Jadambaa, Amarzaya, Spickett, Jeffery, Badrakh, Burmaajav, & Norman, Rosana E.
(2015)
The impact of the environment on health in Mongolia : a systematic review.
Asia-Pacific Journal of Public Health, *27*(1), pp. 45-75.

http://dx.doi.org/10.1177/1010539514545648

The Impact of the Environment on Health in Mongolia: A Systematic Review

Amarzaya Jadambaa, BSc, MPH[1,2], Jeffery Spickett, MSc, PhD[3], Burmaajav Badrakh, PhD, DSc[4], and Rosana E. Norman, PhD[2]

[1] Health Sciences University of Mongolia, Ulaanbaatar, Mongolia
[2] School of Population Health, University of Queensland, Herston, Australia
[3] Curtin University of Technology, Western Australia, Australia
[4] Ministry of Health, Ulaanbaatar, Mongolia

Corresponding Author:
Amarzaya Jadambaa, Health Sciences University of Mongolia, Post Office: 44 Box: Uuruu huleen avah, Ulaanbaatar, 14250, Mongolia.
Email: jzaya@yahoo.com

Abstract

Mongolia has significant exposure to environmental risk factors because of poor environmental management and behaviors, and children are increasingly vulnerable to these threats. This study aimed to assess levels of exposure and summarize the evidence for associations between exposures to environmental risk factors and adverse health outcomes in Mongolia, with a particular focus on children. A systematic review was conducted using the PubMed, EMBASE, Web of Science, Global Health Library, CINAHL, CABI, Scopus, and mongolmed.mn electronic databases up to April 2014 . A total of 59 studies meeting the predetermined criteria were included. Results indicate that the Mongolian population has significant exposure to outdoor and indoor air pollution, metals, environmental tobacco smoke, and other chemical toxins, and these risk factors have been linked to respiratory and cardiovascular diseases among adults and respiratory diseases and neurodevelopmental disorders among children. Well-designed epidemiological investigations in vulnerable populations especially in pregnant women and children are recommended.

Keywords

environmental risk factors, exposure, health outcomes, children's health, Mongolia

Introduction

Mongolia has significant exposure to environmental risk factors because of poor environmental management, population behaviors, and the harsh climate. During winter (December-February), the monthly average temperatures in Mongolia are typically –20°C, and the differences between day and night temperatures are usually very large, with night temperatures falling as low as –40°C. Mongolia has a relatively young population, with almost 40% of the total population aged less than 19 years.[1] The proportion of the population living in rural areas has declined from 42.8% in 2000 to 36.7% in 2010[2] because of internal migration. More than half of the Mongolian population now resides in the capital city Ulaanbaatar and lives under environmental pressure. Rapid urbanization in a short period has led to extended *Ger* (traditional dwelling) areas, overcrowded schools and kindergartens, poor access to water and sanitation facilities, and contamination of air, soil, and water. Ulaanbaatar is now one of the most polluted cities in the world.[3] In rural areas, deforestation, desertification, and soil erosion have increased because of climate change[4] and mining activities.[5] Since the 1990s, the mining sector has grown dramatically. In 2013, 11.4% of the total land in Mongolia was under mining license.[6] The Mongolian desert area is the main source of the Asian dust storm, one of 2 major global dust storms (the other being the African dust storm). Changes in environmental conditions may affect the emergence and distribution of diseases, leading to potential new health risks, including respiratory diseases, among young children.[7]

The contribution of environmental risk factors to child health remains underrecognized in health care and public health policy.[8] Generally, children are particularly vulnerable to the negative health consequences associated with environmental changes and social inequalities. In Mongolia, lower-respiratory infections are the leading cause of disease burden, accounting for about 31% of all disability-adjusted life-years among children younger than 5 years.[9] Poor air quality, both indoors and outdoors, is a major contributor to the high prevalenceof respiratory diseases among children. In addition, contamination of drinking water caused by poor sewerage coverage and a social environment without well-developed policies can act in consort not only to threaten the health and lives of children, but also to determine their vulnerability to these threats. Reducing the burden of disease among Mongolian children requires much more focus on prevention, targeting the environmental causes of childhood diseases.

The aims of this study were to identify and assess the significance of environmental risk factors in the Mongolian population, assess levels of exposure, present the burden of adverse health outcomes that were considered to be associated with environmental risk factors, and review the evidence of associations between environmental risk factors and adverse health outcomes in Mongolia, with a particular focus on children.

Methods

Search Strategy and Inclusion Criteria

The PRISMA 2009[10] revision was used as a basis for processing and reporting results of this systematic review (Text S1). A review protocol was developed with methods and inclusion criteria specified in advance (Text S2). We incorporated published studies meeting the following inclusion criteria: for levels of exposure, studies and/or data sources reported levels and/or prevalence of exposure to environmental risk factors in Mongolia[3,5,11-43]; for health consequences of exposure, we included studies investigating an association between exposure to environmental risk factors (air pollution; exposure to chemicals and metals, including mercury, cadmium, lead, and chromium; and water pollution) and health and well-being in Mongolia.[4,14-19,30-59]

In all, 8 electronic databases (PubMed, EMBASE, Web of Science, Global Health Library, CINAHL, CABI, Scopus, and mongolmed.mn up to April 2014) were searched with the assistance of the librarian. The following search terms were used: ((((Mongolia) NOT China) NOT “inner Mongolia*)) AND (environ* OR pollut* OR air OR soil OR water OR expos* OR level* OR concentration OR mining OR lead OR metal* OR health OR smok* OR tobacco OR particulate matter). The search was not restricted to the English language, nor restricted by any other means. In addition, reference lists of included studies were assessed for other relevant studies. Relevant articles in languages other than English were translated.

In addition to the systematic review of electronic databases, we reviewed the World Health Organization (WHO), United Nations, World Bank, and National Statistical Office of Mongolia’s Web sites to identify country-level data for level and prevalence of exposures.[60-65] A total of 7 relevant reports and data sources were downloaded, reviewed, and included.

Data Collection

After preliminary screening, articles deemed relevant were retrieved for examination. Data extraction sheets were pilot tested and revised to include the following:

1. for identifying level and prevalence of exposure: data source, environmental risk factor, exposure definition, study and data characteristics (period of data collection and location), exposure estimation method, level or prevalence of exposure, and comparison with standards;
2. for identifying association between environmental risk factors and health outcomes: publication details, study characteristics (study design, period of data collection, location, sample size, and age group), exposure type, exposure assessment, measured health outcomes, and effect sizes where possible (Text S2).

We assessed risk of bias by concentrating on a set of methodological issues, including on whether or not the sample was representative of the population, study design, ascertainment of exposure to environmental risk factors (whether objective markers of exposure were used and individual biological samples were taken or whether samples were pooled or residence in an area was used as a proxy for exposure), assessment of health outcome (clinical diagnosis or physical measurements and tests vs self-reported), and whether appropriate methods to control confounding were used because these may affect the results of the systematic review.

Results

Of 121 studies screened and assessed for eligibility, 59 satisfied the predetermined inclusion criteria (Figure 1). The majority of studies were conducted in urban areas and main cities (Ulaanbaatar, Darkhan, and Erdenet; n = 36), with only a few studies conducted in Ger districts (n = 7) and rural areas (n = 11). Tables 1 and 2 show the prevalence and levels of exposure to common environmental risk factors in Mongolia, and associations between environmental risk factors and health outcomes among adults and children are reported in Tables 3 and 4.[3-5,11,14-41,44,45,47-49,51,54,55,58,62,66-82]

Distribution of Exposure to Environmental Risk Factors

Air Pollution. Most reported levels of air pollutants in Mongolia[3,11-24] were much higher than permissible levels and standards (WHO Guideline for outdoor 2005 and indoor air 2008 and Mongolian National Standard 4585:2007) especially during winter (Table 1, Figure 2). Figure 2 shows monthly trends in air pollutant (PM, SO_2 and NO_2) concentrations in capital city during the last 12 months.

The ambient concentrations of PM_{10}, $PM_{2.5}$, NO_2, SO_2, and CO in Ulaanbaatar during winter were extremely high (up to 32 times higher than WHO Guideline 2005; Table 1). According to the WHO Household energy database,[25] 60.9% of Ulaanbaatar's population and more than 95% of Mongolia's rural population use solid fuels for cooking and heating. Results of studies done by Spickett et al[18] and Enkhjargal et al[15] show that concentrations of carbon monoxide and PM of indoor air quality pollutants were statistically different depending on the type of dwelling, with indoor air pollution higher in gers and houses than in apartments.

Generally, children spend more than 80% of their time indoors, in their homes, child care, schools, and/or recreational facilities. Schools are particularly challenging places to address indoor air quality issues. In addition, Mongolia's central heating system cannot reach all facilities located in periurban areas because of poor infrastructure. Thus, some of these schools

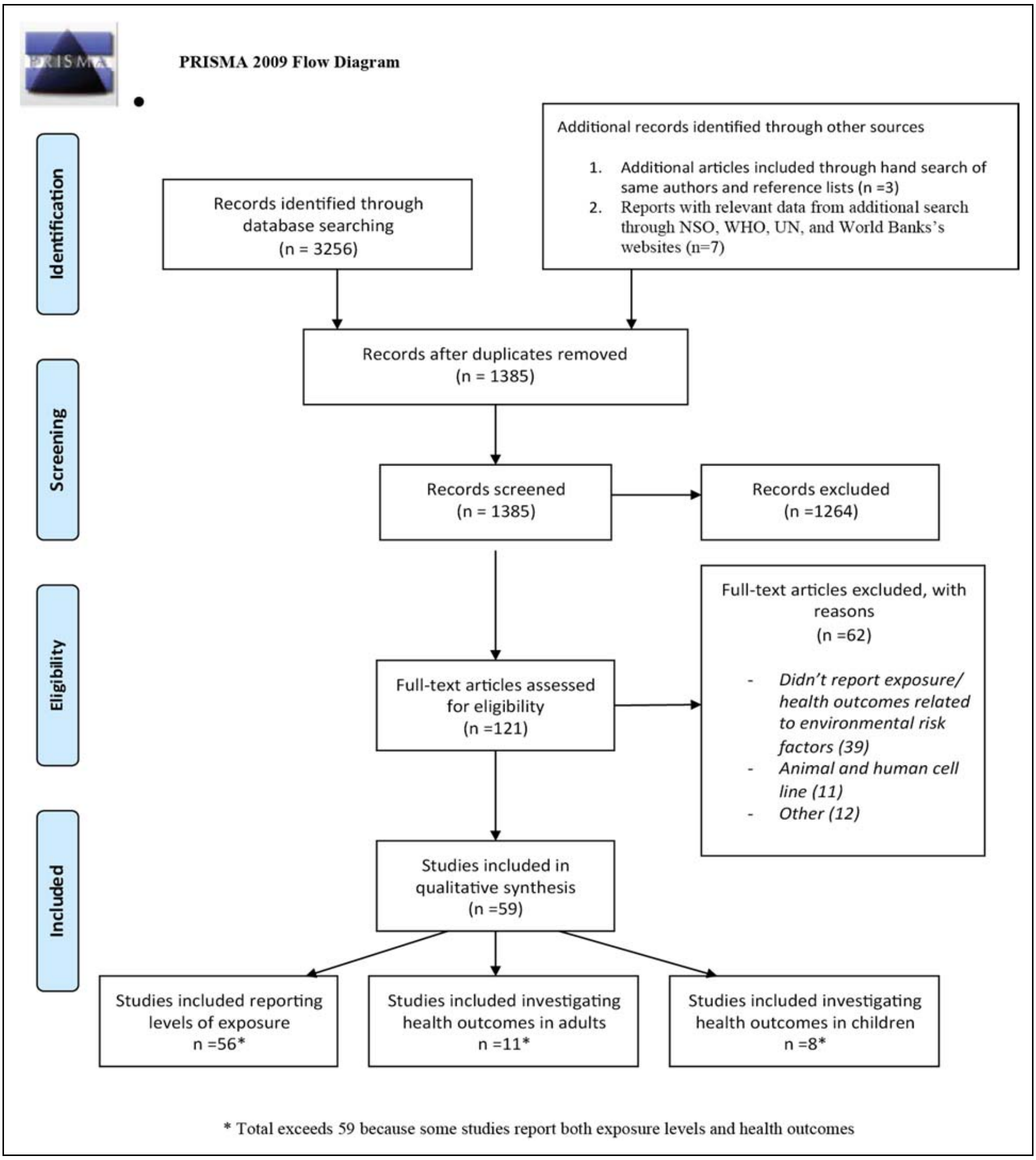

Figure 1. PRISMA flow diagram showing process of study selection for inclusion in systematic review.

