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# The influence of season and living environment on children's urinary 1-hydroxypyrene levels in Ulaanbaatar, Mongolia

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ABSTRACT

*Background:* Heating indoor living environments elevates air pollution in Ulaanbaatar, Mongolia.
*Objective:* This study was conducted to investigate the influence of season and living environment on children's urinary 1-hydroxypyrene (1-OHP) levels in Ulaanbaatar, Mongolia.
*Methods:* Our study subjects were 320 children aged 11–15 years living in gers, brick houses and apartments, in ger and non-ger areas of Ulaanbaatar. Spot urine samples and questionnaires were collected three times from each subject in three seasons, September (warm) and December (cold) in 2011 and March (moderate) in 2012. Urinary 1-OHP was analyzed by high-performance liquid chromatography with fluorescent detection (HPLC/FLD). Generalized estimating equation (GEE) models were applied to estimate the seasonal and residential effects on 1-OHP levels, adjusting for demographic and environmental factors.
*Results:* Children's urinary 1-OHP levels showed significant seasonal differences with $0.30 \pm 0.57$ μmol/mol creatinine in cold season, $0.14 \pm 0.12$ μmol/mol creatinine in moderate season, and $0.14 \pm 0.21$ μmol/mol creatinine in warm season. After controlling confounding factors, the GEE model showed that season, living area, and housing type had significant influence on children's urinary 1-OHP levels. Urinary 1-OHP levels in the cold and moderate seasons were, respectively 2.13 and 1.37 times higher than the warm season. Urinary 1-OHP levels for children living in ger areas were 1.27 times higher than those living in non-ger areas. Children who lived in gers or brick houses had 1.58 and 1.34 times higher 1-OHP levels, respectively, compared with those living in apartments. Children's urinary 1-OHP levels were associated with either estimated $NO_2$ or $SO_2$ concentrations at their home addresses in Ulaanbaatar.
*Conclusion:* Mongolian children's urinary 1-OHP levels were significantly elevated during the cold season, and for those living in ger areas, gers, or brick houses in Ulaanbaatar. Children's urinary 1-OHP levels were associated PAH co-pollutants $SO_2$ and $NO_2$, suggesting elevated 1-OHP levels may be attributable to PAH emissions from coal burning and traffic respectively, with indoor emissions from stoves further contributing to elevated 1-OHP in some children.



## 1. Introduction

Mongolia is located in a high latitude area of extreme continental weather with low temperatures, which makes a heated living environment necessary during the long winter from mid-September to mid-May. The main sources of electricity and heating in Ulaanbaatar city are three coal-fired power plants, two of which are located in the western section of the city and one of which is located near the city center. These three power plants provide both electricity and steam for heating to some but not most residents in Ulaanbaatar through Mongolian central energy and heating system. A recent World Health Organization (WHO) report showed that the annual average ambient particulate matters ($PM_{10}$) concentration in Ulaanbaatar was 279 μg/m$^3$, which was 13 times greater than the WHO annual average guideline of

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20 μg/m$^3$ (WHO, 2005) and ranked second highest among 1100 cities around the world (WHO, 2011). Several studies have suggested that the greatest amount of pollution occurs during the winter. A previous study found that ambient $SO_2$ levels in the capital city of Ulaanbaatar in winter were almost 6-fold higher than those in summer (Luvsan et al., 2012). Another study reported that ambient $NO_2$ levels in winter were significantly higher than those in other seasons in Ulaanbaatar (Huang et al., 2013). Studies have also shown that PM concentrations during cold seasons are higher than those in other seasons. Allen et al. (2013) reported that mean 24-h $PM_{2.5}$ concentrations from December 2009 to February 2010 were $147.8 \pm 61.2$ μg/m$^3$, and Nishikawa et al. (2011) reported that average monthly $PM_{10}$ and $PM_{2.5}$ concentrations in December were approximately 290 and 200 μg/m$^3$, respectively.

Mongolia is also a rapidly urbanizing country. Approximately 1.13 million people, or approximately 45% of the total Mongolian population, live in Ulaanbaatar. Over the past two decades, many Mongolians have immigrated to Ulaanbaatar and live in traditional housing known as gers at the periphery of the city; these gers form many communities known as ger areas. Residents of gers use wood or coal-burning stoves indoors year round for cooking and during the winter for heating. One study estimated that the annual average consumptions of coal and wood in ger areas were 5 t and 3 m$^3$ per household, respectively (Guttikunda, 2007). In addition, traffic has increased significantly, from 42,509 vehicles in 2000 to 209,791 vehicles in 2011 (NSO, 2011). Traffic congestion has become common in the city, especially at the intersection of the three major roads which meet in the city center. One recent study reported that ambient $SO_2$ concentrations in ger areas were higher than in non-ger areas and that ambient $NO_2$ concentrations in areas with traffic were higher than in urban sites in Ulaanbaatar, suggesting that air pollution in Ulaanbaatar was related to both coal combustion and traffic emissions (Huang et al., 2013).

