin dund zam	46	1
38	Narantuul (baruun zam)	47	4
39	Narantuul (uulzvar)	48	4
40	15 khoroolol	49	2

Street sections outside UB centre area

No	Name of points	Number of points	Traffic volume code
1	Bayankhoshuu (araar)	1	2
2	Bayankhoshuu (urduur)	2	2
3	Tolgoit	3	1
4	5 Shar	4	3–4
5	Gurvaljin guur	5	3
6	IY stantsiin yrd zam	6	<1000
7	Yaarmag	7	3
8	Bayanzurkh duureg	8	2–3

Appendix H: Air Pollution Modelling in UB in AMHIB: Methods, Tools and Model Evaluation

Modelling of air pollution in UB using the NILU AirQUIS system

The AirQUIS system

The AirQUIS system (AirQUIS, 2008; Slørdal et al, 2008) is an integrated air quality management system that contains different modules, such as emission inventory module, GIS related geographical information module, measurement module, models module, etc.

The models used in the present AirQUIS system include models for calculating emissions, dispersion and exposure on urban scales:

- Emission model
- Wind field model—The diagnostic wind field model (Mathew)
- Pollution dispersion model—The urban dispersion model (EPISODE)
- Exposure model—For stationary population exposure assessment

The combined functionalities of emission inventory, numerical modelling, on-line monitoring data collection and statistical assessment methods, within an operable and functional GIS platform, makes AirQUIS an effective tool for air quality management, assessing present air quality and projecting future air quality and evaluating available abatement options and strategies.

Modelling tools applied in AMHIB and this Discussion Paper

To carry out the air quality modelling for UB city, the air quality model EPISODE and the meteorological model The Air Pollution Model (TAPM. See below) were used. TAPM has been used for the purpose to prepare the meteorological data for the modelling period, since there were significant gaps in the local meteorological measurement data. The EPISODE model is an urban air quality model integrated in the AirQUIS system. These models were run for UB for evaluating the present air pollution state, human exposure and the effects of planned interventions to improve the air quality.

The EPISODE model

The dispersion model EPISODE (Slørdal et al, 2003) is a Eulerian grid model with embedded subgrid models for calculation of pollutant concentrations resulting from different types of sources (area-, line- and point sources). EPISODE solves the time dependent advection/-diffusion equation on a 3 dimensional grid. The EPISODE model has been applied for the calculation of pollution compounds such as SO_2, CO, O_3, NO_2, NOx, PM_{10} and $PM_{2.5}$.

In addition to the Eulerian grid model, EPISODE also contains different sub-grid models for refined calculations in areas close to important sources.

The sub-grid line source model within the EPISODE is based on a standard integrated Gaussian model, HIWAY-2. This model calculates concentration levels of non-reactive pollutants from road traffic at distances from a few to hundreds of meters downwind of the road. Each lane of traffic defined in the road system is treated as a straight, continuous, finite length, line source with a uniform emission rate. In the UB modelling, the traffic source has been treated as an area source, thus this line source model was not activated there.

Two different types of point-source sub-grid models can be applied optionally in the EPISODE. One is based on a segmented plume/trajectory model, while the other is the puff/trajectory model INPUFF. In both models the emissions from individual sources are treated as a temporal sequence of instantaneous releases of a specified pollutant mass. The air pollution resulting from the power plant emissions in UB was calculated using the embedded INPUFF model.

Input data required by EPISODE

Emissions inventory

The emissions inventory module contains data such as fuel consumption, emission factors, physical description of stacks and processes, traffic load etc. Estimates of hourly emissions of the different air quality components are calculated by application of the emission model. The emission inventory includes three categories of sources:

- Point source emission: Emissions from power plants, large industrial plants and significant single sources (e.g. larger boilers).
- Line source emissions: Emissions from road traffic. In the calculation, roads with annual daily traffic above a user defined limit value are included as line sources. The emissions from the roads with lower annual daily traffic are treated as area sources.
- Area sources emissions: Both stationary sources that are too small to be regarded as point sources as well as road traffic emissions from roads with low traffic loads.