Abbreviations: NSO, National Statistical Office; WHO, World Health Organization; UN, United Nations.

use heating boilers that require solid fuels, particularly coal. Consequently, the school environment can significantly contribute to school-going children's exposure to indoor air pollution. Amardulam et al[26] found that periurban schools located in Ger districts were overcrowded because of internal migration, and the indoor volume of classrooms did not meet hygiene standards.

Exposure to Metals. Generally, the most important sources of metals are smelter wastes, solid waste, and mine tailings. Many metal pollutants were found in soil, water, and air in Mongolia[5,20,27-30] at higher than standard levels according to WHO Guidelines and Mongolian National Standards (Table 1).

Table 1. Prevalence and Levels of Exposure to Environmental Risk Factors in Mongolia.

Data Source	Environmental Risk Factor/Permissible Levels/Standards	Exposure Definition	Area	Exposure Estimation Method	Level or Prevalence of Exposure	Comparison With Permissible Levels/Standards
Air pollution						
Lkhasuren et al, 2007[47]	Mongolian maximum allowable limits: coal dust (silica content 10% or less), 6-10 mg/m^3; gold mine dust (silica content 10% or less), 10 mg/m^3; total dust (silica content 10% to ≥70%), 2 mg/m^3 per mg/m^3	Ambient concentration of dust measured in mg/m^3	Coal mining/Gold mining /Power plant areas	NA	Coal mining: 49.2 (2001), 48.4 (2003), 44.6 (2003); gold mining: 15.7 (2001), 10.9 (2002), 10.6 (2003); power plant: 80.4 (2000); 52.0 (2001), 34.4 (2003); all numbers in mg/m^3	>Mongolian maximum allowable limits
Bolor-Erdene et al, 2008[21]	Ambient particulate matter pollution WHO Guideline 2005: $PM_{2.5}$: annual average, 10 $\mu g/m^3$; daily average, 25 $\mu g/m^3$. PM_{10}: annual average, 20 $\mu g/m^3$; daily average, 50 $\mu g/m^3$. Mongolian National Standards (MNS4585: 2007): $PM_{2.5}$: annual average, 25 $\mu g/m^3$; daily average, 50 $\mu g/m^3$. PM_{10}: annual average, 50 $\mu g/m^3$; daily average, 100 $\mu g/m^3$	Ambient concentration of particles ($PM_{2.5}$ and PM_{10}), measured in $\mu g/m^3$ and mg/m^3	Urban: UB and Erdenet	Continuous monitoring and filtering method	Maximum: PM_{10}: (January) 215.5 $\mu g/m^3$; $PM_{2.5}$: (December) 85.1 $\mu g/m^3$. Minimum: PM_{10}: (July) 31.97 $\mu g/m^3$; $PM_{2.5}$: (July) 7.54 $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Jugder et al, 2010[66]			Urban: UB. Rural: Gobi desert area	Detected by polarization-sensitive Mie lidar measurements	During dust event: UB PM_{10} ($PM_{2.5}$) = 63 (57) mg/m^3. Gobi area: 203 (128) mg/m^3; hourly maximum PM_{10} ($PM_{2.5}$) reached 1139-1409 (384-404) $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Delgerzul et al, 2010[16]			Urban: Sukhbaatar district, UB	NA	Annual average of $PM_{2.5}$: 329.7 $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007
World Bank, 2011[55]			Urban: UB	The receptor modeling approach/The dispersion modeling approach	Annual: Central city areas: PM_{10}, 150-250 $\mu g/m^3$; $PM_{2.5}$, 75-150 $\mu g/m^3$; Peri central (Ger) areas: PM_{10}, 350-700 $\mu g/m^3$; $PM_{2.5}$, 200-350 $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Nishikawa et al, 2011[24]				Continuous monitoring and filtering method	Winter (January): PM_{10}: 237 $\mu g/m^3$. Summer (June): PM_{10}: 71.2 $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007

Lodoyasamba and Pemberton-Pigott, 2011[22]		Air sample collection and filtering method	Ger area: monthly average $PM_{2.5}$: maximum, winter (December), 1421 $\mu g/m^3$; minimum, summer (July), 13 $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Allen et al, 2011[3]		Data from UB City Environmental Monitoring Agency's 4 PM monitoring sites	PM_{10}: 165.1 $\mu g/m^3$; $PM_{2.5}$: summer, 22.8 ± 9 $\mu g/m^3$; winter, 147.8 ± 61.2 $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Nagniin et al, 2011[17]		Based on data of air pollution 2004-2008	$PM_{2.5}$: winter, increased from 83.74 ± 11.77 $\mu g/m^3$ (2004) to 184.32 ± 12.03 $\mu g/m^3$ (2008)	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Gunchin et al, 2012[67]		APM samples were collected on polycarbonate filter	$PM_{2.5}$: 94-343 $\mu g/m^3$; PM_{10}: 15-357 $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Batmunkh et al, 2013[68]		Air sample collection and filtering method	$PM_{2.5}$ (12 hours average): 105.1 ± 34.9 $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Guttikunda et al, 2013[69]		The inventory is spatially disaggregated at 0.01° resolution on a GIS platform for use in a chemical transport model (ATMoS)	PM: 153 ± 70 $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and MNS4585:2007
NSO, 2012[70]; NSO, 2013[11]		NA	Maximum: PM_{10}: (December/2012) 5 mg/m^3; $PM_{2.5}$: (December/2012) 2.646 mg/m^3. Minimum: PM_{10}: (July/2012) 0.109 mg/m^3; $PM_{2.5}$: (October/2012) 0.014 mg/m^3	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Jugder et al, 2011[54]	Rural: Gobi desert area	Monitoring and mass concentration method and analyzed along	Annual PM_{10} ($PM_{2.5}$): 60 (38)-120 (94) $\mu g/m^3$. During dust storm: daily maximum: 821 (500) $\mu g/m^3$	>WHO Guideline for outdoor air 2005 and

				with synoptic observations and passages of atom-spherics fronts	and hourly maximum: 6626 (2899) $\mu g/m^3$	MNS4585:2007
Park et al, 2011[71]		Ambient concentration of particles (PM_{10}), measured in $\mu g/m^3$	Rural: Dundgobi province	The FH62C14 (the β-gauge; PM_{10} concentration measuring instrument) and a sonic anemometer-thermometer mounted at a height of 8 m and PM_{10} concentrations measured at 3 m high for dust events are used to develop an optimal regression equation for each month	The maximum hourly mean dust concentration of the dust event was found to be 4107 $\mu g/m^3$ in May in 2009 and 4708 $\mu g\ /m^3$ in March in 2010, whereas minima of 251 $\mu g/m^3$ in August in 2009 and 662 $\mu g/m^3$ in June in 2010 were found	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Allen et al, 2011[3]	Ambient SO_2 pollution 24 hours mean: 20 $\mu g/m^3$; 10-minute mean: 500 $\mu g/m^3$ (WHO Guideline for outdoor air,2005).	Ambient concentration of SO_2 in air, measured in $\mu g/m^3$ and ppb	Urban: UB	Data from UB City Environmental Monitoring Agency's 4 PM monitoring sites	SO_2: 50.5 $\mu g\ /m^3$ or 17.7 ppb	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Nagniin et al, 2011[17]	Annual: 10 $\mu g/m^3$ (MNS 4585:2007)	Ambient concentration of SO_2 in air, measured in $\mu g/m^3$	Urban: UB	Based on data of air pollution 2004-2008	SO_2: annually increased from 1.39 $\mu g/m^3$ (2004) to 10.9 $\mu g/m^3$ (2008)	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Luvsan et al, 2012[23]			Urban: UB/steel industry site; Darkhan/copper mining site. Erdenet/ rural: 8-province center	Monitored using photo-colorimeter	UB: 12.35 ± 14.53 $\mu g/m^3$. Darkhan: 12.56 ± 28.24 $\mu g/m^3$. Erdenet: 3.34 ± 1.69 $\mu g/m^3$. Rural: 3.59 ± 3.99 $\mu g/m^3$	UB and Darkhan: >WHO Guideline for outdoor air 2005 and MNS4585:2007. Erdenet and rural areas: <WHO Guideline for outdoor air 2005 and

						MNS4585:2007
Huang et al, 2013[72]		Ambient concentration of SO_2 in air, measured in ppb	Urban: UB	Analyzed by ion chromatography and spectrophotometry methods	The SO_2 concentrations in 20 ger sites (46.60 ppb in the cold season and 17.82 ppb in the moderate season) were significantly higher than in 18 non-ger sites (23.35 ppb in the cold season and 12.53 ppb in the moderate season)	
NSO, 2012[70]; NSO, 2013[11]		Ambient concentration of SO_2 in air, measured in mg/m^3	Urban: UB	NA	Maximum concentration: January: 0.241 mg/m^3. Minimum concentration: August: 0.003 mg/m^3	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Suvd et al, 2003[19]	Ambient NO_2 pollution 20 minutes: 85 $\mu g/m^3$; 24 hours: 40 $\mu g/m^3$; annual: 30 $\mu g/m^3$ (MNS 4585:2007)	Ambient concentration of NO_2 in air, measured in mg/m^3	Urban: Khan-Uul district, industrial area of UB	NA	0.035 ± 0.001 mg/m^3 (annual)	>WHO Guideline for outdoor air 2005 and MNS4585:2007
Nagniin et al, 2011[17]		Ambient concentration of NO_2 in air, measured in mg/m^3	Urban: UB	Based on data of air pollution 2004-2008	NO_2: annually increased from 4.49 $\mu g/m^3$ (2004) to 6.9 $\mu g/m^3$ (2008)	<WHO Guideline for outdoor air 2005 and MNS4585:2007
Huang et al, 2013[72]		Ambient concentration of NO_2 in air, measured in ppb	Urban: UB	Analyzed by ion chromatography and spectrophotometry methods	The NO_2 concentrations at 19 traffic/road sites (12.85 ppb in the warm season and 20.48 ppb in the moderate season) were significantly higher than those at 19 urban sites (7.60 ppb and 14.39 ppb in the moderate season)	
NSO, 2012[70] NSO, 2013[11]		Ambient concentration of NO_2 in air, measured in mg/m^3	Urban: UB	NA	Maximum concentration: January, 0.309 mg/m^3 and minimum concentration: August, 0.031 mg/m^3	>MNS4585:2007
Suvd et al,	Ambient CO pollution: 30	Ambient	Urban: Khan-	NA	0.51 mg/m^3 (annual)	