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds and byproduct emissions from various coal combustion sources, including coal-fired power plants, coal and wood stoves, and traffic emissions from vehicles (Slezakova et al., 2013). Urinary 1-hydroxypyrene (1-OHP) concentrations have been identified as a good biomarker of PAH exposure in humans and have been successfully applied to evaluate occupational and environmental exposures in Netherlands (Jongeneelen et al., 1987, 1990). Other studies have used urinary 1-OHP to investigate PAH exposure among children living in the vicinity of major PAH emission sources. One study found that children's urinary 1-OHP concentrations were higher for those living near a coal-fired power plant in Taiwan (Hu et al., 2011). Mucha et al. (2006) found that children who lived in the industrial area had significantly higher urinary 1-OHP concentrations than those in the urban areas in Ukraine. Another study showed that children who lived in homes with indoor coal-burning stoves had higher urinary 1-OHP levels than children who did not live in homes with indoor coal-burning stoves in Poland (Siwinska et al., 1999).

Moreover, previous studies also showed positive associations of $SO_2$ and $NO_2$ concentrations with PAH concentrations as well as urinary 1-OHP levels (Evagelopoulos et al., 2010; Llop et al., 2008). Therefore, the $SO_2$, $NO_2$ and PAH concentrations observed in Ulaanbaatar, Mongolia may come from common emission sources of coal-fired power plants and traffic. However, no such study has been conducted in Mongolia although children's PAH exposure is potentially high in Ulaanbaatar and may be affected by living conditions and weather. Therefore, this study was designed to evaluate PAH exposure among children in Ulaanbaatar in general and to investigate the influence of season and living environment on children's urinary 1-OHP levels in particular. In addition, exposure sources were explored by associating urinary 1-OHP levels with land-use regression models for $SO_2$ and $NO_2$, indicators for PAH emissions from coal burning and traffic, respectively.

## 2. Materials and methods

### 2.1. Sample collection and determination of urinary 1-OHP

A total of 320 children aged 11–15 years from 6 schools in Ulaanbaatar were recruited for this study. The locations of our study subjects' home addresses and those of the power plants, major roads, and ger areas in the city are shown in Fig. 1.

Spot urine samples were collected three times from each study subject: September 2011 (warm season), December 2011 (cold season), and March 2012 (moderate season). We used reverse-phase high-performance liquid chromatography to analyze urinary 1-OHP at the College of Public Health, National Taiwan University (Jongeneelen et al., 1987). Urine samples were first treated with enzymatic hydrolysis by using β-glucuronidase/arylsulfatase. The method of chemical analysis was conducted using high-performance liquid chromatography (HPLC, Waters 2695) with fluorescent detection (FLD, Waters 474) and RP-18 column (XBridge, 150 × 4.6 mm, 5 μm). The mobile phase for HPLC was 65% methanol (methanol/water = 65:35). A 20 μl of the treated samples were injected into the HPLC at room temperature at a flow rate of 1.0 mL/min. The excitation wavelength at 281 nm and emission wavelength at 388 nm were set to detect 1-OHP. The limit of detection is 0.0010 ng/mL. Urinary creatinine, which detected by Enzyme-linked immunosorbent assay (ELISA), was used to adjust the measured levels of 1-OHP, and the urinary 1-OHP concentrations were expressed in μmol/mol creatinine.

A face-to-face questionnaire was conducted to collect personal and residential information related to children's PAH exposure. Personal information included gender, age, and smoking, while residential information included home address, incense burning at home, and housing type (i.e., gers, brick houses, and apartments).

### 2.2. Geographic coding and air pollution exposure modeling

$SO_2$ and $NO_2$ exposure levels for the 320 children were represented by the ambient concentrations at the individual home addresses, which were estimated using five land use regression models in Ulaanbaatar from Huang et al. (Huang et al., 2013). These land use regression models were used to estimate the ambient $NO_2$ concentrations in three seasons and the $SO_2$ concentrations in two seasons (cold and moderate) in Ulaanbaatar. Land use variables, i.e., distances to the nearest major road, the nearest ger area, the power plant, and the city center, were entered into the regression models to calculate the $NO_2$ and $SO_2$

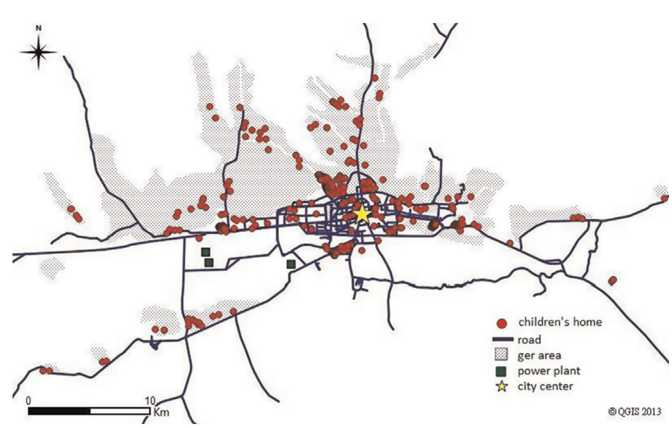


**Fig. 1.** Locations of the 320 children's homes in Ulaanbaatar, Mongolia, 2011–2012.