Meteorological data

Meteorological data is prepared for input to the EPISODE model. The meteorological data can be acquired from local meteorological stations, or simulated by meteorological models. The required meteorological parameters are: wind (speed and direction), temperature, atmospheric stability, horizontal and vertical turbulence and mixing height. Cloud cover, relative humidity and precipitation are asked as optional.

Background concentrations

The contributions of the different species to the pollution of the air transported into the urban area (the regional air pollution component from sources outside the city and transported from larger distances) are specified at the open boundaries of the model domain as a constant value. This value can be user specified or taken from a background measurement station.

The TAPM model

TAPM ('The Air Pollution Model') (Hurley et al, 2005) is a PC-based nestable prognostic meteorological and air pollution model. TAPM was in this work as a meteorological model, to close the data gaps in observational data for parts of the modelling period.

AirQUIS input and model set up

Geographical data

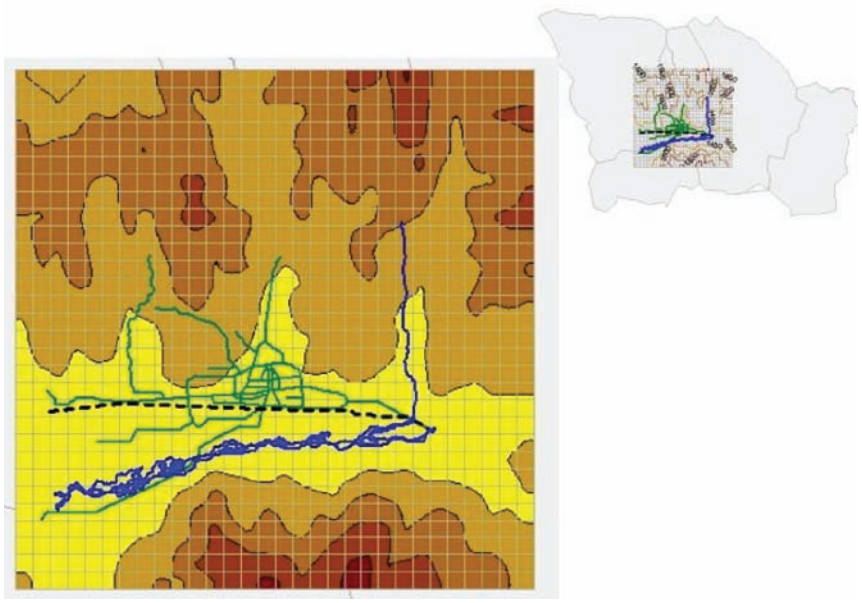
Topography

The terrain information has been downloaded from http://www.esri.com/data/resources/geographic-data.html and prepared for modelling domain on the 1 km resolution.

Model domain and grid

In this GIS based system, UTM coordinates are applied for this work. In order to have all information consistent, all collected information based on Lat/Lon coordinates have been converted to UTM coordinates. The model

Figure H1: The domain used for air pollution modelling in this work (1×1 km² grid)



domain lower left point coordinates are the same as in Guttikunda's (2007) model domain. There are exactly 30×30 grids on a 1 km resolution, covering a 900 km² area. The model domain covers the urban area of UB and its surroundings (Figure H1).

Emission data and inputs

The details of the emissions inventory used for UB in this work are given in Appendix E. The UB sources are introduced into the model system as either point sources or area sources. In the emissions inventory, the traffic source is treated as line sources (road sections). For the modelling, the traffic source emissions are entered as area sources.

Point sources

There are 3 power plants located in the southwest of UB city. The stacks in these power plants have been treated as point sources. Stacks physical information, such as exact coordinates, stack height, width, flow rates and cleaning efficiencies have been input for the simulatio n. The power plants are fully running over the year for supplying electricity for the city, therefore, no time variation factors applied for these power plants. It is assumed that the SO_2 are directly emitted without any cleaning process, and for the dust, the cleaning efficiencies are 80%, 80% and 95% separately.

Area sources

In UB, based on the pollution released height, emissions from households in gers, kiosks, heat only boilers (HOBs), brick plants, and waste burnings are considered as area sources. Those emissions data are taken from Guttikunda (2007) grids emission, as well as the distribution factors. When importing the data to the AirQUIS system, the emissions in the grids was projected from Lat/Lon coordinates to UTM coordinates by its locations, and then redistributed on the new grids.