2003[19]	minutes, 60 000 μg/m^3; 1 hour, 30 000 μg/m^3; 8 hours, 10 000 μg/m^3. Monthly: 1.5 mg/m^3	concentration of CO in air, measured in mg/m^3	Uul district, industrial area of UB			
NSO, 2012[70] NSO, 2013[11]	(MNS 4585:2007)	Ambient concentration of CO in air, measured in mg/m^3	Urban: UB	NA	Maximum concentration: January, 16.875 mg/m^3. Minimum concentration: July, 0.401 mg/m^3	>MNS4585:2007
Dashdendev et al, 2011[45]		Ambient concentration of CO in air, measured in ppb	Rural: Tuv province. Urban: UB	NA	Mean ambient CO levels were 3-fold higher in the city than in the rural aimag (0.63 ppm vs 0.21 ppm, $P < 0.00005$)	
NSO 2012[70], NSO 2013[11]	Ambient ozone pollution 8 hours: 100 μg/m^3 or 0.1 mg/m^3 (MNS 4585:2007)	Ambient concentration of ozone in air, measured in mg/m^3	Urban: UB	NA	Maximum concentration: May, 0.07 mg/m^3. Minimum concentration: January, 0.004 mg/m^3	<MNS 4585:2007
Burmaa et al, 2002[20]	Pb pollution of the air 24 hour: 1 μg/m^3; annual: 0.5 μg/m^3 (MNS	Concentration of Pb in air measured in	Rural/Urban: UB	Analyzed by atomic absorption spectroscopy	Rural: 1.81 ± 0.02 mg/m^3. Urban: 22.96 ± 0.04 mg/m^3	UB: >MNS4585:2007
Enkhjargal et al, 2006[31]	4585:2007)	mg/m^3	Urban: UB	Analyzed by atomic absorption spectrometer “Spectr-5”	0.0053 ± 0.0008 mg/m^3	>MNS4585:2007
Dorogova et al, 2008[27]			Urban: UB	Analyzed by atomic-absorption spectroscopy	0.0014 ± 0.0005 mg/m^3 (1.5 times higher than national standard)	>MNS4585:2007
NSO, 2011[73]	Household air pollution from solid fuels	Proportion of households	Urban: UB	National household survey 2009	60% Of total households in UB use solid fuels	
WHO, 2007[25]		using solid fuels for cooking (coal, wood, charcoal, dung, and agricultural residues)	Urban: UB. Rural: Total	WHO report 2007	Urban: 60.9%. Rural: more than 95%. Total: 76.8% of total households use solid fuels	
Spickett et	SO_2, CO, and PM pollution	Concentration of	Urban:	Monitoring for	Concentration of carbon monoxide	

al, 2005[18]	of the indoor air/CO: 15 minutes, 100 mg/m^3; 1 hour, 35 mg/m^3; 8 hours, 10 mg/m^3; 24 hours, 7 mg/m^3 (WHO Guideline for indoor air quality)	SO_2, CO, and PM in indoor air, measured by mg/m^3	gers/houses/apartments	indicators of products of combustion	(*P* < .001) and PM (*P* < .01) of indoor air quality pollutants was statistically different depending on type of dwelling, and indoor air pollution was higher in gers and houses	
Enkhjargal et al, 2008[15]	SO_2, NO_2, and PM (10 and 2.5) pollution of the indoor air/SO_2: 0.02mg/m^3; NO_2: 0.03 mg/m^3; PM_{10}: 100 μg/m^3; $PM_{2.5}$: 50 μg/m^3 (MNS)	Concentration of SO_2, NO_2, and PM (10 and 2.5) in indoor air, measured by mg/m^3 and μg/m^3	Urban: UB	24 Hours monitoring	SO_2: 0.002 ± 0.008 mg/m^3; NO_2: 0.019 ± 0.0001 mg/m^3; PM_{10}: 134.9 ± 106.9 μg/m^3; $PM_{2.5}$: 71.53 ± 67.32 μg/m^3	SO_2 < MNS; NO_2 < MNS; PM_{10} > MNS; $PM_{2.5}$ > MNS
Amardulam et al, 2010[26]	Outdoor and indoor area in school/indoors: 1.5 m^2 per pupil and 4.5-5 m^3 per pupil (MNS for hygiene)	Outside and indoor area per pupil and inside volume of classroom per pupil	Urban: UB. Rural: 2 province centers. Totally 55 kindergarten and 69 schools	All sizes measured and collected by researchers, analyzed by using SPSS 10.0 and Statgraphics-6 and compared with MNS for hygiene	UB: outside and inside area per pupil (1.4 ± 0.02 m^2) and indoor volume (4.3 ± 0.07 m^3) are lower than hygienic standards. Rural: met hygienic standard	<MNS for hygiene)
Soil pollution						
Batjargal et al, 2010[28]	As pollution of the soil: 6 mg/kg (MNS5850-2008)	Concentration of As in soil	Urban: UB, 22 samples	Analyzed by aqua regia extraction	The concentration of As at all the sampling sites was above the permissible limit (6 mg/kg) stipulated by the Mongolian soil standard	>MNS5850:2008
UNEP, 2008[33]			Mining area: Khongor soum	Samples analyzed in the internationally accredited testing laboratory in the UK	Detected	NA
Burmaa et al, 2002[20]	Pb pollution of the soil, 100 mg/kg (MNS5850-2008)	Concentration of Pb in soil measured in mg/kg	Rural/Urban: UB	Analyzed by atom absorption spectroscopy	Rural: 44.15 ± 2.02 mg/kg. Urban: 91.88 ± 4.49 mg/kg	<MNS5850:2008
Dorogova et al, 2008[27]			Urban: UB	Analyzed by aqua regia extraction	41.7 ± 18.03 mg/kg: 2.1 times higher than national standard	<MNS5850:2008
Batjargalet			Urban: UB,	Analyzed by Perkin-	The surface samples in S4-T	>MNS5850:2008

al, 2010[28]			33 samples	Elmer 500	(132.32 mg/kg) and S8-T (143.88 mg/kg) and the subsoils in the S1-S (100.28 mg/kg) had a Pb concentration higher than the permissible level	
Kosheleva et al, 2010[5]			Urban: UB, Darkhan, Erdenet	Analyzed by atom-absorption spectroscopy	UB: 19.4-69.1 mg/m^3; Darkhan: 28.3-45.8 mg/m^3; Erdenet: 21.7-32.5 mg/m^3	<MNS5850:2008
Murao, 2006[62]	Hg pollution of the grain and nuggets	Concentration of Hg in grain and nuggets	Gold mining areas located 132 km north west of UB	Micro-PIXE and conducted grain-by-grain analysis of electrum	Hg with a range of 3530-8260 ppm and an average value of 6338 ppm	NA
UNEP, 2008[33]	Methyl-Hg (cyanide) pollution of the soil/ 25 mg/kg (MNS5850-2008)	Concentration of Methyl-Hg in soil measured in mg/kg	Gold mining area: Khongor soum	Samples analyzed in the internationally accredited testing laboratory in the UK	Not detected	Not detected
Kosheleva et al, 2010[5]	Hg pollution of the soil, 6 mg/kg (MNS5850-2008)	Concentration of Hg in soil	Urban: UB, Darkhan, Erdenet	Analyzed by atom-absorption spectroscopy	UB: 0.058-0.185 mg/m^3; Darkhan: 0.022-0.083 mg/m^3; Erdenet: 0.037-0.101 mg/m^3	<MNS5850:2008
UNEP, 2008[33]	Cd pollution of the soil, 3 mg/kg (MNS5850-2008)	Concentration of Cd in soil	Gold mining area: Khongor soum	Samples analyzed in the internationally accredited testing laboratory in the UK	Detected	NA
Kosheleva et al, 2010[5]	Zn pollution of the soil, 300 mg/kg (MNS5850-2008)	Concentration of Zn in soil	Urban: UB, Darkhan, Erdenet	Analyzed by atom-absorption spectroscopy	UB: 42-105 mg/m^3; Darkhan: 50-91.4 mg/m^3; Erdenet: 62.2-128 mg/m^3	<MNS5850:2008
Kosheleva et al, 2010[5]	Nickel pollution of the soil, 150 mg/kg (MNS5850-2008)	Concentration of nickel in soil	Urban: UB, Darkhan, Erdenet	Analyzed by atom-absorption spectroscopy	UB: 24.8-31.1 mg/m^3; Darkhan: 23-34.3 mg/m^3; Erdenet: 30-39 mg/m^3	<MNS5850:2008
Kosheleva et al, 2010[5]	Co pollution of the soil, 50 mg/kg (MNS5850-2008)	Concentration of Co in soil	Urban: UB, Darkhan, Erdenet	Analyzed by atom-absorption spectroscopy	UB: 6.8-8.44 mg/m^3; Darkhan: 5.67-10 mg/m^3; Erdenet: 9.33-13.1 mg/m^3	<MNS5850:2008
Kosheleva et al, 2010[5]	Cr pollution of the soil, 150 mg/kg (MNS5850-2008)	Concentration of Cr in soil	Urban: UB, Darkhan, Erdenet	Analyzed by atom-absorption spectroscopy	UB: 54.4-72.6 mg/m^3; Darkhan: 80-704 mg/m^3; Erdenet: 60-113 mg/m^3	UB and Erdenet: <MNS5850:2008; Darkhan: >MNS5850:2008
Kosheleva	Cu pollution of the soil,	Concentration of	Urban: UB,	Analyzed by atom-	UB: 36-60 mg/m^3; Darkhan: 40-	UB and Darkhan:

et al, 2010[5]	100 mg/kg (MNS5850-2008)	Cu in soil	Darkhan, Erdenet	absorption spectroscopy	52.9 mg/m^3; Erdenet: 95-381 mg/m^3	<MNS5850:2008; Erdenet: >MNS5850:2008
Kosheleva et al, 2010[5]	Mo pollution of the soil, 5 mg/kg (MNS5850-2008)	Concentration of Mo in soil	Urban: UB, Darkhan, Erdenet	Analyzed by atom-absorption spectroscopy	UB: 1.14-1.96 mg/m^3; Darkhan: 1.24-2.78 mg/m^3; Erdenet: 1.5-13.6 mg/m^3	UB and Darkhan: <MNS5850:2008; Erdenet: >MNS5850:2008
Water pollution and sanitation level						
Badrakh et al, 2008[38]	Unimproved water source	Proportion of households using an unimproved water source (unprotected wells or springs, vendor-provided water, tanker trucks, surface water, and other unspecified sources)	Rural (99 samples) and urban (UB, 28 samples) areas	Hygienic conditions, physical, microbiological and chemical parameters of springs	78% Not protected; 45.4% of all springs had *Escherichia coli* contamination and UB city springs had highest *E coli* contamination (67.9%) and 47.6% of all studied rural spring waters were significantly polluted by more than 3 parameters especially E. coli, ammonia, oxygen demand	Safe drinking water is basic requirement for human life (WHO Guideline for drinking water)
UNDP, 2009[37]			Mongolia	2007-2008 Household Socio- Economic Survey	54.5% Of total population use unimproved water source	
Sigel et al, 2012[58]			Darkhan city	Household survey conducted in September 2009	50% Of total inhabitants use unimproved water source	
UNDP, 2009[37]	Unimproved sanitation	Proportion of households using unimproved sanitation (traditional latrines, open latrines without squatting slabs, bucket latrines, hanging latrines. Open defecation or no facilities and	Mongolia	2007-2008 Household Socio- Economic Survey	66.9% Of total population and 4.8% of rural households used unimproved sanitation	Improved sanitation is basic requirement for human life (WHO Guideline for sanitation)
Sigel et al, 2012[58]			Darkhan city	Household survey conducted in September 2009	50% Of total inhabitants use unimproved sanitation	

		other unspecified facilities)				
Bolormaa et al, 2006[29]	As pollution of the water 10 μg/L or 0.01 mg/L (WHO guideline for drinking water)	Concentration of As in water	Rural mining area: Boroo River, 13 water samples	Particle-induced X-ray emission (PIXE) technique	As, ND (not detected) to 5.2 μg/L	<WHO Guideline for drinking water
Munkhbaatar et al, 2008[74]			Gobi desert region of Mongolia (wells and springs)	NA	As: 0.0518 mg/L	>WHO Guideline for drinking water
Battogtokh et al, 2013[36]			Mining area: Erdenet	Analyzed by coupled plasma-optical emission spectrometry	As: 0.01-0.03 mg/L	>WHO Guideline for drinking water
Dalai and Ishiga, 2013[75]			Urban: UB: surface 11 and groundwater 5 samples	Examined by field pack test (Kyoritsu Corp)	As: 8-23 ppm	
Bolormaa et al, 2006[29]	Pb pollution of the water 0.01 mg/L or 10 μg/L (WHO guideline for drinking water)	Concentration of Pb in water	Rural mining area: Boroo River, 13 water samples	Particle-induced X-ray emission (PIXE) technique	Pb, 2.8 and 36 μg/L	>WHO Guideline for drinking water
Dorogova et al, 2008[27]			Urban: UB	Analyzed by aqua regia extraction	Not detected	Not detected
UNEP, 2008[33]			Gold mining area: Khongor soum	Samples analyzed in the internationally accredited testing laboratory	Detected in the wastewater coming from wastewater treatment plant	Detected
Unursaikhan et al, 2010[30]			Urban/Rural areas: stored water in	Samples analyzed by Varian 210 D AAS-10 in accordance with the method stated in	In water stored in oil container: 5-8 mg/L; in water stored in large blue plastic: 0.6-0.72 mg/L; in water stored in metal container:	Amounts were 500-800, 60-72, 240-360, and 122-250 times > WHO