The coal consumption in gers and HOBs is used for heating and cooking, therefore, an obvious seasonal variation is applied. This emission time variation is based on the estimated energy consumption during a year. The kiosks, and waste burning are activities do not change

much with seasons, so no time variation factors have been applied. The brick making plants are only in operation about 7 months from April to October and closed in the rest of the year.

Line sources

Traffic related emissions include not only direct exhaust emissions. The fugitive dust from the roads (dry dust on the roads suspended in air due to the action of the turbulence created by passing vehicles) is a very import source of $PM_{2.5}$ and PM_{10} in UB.

Meteorological data

One year's meteorological observation data for UB (year 2007) were provided by NAMHEM. The meteorological data is available for most of the year, but data in January, and the first half of February, April, and December are missing. The meteorological parameters available are wind speed, wind direction, surface temperature, precipitation, radiation, humidity and pressure.

The missing local meteorological data were then supplemented by data calculated by the TAPM model. TAPM was run to calculate the vertical thermal structure over the model domain as the input for EPISODE model. In this work, TAPM set up on a 300 km × 300 km horizontal domain, and nested for UB region on finer scales (27 km × 27 km, 9 km × 9 km, and 3 km × 3 km). Six hourly synoptic analyses data on a longitude/latitude grid at 0.75- or 1.0-degree grid spacing (approximately 75 km or 100 km) were used for driving TAPM, prepared from LAPS or GASP analysis data.

In air pollution modelling, it is important to capture the local-scale meteorological conditions. Especially the stable and low wind speed situations often lead to air pollution episodes (Kukkonen et al, 2005). Meteorological data simulated for UB by TAPM has been evaluated through comparing with the local meteorological measurements for periods when both where available. The results shows that TAPM generally does well at simulating the meteorological parameters under most conditions, except an underestimation of low wind speed during night time. The difficulties of reproducing the low wind speeds is also discussed by previous studies (Anfossi et al, 2005). It is a common problem both for TAPM and MM5 and other similar meteorological models, when turbulent motions may be of the same order as the wind speed (Tang et al, 2009). For better simulation of the distribution of air pollutants, the wind speed from the TAPM model was adjusted during night time for winter months, where observation data were missing. The adjustment is based on the observation that the low wind speed is dominating in winter nights, and a low wind speed 0.7 m/s was fixed during the nights in January and December, between 16:00–03:00 hours.

Air quality measurements

At the start of the AMHIB study, there were limited PM observation data available from UB. There are 4 stations in UB with SO_2 measurements, the data from those 4 stations has been obtained. The measurements are used for model evaluation. SO_2 measurements are available for most of the year 2007 as daily average. The PM data is measured as coarse and fine PM at University site about two times a weeks.

Model evaluation by comparison with measurements

Model set up for year 2007

The modelling year was set to 2007. Meteorological data were available, and the emissions inventory was updated for 2007.

The air quality model was run for the full year of 2007. The model has meteorological and emissions input for every hour, and the model results are also provided on the hourly base. Because all measurements from UB are daily averages, the model results have to be averaged and compared with measurements on the daily basis. The model has a 1 km horizontal resolution, and vertically there are 10 modelling

layers, from surface to 2750 m height, the first layer is 20 meter, and 3 layers close to surface are in the lowest 100 meter.