			containers	the standard of GOST 5370-50	2.4-3.6 mg/L; in water stored in aluminum container: 1.22-2.5 mg/L	Guideline for drinking water
Dalai and Ishiga, 2013[75]			Urban (UB) surface 11 and groundwater 5 samples	Examined by field pack test (Kyoritsu Corp)	Pb: 27 ppm (average)	
Nriagu et al, 2012[76]	Uranium pollution of the water 0.03 mg/L or 30 μg/L (WHO guideline for drinking water)	Concentration of uranium in water	Urban: UB, 129 wells	Analyzed by inductively coupled plasma mass spectrometry (ICP-MS) using Clean Lab methods	The levels of uranium were surprisingly elevated (mean, 4.6 μg/L; range <0.01-57 μg/L, with the values for many samples exceeding the World Health Organization's guideline of 15 μg/L for uranium in drinking water	>WHO Guideline for drinking water
Dalai and Ishiga, 2013[75]	Zn pollution of the water not of health concern at levels found in drinking water (WHO guideline for drinking water)	Concentration of Zn in water	Urban: UB surface 11 and groundwater 5 samples	Examined by field pack test (Kyoritsu Corp)	Zn: 95 ppm (average)	>WHO Guideline for drinking water
Bolormaa et al, 2006[29]			Rural mining area: Boroo River, 13 water samples	Particle-induced X-ray emission (PIXE) technique	Zn: 5.2-23 μg/L	>WHO Guideline for drinking water
Bolormaa et al, 2006[29]	Cu pollution of the water 2000 μg/L or 2 mg/L (WHO Guideline for drinking water)	Concentration of Cu in water	Rural mining area: Boroo River, 13 water samples	Particle-induced X-ray emission (PIXE) technique	Cu: 1-4.2 μg/L	<WHO Guideline for drinking water 2011
Dalai and Ishiga, 2013[75]			Urban: UB, surface 11 and groundwater 5 samples	Examined by field pack test (Kyoritsu Corp)	Cu: 22 ppm (average	<WHO Guideline for drinking water 2011
Battogtokh et al,			Mining area: Erdenet	Analyzed by coupled plasma-optical	Cu: <2 mg/L	<WHO Guideline for drinking water

2013[36]				emission spectrometry		2011
Bolormaa et al, 2006[29]	Fe pollution of the water 0.3 mg/L or 300 μg/L (WHO Guideline for drinking water)	Concentration of Fe in water	Rural mining area: Boroo River, 13 water samples	Particle-induced X-ray emission (PIXE) technique	Fe: 11.5-249 μg/L	<WHO Guideline for drinking water 2011
Unursaikhan et al, 2010[30]			Urban/Rural areas: stored water in containers	Samples analyzed by Varian 210 D AAS-10 in accordance with the method stated in the standard of GOST 5370-50	In water stored in metal container: 17.2-26.8 mg/L	58-90 Times >WHO Guideline for drinking water 2011
Bolormaa et al, 2006[29]	Mn pollution of the water not of health concern at levels causing acceptability problems in drinking water	Concentration of Mn in water	Rural mining area: Boroo River, 13 water samples	Particle-induced X-ray emission (PIXE) technique	Mn: 0.5-8.6 μg/L	>WHO Guideline for drinking water 2011
Bolormaa et al, 2006[29]	Ni pollution of the water 0.07 mg/L or 70 μg/L (WHO guideline for drinking water)	Concentration of Ni in water	Rural mining area: Boroo River, 13 water samples	Particle-induced X-ray emission (PIXE) technique	Ni: 0.7-18 μg/L	>WHO Guideline for drinking water 2011
Unursaikhan et al, 2010[30]	Cd pollution of the water 3 μg/L or 0.003 mg/L (WHO guideline for drinking water)	Concentration of Cd in water	Urban/Rural areas: stored water in containers	Samples analyzed by Varian 210 D AAS-10 in accordance with the method stated in the standard of GOST 5370-50	In water stored in aluminum container: Cd: 30-159 μg/L	10-53 Times >WHO Guideline for drinking water 2011
Lkhasuren et al, 2006[40]	Cr pollution of the water 50 μg/v or 0.05 mg/L (WHO guideline for drinking water)	Concentration of Cr in water	Urban: UB: river water, sediment, and waste water	Samples were collected in acid-cleaned bottles, microwave digested, and analyzed for total Cr by ICP-AES	Cr: In river water: not detected; sediment: 15-64 mg/kg. Waste water from waste water treatment plant: 29 mg/L (before treatment: 1184 mg/L)	<WHO Guideline for drinking water 2011
UNEP, 2008[33]			Gold mining area (Khongor	Samples analyzed in the internationally accredited testing	Detected in the waste water coming from waste water treatment plant	Detected

			soum)	laboratory in the UK		
Dalai and Ishiga, 2013[75]			Urban: UB, surface 11 and groundwater 5 samples	Examined by field pack test (Kyoritsu Corp)	Cr: 24-183 ppm	
Battogtokh et al, 2013[36]	Mo pollution of the water 0.07 mg/L (WHO guideline for drinking water)	Concentration of Mo in water	Mining area: Erdenet	Analyzed by coupled plasma-optical emission spectrometry	Mo: 0.04-0.17 mg/L	>WHO Guideline for drinking water 2011
Battogtokh et al, 2013[36]	Mg pollution of the water 30.0 mg/L (WHO guideline for drinking water)	Concentration of Mg in water	Mining area: Erdenet	Analyzed by coupled plasma-optical emission spectrometry	Mg: 9.91-62.76 mg/L	>WHO Guideline for drinking water 2011
Battogtokh et al, 2013[36]	Hg pollution of the water 0.006 mg/L (WHO guideline for drinking water)	Concentration of Hg in water	Mining area: Erdenet	Analyzed by coupled plasma-optical emission spectrometry	Hg: <0.01-0.065 mg/L	>WHO Guideline for drinking water 2011
Battogtokh et al, 2013[36]	Ca pollution of the water 100 mg/L (WHO guideline for drinking water)	Concentration of Ca in water	Mining area: Erdenet	Analyzed by coupled plasma-optical emission spectrometry	Ca: 39-171.6 mg/L	>WHO Guideline for drinking water 2011
Battogtokh et al, 2013[36]	Al pollution of water 0.002 mg/L (WHO guideline for drinking water)	Concentration of Al in water	Mining area: Erdenet	Analyzed by coupled plasma-optical emission spectrometry	Al: <0.002 mg/L	<WHO Guideline for drinking water 2011
Battogtokh et al, 2013[36]	Ag pollution of water 0.002 mg/L (WHO guideline for drinking water)	Concentration of Ag in water	Mining area: Erdenet	Analyzed by coupled plasma-optical emission spectrometry	Ag: <0.002 mg/L	<WHO Guideline for drinking water 2011
Nyamragchaa et al, 2003[39]	Bacteriological contamination in drinking water: no *E coli*/100 mL (WHO Guideline for drinking water)	Concentration of bacteria in water	Urban: UB	Counting methods and statistical programme Epi-Info and SPSS used	28.6% Of water samples from springs, 17.9% of water samples from kiosk, and 5.5% of water samples from central water supply systems are contaminated by *E coli*	>WHO Guideline for drinking water
UNEP, 2008[33]	Methyl-Hg (cyanide) pollution of water	Concentration of methyl-Hg in	Gold mining area	Samples analyzed in the internationally	Not detected	

		water	(Khongor soum)	accredited testing laboratory in the UK		
UNEP, 2008[33]	Boron pollution of water/2400 μg/L or 2.4 mg/L (WHO Guideline for drinking water)	Concentration of boron in water	Gold mining area (Khongor soum)	Samples analyzed in the internationally accredited testing laboratory in the UK	Detected in the waste water coming from waste water treatment plant	
Unursaikhan et al, 2010[30]	Formaldehyde/Formalin pollution of the water 3 μg/L or 0.003 mg/L (WHO guideline for drinking water)	Concentration of formaldehyde/formalin in water	Urban/Rural areas: stored water in containers	Samples analyzed by Varian 210 D AAS-10 in accordance with the method stated in the standard of GOST 5370-50.	Formaldehyde: in water stored in plastic container: 180-390 mg/L; in water stored in large blue container: 360-690 mg/L. Formalin: in water stored in oil container: 27-39.17 mg/L; in water stored in large blue plastic container: 37.67-53.43 mg/L	10-53 Times >WHO Guideline for drinking water 2011
Environmental tobacco smoke						
Rudatsikira et al, 2007[41]	Second-hand smoke	Proportion of children and nonsmoking adults reporting exposure to second-hand smoke	Urban: UB, school children	Global Youth Tobacco Survey	Children: males, 73.7%; females, 71.9%	
Ochir et al, 2011[77]			Urban: UB, bar and nightclub workers	Air nicotine and hair nicotine concentrations were assessed using gas chromatography	Nonsmoking adults: 100%; The mean (SD) hours of operation were 10.8 (2.6). Median (range) air nicotine concentrations were 14.8 (4.0, 25.2) $\mu g/m^3$. Concentrations were higher in venues with no outdoor area (median, 20.7 vs 14.1 $\mu g/m^3$)	

Abbreviations: UB, Ulaanbaatar; PM, particulate matter; MNS, Mongolian National Standard; SD, standard deviation; APM, air particulate matter; GIS, geographic information system; ATMoS, a chemical transport model.

Table 2. Human Exposure to Metals.

Population Area	Year	Study Design/ Population Size	Population Age Group	Name of Heavy Metal	Biological Samples	Level of Heavy Metal (Mean Concentration)	Data Source
Urban (Ulaanbaatar)	1999	Cross-sectional study/142	Children <5 years old	Pb	Blood	1.75 ± 0.07 μg/100 mL (Children ≤12 years: suspended HBM)	Burmaa et al, 2002[20]
Urban (Ulaanbaatar)	2005	Pilot study/83	Adults	Cr	Urine	6.9-18.4 μg/L	Lkhasuren et al, 2006[40]
Urban (Ulaanbaatar)	2006	Cross-sectional study/120	6- to 14-Year-olds	Pb	Blood	16.54 ± 9.50 μg/dL (children ≤12 years: suspended HBM)	Baigal et al, 2006[32]; Dorogova et al, 2008[27]
Rural mining area Khongor soum	2008	Cross-sectional study/109	NA	Hg	Urine	Only 4 samples >7 μg/L (HBM1 level)	UNEP, 2008[33]
Rural mining area Khongor soum	2008	Cross-sectional study/47	NA	Hg	Blood	Only 14 samples >5 μg/L (HBM1 level)	UNEP, 2008[33]
Rural mining area Khongor soum	2008	Cross-sectional study/NA	NA	Methyl-Hg	Hair scalp	All samples <0.1 μg/g (HBM1 level)	UNEP, 2008[33]
Rural (Khuvsgul, Govisumber)	2008-2009	Case-control/244	39.7 ± 13.4	Mn	Hair scalp	2067 ± 2028 ppm	Komatsu et al, 2011[78]
Rural (Khuvsgul, Govisumber)	2008-2009	Case-control/244	39.7 ± 13.4	Fe[20]	Hair scalp	15.4 ± 7.5 ppm	Komatsu et al, 2011[78]
Rural (Khuvsgul, Govisumber)	2008-2009	Case-control/244	39.7 ± 13.4	Cd	Hair scalp	46.0 ± 45.6 ppb	Komatsu et al, 2011[78]
Rural (Khuvsgul, Govisumber)	2008-2009	Case-control/244	39.7 ± 13.4	Al	Hair scalp	10.0 ± 7.0 ppm	Komatsu et al, 2011[78]
Rural (Khuvsgul, Govisumber)	2008-2009	Case-control/244	39.7 ± 13.4	Pb	Hair scalp	1789 ± 1705 ppb	Komatsu et al, 2011[78]
Rural (mining areas)	2008	Cross-sectional study/198	Women of reproductive age	Hg	Blood	0-9.6 μg/L (Women of reproductive age: suspended HBM)	Steckling et al, 2011[34]

Rural (mining areas)	2008	Cross-sectional study/198	Women of reproductive age	Hg	Urine	0-78.5 μg/L (Women of reproductive age: suspended HBM)	Steckling et al, 2011[34]
Rural (mining areas)	2008	Cross-sectional study/198	Women of reproductive age	Hg	Hair scalp	0.1-2.71 μg/g	Steckling et al, 2011[34]
Rural (Tuv province: Jargalant and Bornuur)	2009	Cross-sectional study/200	Adults	Hg	Urine	0.1-2.88 μg/L, <7 μg/L (HBM1 level)	Unursaikhan et al, 2010[79]
Rural (Tuv province: Jargalant and Bornuur)	2009	Cross-sectional study/200	Adults	Hg	Blood	0.24-0.55 μg/L, < 5 μg/L (HBM1 level)	Unursaikhan et al, 2010[79]
Rural (Tuv province: Jargalant and Bornuur)	2009	Cross-sectional study/ 200	Adults	Hg	Hair scalp root/tip	0.11/0.08-0.31/0.26 μg/L	Unursaikhan et al, 2010[79]
Urban (Ulaanbaatar)	2010	Case-control study/11	Average age: 57.3 years	Cd	Hair scalp	29.87 ppb	Dashdorj, U. 2012[80]
Urban (Ulaanbaatar)	2010	Case-control study/11	Average age: 57.3 years	Iron	Hair scalp	14614 ppb	Dashdorj et al, 2012[80]
Urban (Ulaanbaatar)	2010	Case-control study/11	Average age: 57.3 years	Pb	Hair scalp	147.7-962.8 ppb	Dashdorj et al, 2011[81]
Urban (Ulaanbaatar)	2010	Case-control study/11	Average age: 57.3 years	Mn	Hair scalp	322.4-3083.0ppb	Dashdorj et al, 2011[81]
Rural (mining area Khongor soum)	2010	Cross-sectional study/32	Adults	Pb, Cd, Cr, B, and Hg	Hair scalp/blood/urine	Urine, and blood <(HBM1 level)	Unursaikhan et al, 2011[82]
Rural (mining area Khongor soum)	2010	Cross-sectional study/32	Adults	As	Hair scalp/blood/urine	Urine, and blood (0.0014 mg/L) <(HBM1 level)/blood	Unursaikhan et al, 2011[82]

Abbreviations: HBM, human biomonitoring.

Table 3. Health Outcomes in Adults.

Data Source	Study Design	Location Study Period	Sample Size	Age Group	Exposure Type	Exposure Assessment	Health Outcome Measured	Results
Dashdorj et al, 2012[80]	Case-control study	Ulaanbaatar, Mongolia	11 Patients with Parkinson's disease (PD)	Average age, 57.3 years	Al, Cd, Hg, Cu, and Fe	Cd (29.87 ppb) and Fe (14 614 ppb) in scalp hair in PD patients were 3 times higher than in healthy Japanese, and Al (907-11 460 ppb) accumulation was much higher than Japanese standard and that in healthy Mongolians	PD diagnosed by neurologist	Exposure to heavy metals was associated with increased risk of PD in Mongolians
Dashdorj et al, 2011[81]	Case-control study	Ulaanbaatar, Mongolia	11 Patients with PD	Average age, 57.3 years	Mn and Pb	Mn (322.4-3083 ppb) and Pb (147.7-962.8 ppb), whereas Japanese standards are 52-248 ppb and 548 ppb, respectively	PD diagnosed by neurologist	The high hair accumulation of Mn and Pb could be related to environmental causes of PD
Enkhjargal et al, 2008[14]	Cross-sectional study	Ulaanbaatar, Mongolia, June 2008 to June 2009	Residents of capital city	All	Air pollutants (PM_{10}, $PM_{2.5}$, NO_2 and SO_2) and meteorological parameters (average temperature, humidity, and wind speed)	Concentrations of PM_{10}, $PM_{2.5}$, SO_2, and NO_2 in ambient air during the whole year	Cardiovascular and respiratory diseases registered in hospital records	There is association between air pollution and respiratory diseases (especially among children) and cardiovascular diseases (especially among adults), especially during winter. In addition, residents of ger areas had more visits to family hospitals than residents of apartments
Greene et al, 2010[35]	Retrospective cohort study	Ulaanbaatar, Mongolia June to	80 Employees from tanneries and 85	Adults	Trivalent Cr [Cr(III)]	Self-reported: employment and reproductive survey	Spontaneous abortion, stillbirth,	After adjusting for the current age of the female participant, couples who

		August 2006	employees from the bread-making industry				preterm delivery, low birth weight, malformations, or reduced fertility were reported	reported a history of paternal tannery exposure were 5.6 times more likely to have experienced a period of infertility at some time in the past or present (95% CI = 1.4-21.5). This finding was statistically significant
Komatsu et al, 2011[78]	Case-control study	Ulaanbaatar and 5 country areas of Mongolia compared with Tokyo area, Japan, summer 2009	299 Participants: 269 healthy and 21 Parkinsonism and 15 arthritis cases in Mongolia compared with 81 healthy Japanese	Adults	Mn, Fe, Pb, Cd, and Al	To measure the accumulation level of minerals in scalp hair, the level of urinary 8-OHdG. Minerals contained in drinking water, sheep meat, wild grasses, and soil were measured	Oxidative stress and PD diagnosed by doctors	This finding suggests that the high accumulation of these minerals may have an association with Parkinsonism and arthritis by increasing oxidative stress. In particular, Mn accumulation was higher in Parkinsonism than in arthritis, and Fe, Pb, Cd, and Al accumulations were higher in arthritis than in Parkinsonism.
Delgerzul et al, 2010[16]	Cross-sectional study	Sukhbaatar district, Ulaanbaatar, Mongolia 2008-2009	1239 Patients with cardiovascular diseases	Average age was 54.69 ± 15.82, and most of them (51.5%, 638) were >55 years old	$PM_{2.5}$	An annual average of $PM_{2.5}$ (329.17 $\mu g/m^3$) concentration was 32 times higher than 2005, WHO, AQG	Cardiovascular diseases registered in hospital registration	Correlation between cardiovascular diseases and PM2.5 (Rxy = 0.184; *P* = .049); correlation between $PM_{2.5}$ and temperature was (Rxy = –0.354; *P* = .000).
Lkhasuren	Retrospecti	Mongolia,	7600 Patients	Adults	Coal dust with	143 Samples collected	Silicosis,	Number of occupational

et al, 2007[47]	ve cohort	1967-2004	with occupational diseases, including 5154 cases of dust-induced chronic bronchitis and pneumoconiosis		silica content 10% or less; gold mine dust with silica content 10% or less; total dust, respirable dust, and silica dust	from the mines and power plants (1980-2003) exceeded the Mongolian maximum allowable limits, but there is decline in total dust levels from all areas	Welder's pneumoconiosis, anthraco-silicosis, and dust-induced chronic bronchitis diagnosed by doctors	diseases increased annually
Mu et al, 2011[4]	Cross-sectional survey	Urban: Ulaanbaatar. Rural: Gobi desert area-South Mongolia. May 2008	36 Responses from urban and 87 responses from nomad gers (dwellings)		Dust storm and PM	Self-reported method	Eye (itchy eye, bloodshot eye, and lacrimation) and respiratory (mucus, nasal congestion, coughing, sputum, and breathlessness) symptoms	The occurrence of bloodshot eyes and lacrimation differed significantly (*P* = .025, *P* = .001) between the desert area and urban area
Oyunbileg et al, 2011[48]	Retrospective cohort	The National Centre of Workplace Conditions and Occupational Diseases, Mongolia 1986-2006	4598 Patients (91.2% males)	Average age is between 30 and 59 years	Dust around mining, construction, power plant, manufacturing, industrial, and agricultural areas	Occupational history	Occupational diseases diagnosed by doctors (work and medical history, physical examination, and laboratory tests)	Incidence rate of occupational diseases increased
Oyunbileg et al, 2011[49]	Retrospective cohort	The National Center of Workplace Conditions and	432 Patients with occupational pneumoconiosis	Adults	Dust around mining, construction, power plant, manufacturin	Occupational history	Occupational pneumoconiosis diagnosed by doctors	Shorter life expectancy and quality-adjusted life expectancy and 45% health gap for patients with pneumoconiosis

		Occupational Diseases, Mongolia 1986-2006			g, industrial, and agricultural areas			obtained
Nagniin et al, 2011[17]	Cross-sectional study	Ulaanbaatar, Mongolia 2004-2008	Residents of Ulaanbaatar	All age group	SO_2, NO_2, PM of different sizes	Data on meteorological measurements using appropriate methodology	2004–2008 Statistical data on morbidity and mortality from respiratory diseases	The mortality rate of respiratory diseases increases when the concentration of SO_2, NO_2, and PM in ambient air increases

Abbreviations: CI, confidence interval; PM, particulate matter; OHdG, hydroxydeoxyguanosine; AQG, air quality guidelines; Rxy, relationship coefficient.

Table 4. Health Outcomes in Children.

Data Source	Study Design	Location/Study Period	Sample Size	Age Group (years)	Exposure Type	Exposure Assessment	Health Outcome Measured	Results
Nansalmaa et al, 1999[51]	Cross-sectional study	Rural: Khuvsgul province 1998	Total number of children received health care services	0-15	Altitude, precipitation and negative atmospheric temperature	Reports of meteorological measurements	Respiratory diseases (pneumonia, bronchitis, and cold and grippe) reported in hospital registration	Altitude, precipitation, and atmospheric temperature have a strong direct impact on the prevalence of respiratory diseases among children living in cold areas
Baigal et al, 2006[32]	Cross-sectional study	5 Districts of Ulaanbaatar, Mongolia 2006	120	7-14	Pb	Blood level of Pb = 16.5 ± 9.50 μg/dL, higher than WHO (≥10 mg/dL)	Neurological disorders (impairment of memory, inattentiveness, getting angry easily) diagnosed by GP	Association between high blood level of Pb and the impairment of memory (r = 0.201, $P < .005$), inattentiveness (r = 0.298, $P < .001$), and getting angry easily (r = 0.175, $P < .001$)
Burmaa et al, 2000[44]	Cross-sectional study	Urban: Ulaanbaatar. Rural: Mandalgovi	More than 1000	4-11	SO_2 and NO_2	Ulaanbaatar: SO_2, 2.2, and NO_2,1.8 times more than the	Decreased respiratory capacity among children living in urban areas, measured by	Inverse relationship between decreased respiratory capacity among children in Ulaanbaatar and high

		and Arvaikheer 2000				permissible maximum level	spirometer	concentration of air pollution
Burmaa et al, 2002[20]	Cross-sectional study	Urban: Ulaanbaatar. Rural: Province centers 1999	142	<5	Pb	Blood level of Pb and soil, air, snow, and water levels of Pb	Mortality caused by neurological diseases	Association between high level of blood Pb and high level of Pb in air. High mortality rate in region with high rate of Pb in environment and high mortality rate among children whose parents work in Pb-polluted area
Dashdendev et al, 2011[45]	Cross-sectional study	Urban: Ulaanbaatar. Rural: Tuv province during summer time	Urban: 116. Rural: 108	5-15	Chemical exposure: CO	Ambient CO (3-fold) and exhaled CO (2-fold) levels in urban air are higher than rural	Decreased lung function (FEV1 and FEF25%-75%), measured by spirometer, among children from Ulaanbaatar	Decreased lung function (FEV1 and FEF25%-75%), measured by spirometer among children from Ulaanbaatar
Dorogova et al, 2008[27]	Cross-sectional study	Urban: Ulaanbaatar 2005	120	8-12	Pb	Ambient Pb and blood level of Pb: 16.54 $\pm$ 9.5 μg/dL	Memory disorder, irritability, hyperexcitability, inattentiveness, and neurasthenia diagnosed by doctors	If blood level of Pb is more than 10 μg/dL in children, neurological disorders are more likely to be diagnosed
Spickett et al, 2005[18]	Cross-sectional study	Sukhbaatar and Bayangol district of Ulaanbaatar 2003-2004	Totally 500 children,150 dwellings and apartments	2-8	SO_2, CO, and suspended particulates from smoke	NA	Bronchitis, asthma, chest tightness, morning cough, shortness of breath, and morning phlegm	Levels of carbon monoxide and PM were significantly higher in ghers and houses than in apartments, and children living in ghers and houses reported higher levels of respiratory symptoms than those living in apartments

Suvd et al, 2003[19]	Cross-sectional study	Khan-Uul district, Mongolia 1 997-2001	Total population of 1, 4, and 14 *khoroos*	0-14	SO_2, NO_2, CO, and dust	During 1997-2001, concentration of ambient SO_2, NO_2, CO, and dust gradually increased, especially in winter (Jan-Mar) time.	Respiratory diseases diagnosed by professionals	Associations between SO_2 and respiratory diseases, especially acute bronchitis ($r = 0.6$; $P < .05$) and asthma ($r = 0.8$; $P < .05$). Strong association ($r = 0.8$; $P < .05$) between acute bronchitis in children 0-14 years of age and air pollution (2001) and PM (1998). Strong association ($r = 0.9$; $P < .01$) between chronic bronchitis in children 0-14 years of age and CO (1999)

Abbreviations: FEV1, forced expiratory volume in 1 s; FEF, forced expiratory flow; PM, particulate matter.