Meteorological conditions during this period

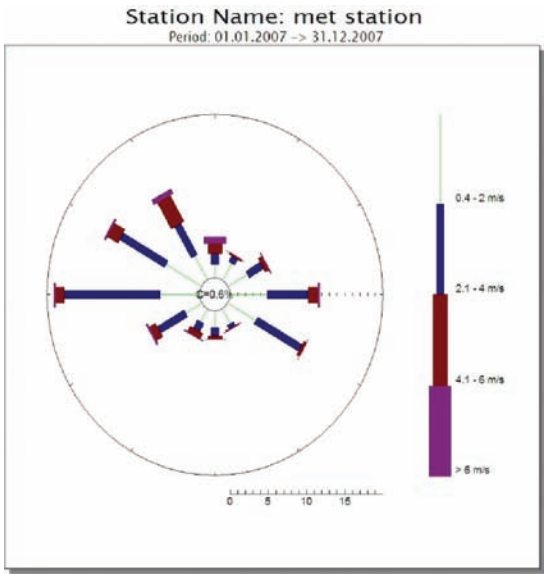
Local wind measurements have been acquired from NAMHEM, and wind rose fractions and stability frequency for this period are presented here. It shows that the dominating winds during 2007 are westerly with wind speeds generally below 4m/s. The second dominating wind sectors are from northwest and east/southeast. Because the large point sources are located to the west of the city and the often-occurred stable conditions, their influence over the urban areas of UB is expected to be small. The stability frequencies show that the stable, light stable and neutral conditions occupy most of the evening, night time and early morning hours, when the coal consumption in ger households also peaks. These kinds of meteorological conditions limit the vertical dispersion of air pollutants, especially in the winter days when air is stable and emissions are high, creating episodes of very high pollution levels.

Model simulated SO_2 concentrations and comparison with measurements

Figure H3 shows the comparison of modelled with measured concentrations of SO_2 at the four CLEM monitoring stations UB 1–4, located as shown in the report. The measured concentrations have been adjusted according to comparison results described in section 4.3.4 below. The measured SO_2 levels vary considerably between the sites, with high winter concentration levels from as low as 50 µg/m³ at UB-1 to about 100 µg/m³ at UB-2. The seasonal variation is similar at all stations, with very low concentrations in the summer, reflecting the low consumption of coal for ger heating and for HOBs then. The CHPs are also operating in the summer, and the low summer concentrations reflect the small contribution from the CHPs to ground level concentrations, because of the tall stacks.

Figure H2: Meteorological conditions during the modelling period

a) Wind rose with wind classes



b) Stability frequency by hour of the day

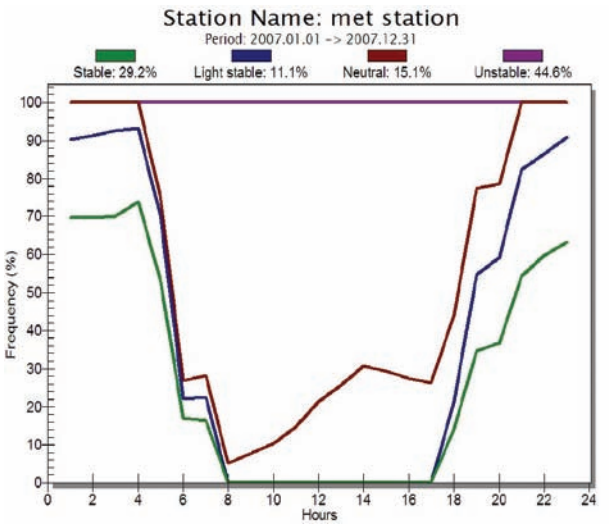


Figure H3: SO_2 concentrations at stations UB 1–4. Measured and modelled daily average concentrations, 2007 (µg/m³)