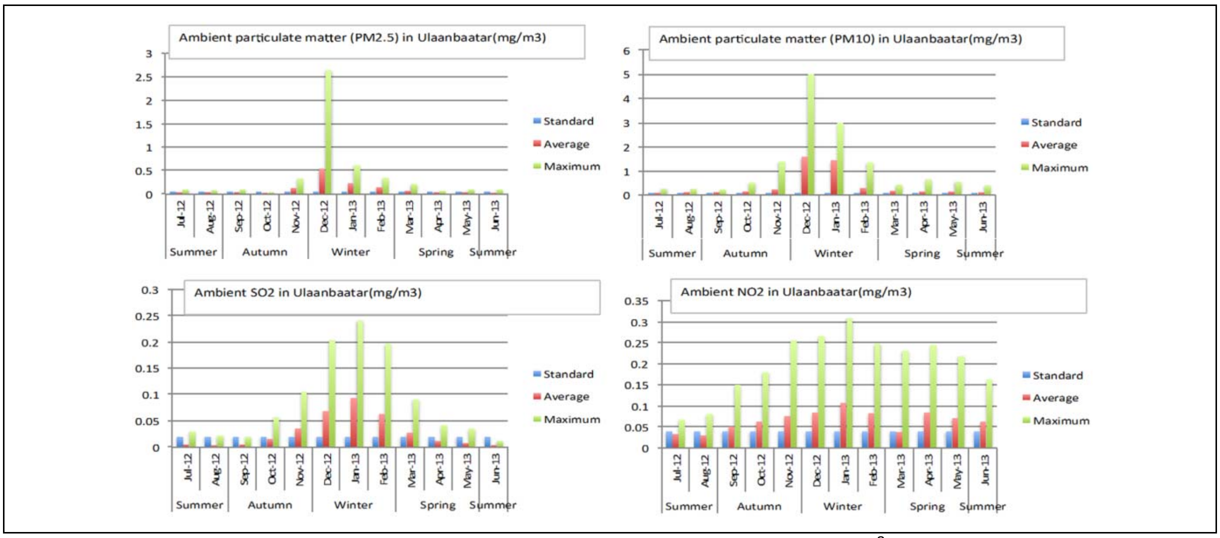

Figure 2. Monthly trends in air pollutant concentration in Ulaanbaatar, 2012-2013.[a]
[a]Source: National Statistical Office (NSO) data 2012-13. Standard: Mongolian National Standards (MNS4585: 2007).

The most commonly dispersed and studied metal was lead, which was detected not only in stored drinking water[30] and surface water around mining areas[29] but also in the air and soil of Ulaanbaatar[20,27,28,31] (Table 1). Traditionally, Mongolians living in Ger districts store drinking water in wooden water containers, but in recent years, different types of containers have been used. Lead was detected at levels 500 to 800 times higher than the permissible maximum level, according to the WHO reference level, in water stored in oil containers and 60 to 72 times higher in water samples from large blue plastic containers.[30] The evidence shows that migration of toxic chemicals from nonstandardized water containers into stored water is very high, and hence, plastic containers should not be used for keeping drinking water and food products.

A number of studies have addressed populations exposed to metals. Biological samples, including urine, hair, scalp, and blood, were used to determine exposure levels to metals (Table 2). In 2006, researchers[27,32] reported that blood lead concentrations in blood samples from children in Ulaanbaatar (16.54 ± 9.5 μg/dL) were higher than human biomonitoring (HBM) I values.

Moreover, many of the individual chemical pollutants, including lead,[20,27,28,30,32] arsenic,[28] mercury,[5,33,34] zinc,[5,29] chromium,[5,35] cadmium,[30] iron,[30] nickel,[29] molybdenum,[36] and formaldehyde[30] found in air, water, soil and biological samples exceeded the permissible maximum levels set by WHO and MNS (Tables 1 and 2). Very high levels of lead, cadmium, iron, and formaldehyde were detected in water stored in nonstandardized containers,[30] which means that residents in ger districts are more likely to be exposed to hazardous chemicals via this source.

Water and Sanitation. More than half (54.5%)[37] of the Mongolian population use unimproved water sources (springs or wells, vendor-provided water, tanker, trucks, and surface water), and 78% of the springs studied are unprotected.[38] Research shows that 45.4% of all springs from rural areas and Ulaanbaatar had *Escherichia coli* contamination in 2008.[38] A 2003 study[39] found that 28.6% of water samples from springs, 17.9% of water samples from kiosks, and 5.5% of water samples from central water supply systems were contaminated by *E coli*, with a decreasing trend from August to October (autumn).

According to UNDP data,[37] 43.1% of the Mongolian population had access to improved sanitation, but only 4.8% of rural households had access to improved sanitation facilities.

Occupational Exposures. Industrialization in Mongolia has had a tangible effect on environmental pollution and a direct influence on children's health. With increasing industrialization, increasing incidence of work-related illnesses has been reported. The main risk factors were coal dust, silica dust, asbestos, and metals, which can be carried by work clothes and other work-related items. Also, some researchers noted that some metals, including mercury and methyl mercury, have been kept in homes,[33] and that there is an increasing number of women of reproductive or child-bearing age working in illegal and small mining activities[34] and in contact with mercury. Furthermore, chromium-based technology is used in some industries (tanneries and the waste water treatment plant) in Ulaanbaatar.[40]

Environmental Tobacco Smoke (ETS). Researchers conducting the Global Youth Tobacco Survey[41] found very high levels of exposure to ETS among school-going children in Mongolia (73.9% of boys and 71.7% of girls). The main reasons are the very high prevalence of tobacco smoking and poor tobacco control in Mongolia. Currently, one-third of Mongolian adults smoke, and public places (including educational and health care facilities, restaurants, pubs, bars, and offices), except for public transportation, are not subject to smoke-free legislation.[42] Furthermore, the prevalence of current smoking among school-going children in grades 6 to 8 was 9.2% (15.4% boys vs 4.4 girls) in 2003.[41] Recent research in Mongolia found that smoking prevalence in schoolchildren in grades 6 to 11 was 33.7% and 2 in 3 school-going girls are exposed to ETS.[43]

Related Health Outcomes

Totally, 19 studies reported the effects of environmental risk factors on disease outcomes among adults (n = 11) and children (n = 8), and the majority of the studies (n = 12) were cross-sectional. Several epidemiological studies[14,17,19,44] have been conducted to determine whether an association exists between air pollution and health outcomes and reported that the increased levels of NO_2, SO_2, and PM in ambient air were linked to respiratory diseases in both adults and children, particularly during winter (Tables 3 and 4). Dashdendev et al[45] aimed to assess the effects of rapid urbanization on the lung health of children and found correlations between exposure to SO_2, NO_2, and CO and decreased lung function among children from Ulaanbaatar. Mu et al[4] surveyed the subjective respiratory symptoms among residents in a desert area and compared this with symptoms in residents in an urban area immediately after a dust storm. The prevalence of respiratory symptoms was slightly higher among participants from the desert area. In addition, associations between high levels of indoor CO and PM and respiratory symptoms were reported in studies[18,19] that involved children from Ulaanbaatar only. The results of studies carried out in Mongolia[15,18] indicate that the children living in traditional ger dwellings are more likely to be affected by indoor air pollution, and respiratory symptoms are more common among these children.

Enkhjargal et al[14] and Delgerzul et al[16] found an increased risk of cardiovascular diseases with increased exposure to NO_2 and $PM_{2.5}$. Generally, these cross-sectional studies showed similar results to findings of other studies included in a systematic review,[46] showing significant associations between cardiovascular mortality and morbidity and particulate matter (PM).

The retrospective-cohort studies included[47-49] found an overall increase in the annual incidence rates of occupational diseases, including chronic bronchitis, pneumoconiosis, asthma, tuberculosis, lung cancer, poisonings, and musculoskeletal and cardiovascular diseases. Oyunbileg et al[48] reported increases in the cumulative incidence rate[30-59] of occupational respiratory diseases (1.4% per year) and in the cumulative incidence rate[30-59] of musculoskeletal disorders (2.3% per year) in the period from 1986 to 2006. Actually, these increases might be more than the reported values because of underreporting of these diseases resulting from the presence of informal and/or unregistered factories, especially in the mining industry. There is suggestive evidence that chromium exposure in the Mongolian leather tanning industry may negatively affect fertility.[35] The analysis only controlled for age but did not control for other possible confounders. In addition, self-reported retrospective information was a limitation of this study. Prospective cohort studies are needed to confirm these relationships.

In children, high blood lead levels were found to be significantly associated with the impairment of memory , inattentiveness , and getting angry easily .[32] In addition, Burmaa et al[20] reported that high blood lead levels were directly related to a high level of lead in air and that deaths from neurological diseases were more likely among children who lived in environments with a high level of lead and whose parents worked in a lead-polluted area. Dorogova et al[27] found that neurological disorders were more common in Mongolian children whose blood lead levels were greater than 10 μg/dL.

Assessment of Evidence

Although this systematic review was limited to Mongolia, we still included an assessment of the evidence of causality between exposure to environmental risk factors and health outcomes within the Bradford Hill framework[50] focusing on temporality, strength, and consistency of the associations; dose-response relation; biological plausibility; and the consideration of alternative explanations. Several studies[4,14,16-19,44,45,51] have consistently reported associations between environmental pollution in Mongolia and adverse health effects, including respiratory and cardiovascular diseases among adults and respiratory diseases and neurodevelopmental disorders in children. Unfortunately, we were unable to assess temporality of associations in the absence of prospective studies because, by definition, it is not possible to establish temporality in cross-sectional studies. Furthermore, retrospective, self-reported information on exposure and outcomes may be subject to recall bias. In some studies, investigators did not adjust for the effect of confounders,[19,35] especially smoking, on neonatal outcomes,[35] and hence, some of the effects of these environmental exposures on health outcomes could still be explained by confounding. We also did not identify studies in Mongolia indicating a dose-response relationship. Although the rather limited epidemiological data available for Mongolia may preclude the establishment of a causal relationship between exposure to some of these environmental risk factors and adverse health outcomes in an assessment of evidence by conventional epidemiological approaches, it is important to note that extensive evidence exists of a causal link between exposure to indoor and outdoor air pollution, unimproved water and sanitation, and exposure to lead and chemical pollutants and adverse health outcomes.[9,52,53] There is also strong biological plausibility of an association between exposure to these environmental risk factors and health outcomes.

Discussion and Recommendations

Mongolia's windy and cold climate and geographical location can contribute to high environmental pollution levels. Ambient PM_{10} concentrations are high in winter, owing to air pollution, as well as in spring, owing to dust storms.[54] Correlations between dust storms or sandy wind pollution and respiratory and eye symptoms in the population, including children, living in Mongolian windy desert areas have been reported.[4] The extremely cold weather creates great demand for heating facilities. In addition, Ulaanbaatar's topography makes the city particularly susceptible to high air pollution concentration. Allen et al[3] concluded that Ulaanbaatar is one of the most polluted cities and the coldest capital city in the world. Consequently, residents of Ulaanbaatar are exposed to much higher air pollution levels compared with people living in rural areas and even in other big cities such as Beijing, Chongqing, San Salvador, Cairo, Lima, and Los Angeles.[55]

Allen et al[3] calculated that 623 deaths (9.7% of total deaths) in Ulaanbaatar and 4% of the 15 522 annual deaths in Mongolia in 2009 were attributable to air pollution based on 2009 mortality statistics. The estimate from the 2010 Global Burden of Disease study was lower, with only 2.75% of deaths in Mongolia attributable to ambient PM.[9]

According to WHO,[25] more than three-quarters (76.5%) of households in Mongolia use solid fuels for cooking and heating dwellings, compared with 8.5% and 49.3% of households in Russia and China, respectively, where the use of clean fuels, including electricity, natural gas, and biogas is much higher than in Mongolia. Thus, children in Mongolia are more exposed to indoor air pollution from solid fuel compared to these neighboring countries with similar climates.