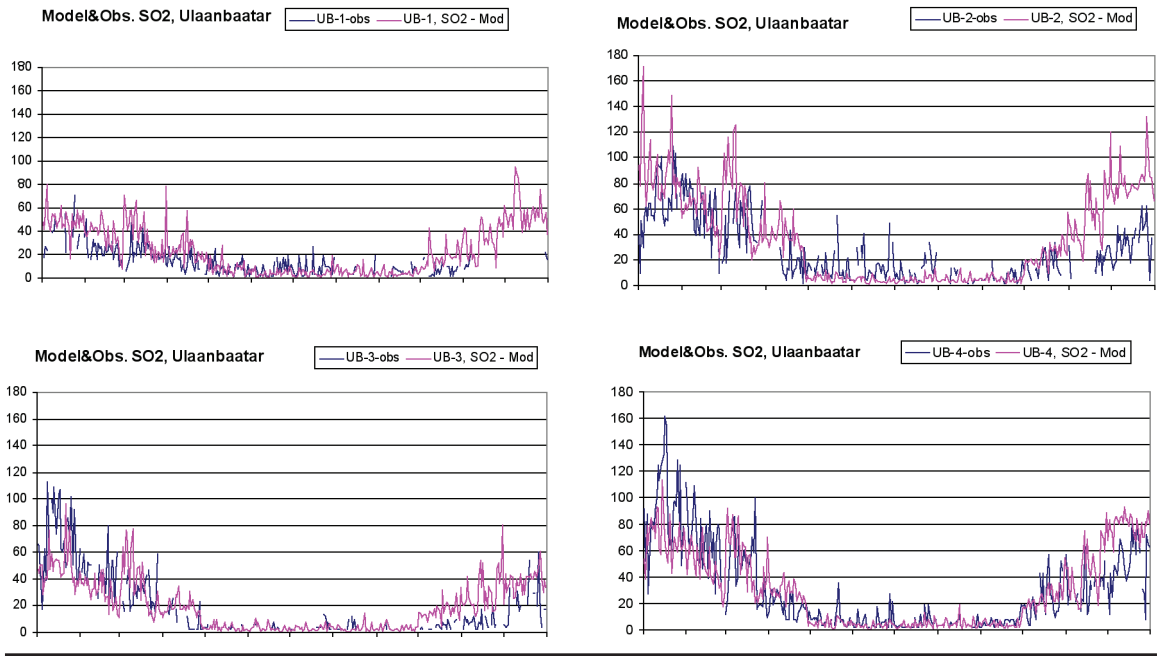


Table H1: Measured and modelled annual average SO_2 (µg/m³) for stations UB 1-4, 2007

Mon. station	Measured	Modelled	Comment
UB-1	14.2	19.2	1 Jan–10 Nov
UB-2	28.4	35.9	Entire year
UB-3	23.0	19.6	Entire year
UB-4	31.1	30.6	Entire year

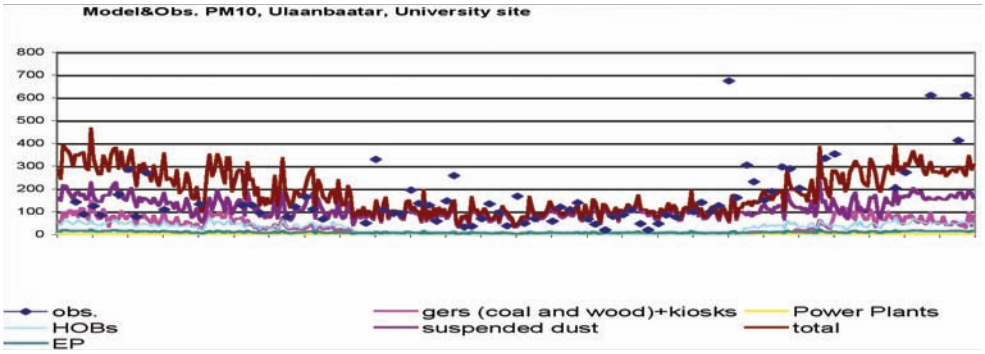
The emissions that are input to the model calculations, total emissions per source and its spatial distribution and time variation, are according to the emissions inventory in Chapter 4.

The modelled concentrations follow the seasonal variation of the measurements well, and also reflect the different levels at the four stations. There are some deviations from the measurements in some periods, such as for the UB-2 station, located a bit to the west of UB centre area: overestimation during early January and in November–December, and in early March, there is overestimation at 3 stations, UB-1,2 and 3, but not at UB-4. Apart from this, the agreement between measured and modelled concentrations is quite good. Table H1 shows measured and modelled annual averages.

Model simulated PM concentrations and comparison with measurements

For the purpose of the model simulation, PM is measured at only one station, the NUM station at National University of Mongolia. As described in Appendix C, the NUM sampler gives reasonably good data for PM_{10}, while it underestimates the

Figure H4: Measured and modelled PM_{10} (daily average) at the NUM measurement site



Contributions from various sources.

concentration of $PM_{2.5}$. Thus comparison of modelled concentrations with measured ones can only be done for PM_{10}.

Figure H4 shows measured data and modelled contributions to PM_{10} from a number of sources. The measurements are taken generally on two days per week. The brown line shows the total modelled PM_{10} concentration, with contributions from ger and kiosks coal and wood, HOBs, CHPs, vehicle exhaust particles and suspended dust from roads.

Note that Figure H4 represents the NUM site only. The contributions from the various PM sources to ground level concentrations varies substantially throughout the city: e.g. in ger areas the ger household emissions will dominate more, while in the city centre the exhaust emissions and suspension will be more dominant. This is shown in detail in Chapter 3.

The model results overestimate the measurements early in the year (January–February) and underestimates at the end of the year (November–December) 2007. Inspection of the measurements as shown in Chapter 3 shows that the amount of suspension of dry dust (the coarse fraction of PM) was small in January–February and very large in November–December in that year. Suspension of dust from surfaces is to a large extent a non-steady mechanism. Dust is building up on the surfaces during humid and low wind periods, and then released when exposed to turbulence when it is very dry. We do not have independent data for dryness/wetness to study such details. Our model gives a steady suspension from the roads, hour-by-hour only dependent upon traffic amount. Thus, the model cannot reproduce the winter-time suspension dynamics day-by-day. During the summer period, suspension is the completely dominating PM_{10} source. Figure H4 shows that the model estimates the summer-time PM_{10} reasonably well on the average.

The model predicts an annual average PM_{10} of 163 µg/m³, all source contributions added. The measurements give 157.7 µg/m³ (see Table H2 below). Each of the source contributions have been modelled based upon separate scientific considerations and upon the input of emissions as inventoried in Chapter 3. The estimated annual average concentration from the measurements is made up of data from only 2 days per week. The annual average produced by this time coverage will deviate from an annual average if all days had been sampled, while the modelled annual average is based upon hourly data throughout the year. The uncertainty related to the 2-day-per-week sampling instead of all days in the year is estimated to about –/+ 4%. This comes on top of the uncertainty in each of the sampled values, which can be estimated to be +/– 20–25%. Another factor, which is discussed in Appendix C, is that the sampler used for these measurements operates, when the concentrations are high, only during part of the day, from 10 AM and then 6–10 hours. The effect of that is that the sampler

Table H2: Measured PM_{10} and modelled source contributions at the NUM station, 2007 (µg/m³)

a. Concentrations

Source	Measured	Modelled
Ger coal and wood + kiosks		45
HOBs		25
CHPs		1
Vehicle exhaust		10
Suspension		
Paved roads		70
Unpaved roads		12
Total	**157.7**	**163**

b. Source contributions

Source	Source apportionment	Dispersion modelled
Coal and wood combustion	35%	44%
Suspended dust	58%	50%
Vehicle exhaust	6%	6%

generally misses parts of the afternoon-evening peak as well as much of the morning peak, and thus generally gives too low PM values when compared to 24-hour averages, which is what the modelled levels give. Thus, the measured annual average tends to underestimate the PM level systematically.

The modelled PM_{10} concentrations (see the table above) give the following contributions from the main source categories at the NUM station:

- Coal and wood combustion: 71 ug/m³, or 44%
- Suspended dust: 82 ug/m³, or 50%
- Vehicle exhaust: 10 ug/m³, or 6%

The statistical source apportionment from the NUM measurement data (Chapter 3) give 26–35% for combustion—sulphate particles, 51–58% for the soil—construction particles and 6% for motor vehicle particles. Our model thus gives about 10% higher combustion particles contribution at the expense of the soil contribution, while the vehicle exhaust particle contribution is about the same for the two methods. This deviation is within what can be expected, given the uncertainties of both methods.

Environment and Social Development
East Asia and Pacific Region

THE WORLD BANK

1818 H. Street N.W.
Washington, D.C. 20433 USA
Tel: (202) 473-1000
Fax: (202) 473-6391
Internet URL: www.worldbank.org, worldbank.org/eapenvironment

THE WORLD BANK OFFICE ULAANBAATAR

5F, MCS Plaza Building
Seoul Street 4
Ulaanbaatar 210644, Mongolia
Tel: (976-11) 312.647; 312.654
Fax: (976-11) 312.645
Internet URL: www.worldbank.org.mn