The Mongolian Government has proposed a number of programs to decrease air pollution, with financial and professional support from international organizations. The government programs mainly focused on reducing air pollution in the capital city through distribution of air quality measurement instruments, implementing vehicle emission control and banning systems, and improving coal quality as well as efficiency of heating boilers and household stoves. Gordon et al,[56] conducted face-to-face interviews with users of different stoves (traditional and improved) and found that all stove users recognized respiratory symptoms (a sore throat, cough, and sneeze) caused by stove smoke. Enkhjargal et al[15] reported that the type of house and type of fuel influence indoor air quality. This research showed that there is no difference between traditional and improved stoves but that improving coal quality reduced indoor air pollution.

According to the Global Burden of Disease 2010 study,[57] diarrheal diseases were the sixth leading cause of disease burden among children <5 years old in Mongolia, and available local data[37,39,58] suggest that environmental factors, such as poor access to drinking water and sanitation and water pollution, especially bacteriological contamination of water during the warm season, adversely affect public health in both rural and urban areas. A child's well-being is highly dependent on both the quality and the availability of water.

In big cities in both developed and developing countries, the primary environmental sources of lead exposure are leaded gasoline and lead-based paint. Mongolian annual demand for oil products (fuel, diesel, black oil, or mazut and lubrication products) is continuously rising because of the increasing number of vehicles, most of which are imported from Russia. In 2005, nearly 126 000 kg of paint was imported to Mongolia, 81.6% of which was from China.[31]

The median blood lead level in Russian children aged 6 to 9 years was 3 μg/dL in 2005,[59] and the mean blood lead level in children in China was 8.07 μg/dL in studies done between 2001 and 2004.[60] These mean blood lead levels are lower than blood lead levels (16.54 ± 9.5 μg/dL) detected in Mongolian children in 2006.[27,32] These findings suggest that the level of lead exposure in Mongolian children is higher than in the 2 neighboring countries that are major suppliers of lead-based products to Mongolia. In 2010, the HBM Commission concluded that establishing an effect threshold for blood lead levels would be arbitrary and, therefore, not justified and suspended the HBM levels for lead in blood of children younger than 12 years and women of reproductive age[61]; hence the very high blood lead concentrations among Mongolian children are of particular concern. In addition, exposure to chemicals such as arsenic, mercury, lead, zinc, chromium, cadmium, molybdenum, and formaldehyde in Mongolia, which exceeded the permissible maximum levels set by WHO and MNS, is known to have significant effects on human health.

Increasing numbers of women of reproductive age work in the formal and informal mining sector in Mongolia.[34,62] Thus, the fetus can be exposed to the mother's ongoing exposure to contaminants as well as to stored contaminants that can be liberated during pregnancy. Occupational exposure of parents to chromium has been associated with children's health in the early stages of life. Consequently, children living with parents who work in mining or power plant industries or wastewater treatment plants could have higher exposures to metals and chemicals than do other children living in the same community.

According to Cheraghi et al,[63] children's exposure to ETS at home varies from 27.6% in Africa and 34.3% in South East Asia, to 50.6% in the Western Pacific, and the proportion of children exposed to ETS in public places is about 64.1% in Western Pacific countries and 43.7% in Africa. Hence Mongolian children (73.9% of school boys and 71.7% of school girls exposed to ETC either in the home or elsewhere[41]) are more exposed to ETS than children in other countries. In China, higher percentages of respiratory symptoms were consistently found in children who were exposed to ETS.[64] The very high exposure to ETS among children in Mongolia may therefore be an important contributor to the very high burden from lower-respiratory infections.

Recommendations

- Disseminate the experience of countries with same geographical location (northern hemisphere) and weather condition.
- Disseminate the experience of using clean fuels, including natural gas and biogas.
- Create monitoring and controlling systems for springs and wells.
- Support households to connect to the central water supply system.
- Conduct additional surveys of waterborne diseases especially among children.
- Develop and implement strategies to encourage the safe elimination of metal hazards, using trained workers and safe work practices, in compliance with federal, state, and local regulations.
- Expand availability and promote the use of early enrichment programs for all children from families living in areas where exposure to lead is likely.
- Develop and implement strategies to ban the use of nonstandardized containers for keeping water and food.
- Conduct additional surveys of exposures of children with parents working in those sectors.
- Promote implementation of the smoke-free policy in public places, including schools, universities, and restaurants, and provide a high level of support for governmental policy.
- Educate parents about the harmful effects of tobacco and ETS on their children.

Study Limitations

First, our study focused on traditional environmental risk factors, such as air pollution, unsafe water, and lead exposure, and this may underestimate the contribution of the environment to disease. It has been argued that environmental causes of disease should include all factors other than genetic factors (the classic dichotomy between nature and nurture).[65] Second, a limited number of studies have investigated the impact of environmental risk factors on health in Mongolia. Third, the majority of studies on health outcomes, except 2 included retrospective cohort studies addressing occupational diseases, were cross-sectional, and some researchers reported only qualitative results. Also, different measurement units were used in studies, making comparisons difficult. In some studies, authors had not adjusted for confounders—for example, smoking and age on male infertility. A fourth limitation to this review is measurement bias. Measurement bias with respect to health outcomes and the questionable reliability of self-reported data[4,35] may have also affected the results.

Conclusion

This study provides important local information to guide the identification and prioritization of environmental risk factors to be targeted for interventions and further study in Mongolia. In the past 2 decades, levels of environmental pollutants in rural and urban areas have increased because of rapid urbanization and industrialization and Mongolia's harsh climate and geographical location. This overview of the evidence shows that children living in ger districts have significant exposure to outdoor and indoor air pollution and toxic chemicals, and these risk factors have been linked to respiratory diseases and neurodevelopmental disorders among the children. Moreover, Mongolian children have greater exposure to environmental risk factors, including ETS, metals, and air pollution, than children living in other developing and developed countries, but few epidemiological studies of the effect of environmental risk factors on children's health outcomes have been conducted in Mongolia.

There is a need for prospective, long-term cohort studies to study children and adults from the time of exposure to environmental risk factors, measuring body burden and investigating not only health but also educational, employment, and other outcomes of interest. The Mongolian government has implemented a number of programs to decrease air pollution in Ulaanbaatar, and the improving coal quality program has had a positive influence on reducing air pollution. Nevertheless, there is much more to be done, and it is important for Mongolia to learn from the experiences of other countries that have environmental impact assessment and health impact assessment.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. UNICEF. Situation Analysis of Children and Women in Mongolia 2009. http://www.unicef.org/sitan/files/SitAn_Mongolia_2009.pdf. August 15, 2013.
2. National Statistical Office. Resident population, by urban and rural population, by area and year. http://web.nso.mn:8080/userdata/Dialog/varval.asp?ma=2_1_2_Population_en&ti=&path=../Database/Mongolian/POPULATION/&lang=1. Accessed August 15, 2013.
3. Allen RW, Gombojav E, Barkhasragchaa B, et al. An assessment of air pollution and its attributable mortality in Ulaanbaatar, Mongolia. *Air Qual Atmos Health.* 2011;6:137-150.
4. Mu H, Battsetseg B, Ito TY, Otani S, Onishi K, Kurozawa Y. Health effects of dust storms: subjective eye and respiratory system symptoms in inhabitants in Mongolia. *J Environ Health.* 2011;73(8):18-20.
5. Kosheleva NE, Kasimov NS, Bazha SN, et al. Contamination of soils with heavy metals in the industrial centers of Mongolia. *Vestnik Moskovskogo Universiteta, Seriya 5: Geografiya.* 2010;(3):20-27.
6. Mineral Resources Authority of Mongolia. Statistical information by Mineral Resources Authority of Mongolia 8/2013 2013; http://www.mram.gov.mn/images/stories/mram/statistek/monthly_report_2013.08.01.pdf. Accessed August 27, 2013.
7. Spickett J, Batmunkh T, Jones S. Health impact assessment in Mongolia: current situation, directions, and challenges [published online August 10, 2012]. *Asia Pac J Public Health.* doi:10.1177/1010539512455043.
8. Gavidia TG, de Garbino JP, Sly PD. Children's environmental health: an under-recognised area in paediatric health care. *BMC Pediatr.* 2009;9:10.
9. Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet.* 2012;380:2224-2260.
10. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg.* 2010;8:336-341.
11. National Statistical Office. *Bulletin of Statistics Ulaanbaatar Jan, Feb, Mar, Apr, May, Jun, Jul, and Aug/2013.* Ulaanbaatar, Mongolia: NSO; 2013.
12. Guttikunda S. *Urban Air Pollution Analysis for Ulaanbaatar*. Washington, DC: World Bank; 2007.
13. World Bank. *Mongolia: Handbook on Environmental Standards*. Washington, DC: World Bank. 2010; http://documents.worldbank.org/curated/en/2010/01/17033807/mongolia-handbook-environmental-standards. Accessed July 23, 2014.
14. Enkhjargal A, Suvd B, Burmaa B, Enkhtsetseg S. Health effects of PM2.5 and PM10 in Ulaanbaatar. *J Mongolian Health Sci.* 2008;8:21-22.
15. Enkhjargal A, Suvd B, Tsegmed S, et al. Indoor air quality in Ulaanbaatar, Mongolia. *J Mongolian Health Sci.* 2008;(2):144-145.
16. Delgerzul L, Suvd B, Enkhjargal A, Burmaa B. Particulate matter (PM2.5) air pollution and Ulaanbaatar city Suhknaatar district 9th khoroo's "Enkhiin sanaa" family hospital admission for cardiovascular disease. *J Mongolian Health Sci.* 2010;(4):4-6.
17. Nagniin S, Janchiv O, Palam E, Jalkhaa K. Air pollution and health Ulaanbaatar city of Mongolia. *Epidemiology.* 2011;22:S149-S150.
18. Spickett J, Enkhtsetseg S, Suvaad N, Rumchev K, Enkhjargal G, Burmaa B. Indoor air quality and respiratory symptoms in children in Ulaanbaatar (Mongolia). *Indoor Air.* 2005;15:3655-3658.

19. Suvd N, Oyunbileg D, Burmaa B, Enkhtsetseg S. Relationship between air pollution and some diseases among people living in Khan-Uul district. *J Mongolian Health Sci.* 2003;3(125-128).
20. Burmaa B, Dorogova VB, Enkhtsetseg S, Erdenechimeg E, Enkhzhargal A. Impact of lead-induced environmental pollution on children's health in Mongolia. *Gigiena i sanitariia.* 2002;(3):21-23.
21. Bolor-Erdene D, Ganbaatar D, Shagjjamba D. Study on ambient air quality in the some cities of Mongolia. http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4602987&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4602987. Accessed July 23, 2014.
22. Lodoyasamba S, Pemberton-Pigott C. Mitigation of Ulaanbaatar city's air pollution-from source apportionment to ultra-low emission lignite burning stoves. Paper presented at: the 19th International Conference Domestic Use of Energy; April 12-13, 2011; Cape Town, South Africa.
23. Luvsan ME, Shie RH, Purevdorj T, Badarch L, Baldorj B, Chan CC. The influence of emission sources and meteorological conditions on SO 2 pollution in Mongolia. *Atmos Environ.* 2012;61:542-549.
24. Nishikawa M, Matsui I, Batdorj D, et al. Chemical composition of urban airborne particulate matter in Ulaanbaatar. *Atmos Environ.* 2011;45:5710-5715.
25. World Health Organization. WHO Household energy database: main cooking fuel among households. http://www.who.int/indoorair/health_impacts/he_databasecont/en/index.html. Accessed August 31, 2013.
26. Amardulam D, Burmaa B, Kupul J, et al. The hygienic assessment of secondary school of organization of teaching and educational activity, chemical and bacterial contamination on teaching environment. *J Mongolian Health Sci.* 2010;(3):153-155.
27. Dorogova VB, Burmaa B, Enkhtsetseg B, et al. Environmental lead pollution in Ulan-Bator and children's health. *Gigiena i sanitariia.* 2008;(4):8-9.
28. Batjargal T, Otgonjargal E, Baek K, Yang JS. Assessment of metals contamination of soils in Ulaanbaatar, Mongolia. *J Hazard Mater.* 2010;184:872-876.
29. Bolormaa O, Baasansuren J, Kawasaki K, Watanabe M, Hattori T. PIXE analysis of heavy metals in water samples from a mining area in Mongolia. *Nucl Instrum Methods Physics Res B Beam Interact Mater Atoms.* 2006;243(1):161-166.
30. Unursaikhan S, Ichinkhorloo B, Khishigbuyan B, Gantsetseg P, Sodnomtseren B, Enkhtsetseg S. The migration of toxic chemicals from water containers into stored water. *J Mongolian Health Sci.* 2010;(4):154-156.
31. Enkhjargal G, Baigali O, Dolgorsuren L, Dorogova VB, Zina P, Burmaa B. Research on lead pollution at some workplaces of Ulaanbaatar city. http://moh.mn/moh%20db/healthreports.nsf/32fe9f3e7452a6f3c8256d1b0013e24e/235cdcaa0a07f777c8257244000f467e/$FILE/report_workplace%20ENG.pdf. Accessed July 23, 2014.
32. Baigal O, Burmaa B, Enkhtsetseg B, et al. Impact of lead-induced environmental pollution on children's neurological disorders in Mongolia. *J Mongolian Health Sci.* 2006;1(135):28-33.
33. United Nations Environment Programme. Mongolia Mercury Information. http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/INC1/Mongolia%20submission.pdf. Accessed July 23, 2014.
34. Steckling N, Boese-O'Reilly S, Gradel C, et al. Mercury exposure in female artisanal small-scale gold miners (ASGM) in Mongolia: an analysis of human biomonitoring (HBM) data from 2008. *Sci Total Environ.* 2011;409:994-1000.
35. Greene LE, Riederer AM, Marcus M, Lkhasuren O. Associations of fertility and pregnancy outcomes with leather tannery work in Mongolia: a pilot study. *Int J Occup Environ Health.* 2010;16:60-68.
36. Battogtokh B, Lee JM, Woo N. Contamination of water and soil by the Erdenet copper–molybdenum mine in Mongolia. *Environ Earth Sci.* 2013:1-12.
37. UNDP. Third national report: the millennium development goals implementation, Mongolia. 2009. http://www.mn.undp.org/content/dam/mongolia/Publications/MDGreports/MDGs_3_Report_English resized.pdf. Accessed August 29, 2013.
38. Badrakh A, Chultemdorji T, Hagan R, et al. A study of the quality and hygienic conditions of spring water in Mongolia. *J Water Health.* 2008;6:141-148.
39. Nyamragchaa C, Ichinkhorloo B, Burmaa B, Suvd N, Enkhtsetseg S. Hygienic measurement on bacterioloical contamination in drinking water of Ulaanbaatar. *J Mongolian Health Sci.* 2003;(3):125-127.
40. Lkhasuren O, Riederer A, Galsandamba N, Ochir C. Pilot study of chromium exposures in the Mongolian leather tanning industry. *Epidemiology.* 2006;17:S184-S185.
41. Rudatsikira E, Siziya S, Dondog J, Muula AS. Prevalence and correlates of environmental tobacco smoke exposure among adolescents in Mongolia. *Indian J Pediatr.* 2007;74:1089-1093.
42. World Health Organization. Report on the global tobacco epidemic, country profile: Mongolia. http://www.who.int/tobacco/surveillance/policy/country_profile/mng.pdf?ua=1. Accessed July 23, 2014.
43. Erdenebayar L, Elena K, Munkhtuya S. The prevalence of smoke among female pupils of 6-11th grade in Mongolia and its risk factors. *J Mongolian Health Sci.* 2013;(1):63-64.
44. Burmaa B, Enkhtsetseg S, Erdenechimeg E, Ichinkhorloo B. Air pollution influense on physiological indices of children residing in cities /Ulaanbaatar, Mandalgovi, Arvaikheer/ with different levels of air pollution. *J Mongolian Health Sci.* 2000;4(113):15-18.
45. Dashdendev B, Fukushima LK, Woo MS, Ganbaatar E, Warburton D. Carbon monoxide pollution and lung function in urban compared with rural Mongolian children. *Respirology.* 2011;16:653-658.
46. Goldberg M. A systematic review of the relation between long-term exposure to ambient air pollution and chronic diseases. *Rev Environ Health.* 2008;23:243-298.

47. Lkhasuren O, Takahashi K, Dash-Onolt L. Occupational lung diseases and the mining industry in Mongolia. *Int J Occup Environ Health.* 2007;13:195-201.
48. Oyunbileg S, Sumberzul N, Oyuntogos L, Javzmaa J, Wang JD. Analysis of incidence rates of occupational diseases in Mongolia, 1986-2006. *Int J Occup Environ Health.* 2011;17(1):31-37.
49. Oyunbileg S, Wang JD, Sumberzul N, Chang YY, Erdenchimeg E. Health impact of pneumoconiosis in Mongolia: estimation of losses in life expectancy and quality adjusted life expectancy. *Am J Ind Med.* 2011;54:285-292.
50. Hill AB. The environment and disease: association or causation? *Proc R Soc Med.* 1965;58:295-300.
51. Nansalmaa M, Burmaa B. Correlation of morbidity and mortality 0-15 age children and winter outdoor air temperature in Huvsgul aimag. *J Mongolian Health Sci.* 1997;(4):101-104.
52. Lipsett MJ, Ostro BD, Reynolds P, et al. Long-term exposure to air pollution and cardiorespiratory disease in the California teachers study cohort. *Am J Respir Crit Care Med.* 2011;184:828-835.
53. Miller KA, Siscovick DS, Sheppard L, et al. Long-term exposure to air pollution and incidence of cardiovascular events in women. *N Engl J Med.* 2007;356:447-458.
54. Jugder D, Shinoda M, Sugimoto N, et al. Spatial and temporal variations of dust concentrations in the Gobi Desert of Mongolia. *Global Planetary Change.* 2011;78(1):14-22.
55. World Bank. Ulaanbaatar, Mongolia, Air Monitoring and Health Impact Baseline (AMHIB) report. http://siteresources.worldbank.org/INTMONGOLIA/Resources/Press_Briefing_in_Eng.pdf. Accessed July 23, 2014.
56. Gordon JK, Emmel ND, Manaseki S, Chambers J. Perceptions of the health effects of stoves in Mongolia. *J Health Organ Manag.* 2007;21:580-587.
57. Murray CJ, Vos T, Lozano R, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet.* 2012;380:2197-2223.
58. Sigel K, Altantuul K, Basandorj D. Household needs and demand for improved water supply and sanitation in peri-urban ger areas: the case of Darkhan, Mongolia. *Environ Earth Sci.* 2012;65:1561-1566.
59. Williams PL, Sergeyev O, Lee MM, et al. Blood lead levels and delayed onset of puberty in a longitudinal study of Russian boys. *Pediatrics.* 2010;125:e1088-e1096.
60. He K, Wang S, Zhang J. Blood lead levels of children and its trend in China. *Sci Total Environ.* 2009;407:3986-3993.
61. Schulz C, Wilhelm M, Heudorf U, Kolossa-Gehring M. Reprint of "Update of the reference and HBM values derived by the German Human Biomonitoring Commission". *Int J Hyg Environ Health.* 2012;215:150-158.
62. Murao S, Naito K, Dejidmaa G, Sie SH. Mercury content in electrum from artisanal mining site of Mongolia. *Nucl Instrum Methods Physics Res B Beam Interact Mater Atoms.* 2006;249(1):556-560.
63. Cheraghi M, Salvi S. Environmental tobacco smoke (ETS) and respiratory health in children. *Eur J Pediatr.* 2009;168:897-905.
64. Spickett J, Rumchev K, Jing H. The domestic environment and respiratory health of school children in Zongshan, China [published online January 25, 2013]. *Asia Pac J Public Health.* doi:10.1177/1010539512472944.
65. Norman RE, Carpenter DO, Scott J, Brune MN, Sly PD. Environmental exposures: an underrecognized contribution to noncommunicable diseases. *Rev Environ Health.* 2013;28:59-65.
66. Jugder D, Sugimoto N, Shinoda M, Kimura R, Matsui I, Nishikawa M. Dust, biomass burning smoke, and anthropogenic aerosol detected by polarization-sensitive Mie lidar measurements in Mongolia. *Atmos Environ.* 2010;54:231-241.
67. Gunchin G, Sereeter L, Dagva S, et al. Air particulate matter pollution in Ulaanbaatar city, Mongolia. *Int J PIXE.* 2012;22:165-171.
68. Batmunkh T, Kim YJ, Jung JS, Park K, Tumendemberel B. Chemical characteristics of fine particulate matters measured during severe winter haze events in Ulaanbaatar, Mongolia. *J Air Waste Manage Assoc.* 2013;63:659-670.
69. Guttikunda SK, Lodoysamba S, Bulgansaikhan B, Dashdondog B. Particulate pollution in Ulaanbaatar, Mongolia. *Air Qual Atmos Health.* 2013:1-13.
70. National Statistical Office. *Statistical Yearbook of Ulaanbaatar City*. Ulaanbaatar, Mongolia: National Statistical Office; 2012.
71. Park S-U, Park M-S, Chun Y. Asian dust events observed by a 20-m monitoring tower in Mongolia during 2009. *Atmos Environ.* 2010;44:4964-4972.
72. Huang Y, Luvsan ME, Gombojav E, Ochir C, Bulgan J, Chan C. Land use patterns and SO 2 and NO 2 pollution in Ulaanbaatar, Mongolia. *Environ Res.* 2013;124:1-6.
73. National Statistical Office. *Statistical Year Book of Ulaanbaatar City*. Ulaanbaatar, Mongolia: National Statistical Office; 2011.
74. Munkbaatar P, Sukhbaatar I, Hamada E, Morimo R, Hirabaru O. Drinking water quality of Gobi region of Mongolia. Paper presented at: Strategic Technologies, 2008, IFOST 2008, Third International Forum; June 23-29, 2008; Novosibirsk, Russia.
75. Dalai B, Ishiga H. Geochemical evaluation of present-day Tuul River sediments, Ulaanbaatar basin, Mongolia. *Environ Monit Assess.* 2013;185:2869-2881.
76. Nriagu J, Nam DH, Ayanwola TA, et al. High levels of uranium in groundwater of Ulaanbaatar, Mongolia. *Sci Total Environ.* 2012;414:722-726.
77. Ochir C, Shahrir S, Noijmaa L, Breysse PN, Navas-Acien A. Secondhand smoke exposure among bar and nightclub employees Mongolia. *Epidemiology.* 2011;22:S234-S235.

78. Komatsu F, Kagawa Y, Kawabata T, et al. A high accumulation of hair minerals in Mongolian people: 2nd report; influence of manganese, iron, lead, cadmium and aluminum to oxidative stress, Parkinsonism and arthritis. *Curr Aging Sci.* 2011;4:42-56.
79. Unursaikhan S, Ichinkhorloo B, Enkhtsetseg S, et al. Result of laboratory analyses for study health effects related to mercury in Bornuur and Jargalant Soum of Tuv aimag. *J Mongolian Health Sci.* 2010;4:154-155.
80. Dashdorj U, Tserensodnom B, Bold B, Chimedregzen U, Komatsu F, Kagawa Y. Association of cumulative some heavy metal exposure with Parkinson's disease. *Mov Disord.* 2012;27:S1.
81. Dashdorj U, Tserensodnom B, Komatsu F, Jigjidsuren B, Chimedregzen U. High hair manganese and lead accumulation in Mongolians with Parkinson's disease. *Mov Disord.* 2011;26:S50-S51.
82. Unursaikhan S, Burmaajav B, Ichinkhorloo B, Baatartsol D, Govigerel B, Bayasgalan B. Re-survey study of environmental pollution in Khongor soum, Darkhan-Uul province. *J Mongolian Health Sci.* 2011;(3):157-158.