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Chemical Characteristics Of Indoor Pm2.5 In Urban China: An Exposure Assessment Study

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Abstract:

Today, 690 million people, or double the population of the United States, live in urban areas of China accounting for over 50% of the country's population. Many studies have analyzed the outdoor levels of particulate matter with aerodynamic diameter <2.5 micrometers (PM 2.5) instead of indoors, where individuals spend the majority of their time. In this study, we investigated the levels of PM 2.5 and chemical composition of the PM in 15 households in Taiyuan, China. 24 hour measurements were captured on Teflon filters in China and then analyzed using X-ray fluorescence in the United States. Mass concentrations of the 32 filters from Taiyuan ranged from 38.6 $\mu g/m^3$ to 127.7 $\mu g/m^3$, with a mean of 65.1 $\mu g/m^3$, over two times higher than the WHO standard. High levels of mercury, zinc, lead, manganese, copper, chromium and sulfur were found indoors of homes. Within a 24-hour sample period, 3 filters recorded lead levels higher than the EPA's 3 month rolling average of 150ng/m^3 (nanograms per cubic meter), while all filters averaged a reading of 88 ng/m^3. Our findings suggest that residents of Taiyuan, China are exposed to a large concentration of particulate matter and heavy metals inside their homes.

Introduction:

In the past several decades a great migration of individuals from rural villages to urban cities has occurred in China. Today, 690 million people, or double the population of the United States, live in urban areas of China accounting for over 50% of the country's population (World Bank, 2014). Although a large cohort of China's population is still exposed to air pollution in the villages, a greater share of individuals is now being exposed to pollution in China's growing urban cities. According to the World Bank, 16 of the world's 20 most polluted cities are in China, exposing millions to high levels of air pollution (World Bank, 2007).

Due to greater urbanization and economic growth, China has seen an increase in anthropogenic activities such as power generation, waste combustion, construction, increasing use of automobiles, and heating (Li, W et al 2014). These activities have caused drastic increases in the levels of particulate matter with aerodynamic diameter <2.5 *micrometers* (PM2.5) all across cities in China. For example, in the years between 2004 and 2008, the mean daily PM 2.5 concentration in Beijing was 105 $\mu g/m^3$, approximately four times higher than the World Health Organization's guideline of 25 $\mu g/m^3$ per 24 hour average (Guo Y et al. 2013, WHO 2006). This burden of air pollution has caused both an economic and health impact on the country. One study estimated that the impact of ozone and particulate-matter concentrations on the Chinese economy rose from US$22 billion during the period of 1975 to 1997 to US$112 billion in 2005 (Matus K et al 2012). Furthermore, a risk assessment study conducted by Institutes of Health Metrics and Evaluation concluded that ambient urban air pollution (PM2.5) causes 1.2 million premature deaths annually in China (Aunan K et al. 2014). In this study, we looked at air pollution in the city of Taiyuan, which is the capital city of Shanxi Province, China. With a population of over 2.6 million, Taiyuan is one of the most polluted cities in the world (Mestl et al. 2003, Fu Shan et al. 2009). In 1999 the Chinese government reported Taiyuan to be the most polluted city in China and in 1998 the average annual concentration of particulate matter was 498 $\mu g/m^3$ (Shan Fu et al). Many of Taiyuan's major industries including energy, metallurgy, machinery, chemical, textile, medicine, and building material, all contribute to the high levels of pollution and emission of heavy metal elements (Fu Shan et al. 2009, Wang et al. 2013). The city produces one fourth of China's raw coal and consumes over 25 million tons of coal of which approximately 40% is used for energy

Figure 1: Taiyuan, China

production (Xie RK et al. 2009).

Most studies in China, including those in the city of Taiyuan, have focused on measuring particulate matter exposure outdoors, while few exposure assessments have focused on indoor air pollution (Kan H. et al 2003, Fu Shan et al. 2009, Jiang R et al 2007, Zhang et al 2013). Indoor exposure assessments in rural China have shown that individuals are exposed to large quantities of particulate matter. In a study conducted by Jiang R et al, PM10 levels in rural kitchens were three times higher than those in urban locations (Jiang R et al, 2007). An outdoor exposure assessment study conducted by W. Li et al, found the average annual concentrations of PM10 in the rural field and village sites of Taiyuan were 144 $\mu g/m^3$ and 182 $\mu g/m^3$ respectively compared to 288 $\mu g/m^3$ in the urban areas (Li W et al 2014). As the Chinese population has started to migrate from rural to urban areas, some studies suggest a reduction of PM exposure attributed to the reduced use of solid fuels (Aunan K et al. 2014). However many of these studies have focused on outdoor readings to estimate exposures and still do not give a clear understanding of indoor exposures for the urban Chinese.

In China, few studies focus on the indoor air pollution exposures of individuals living in urban locations. Furthermore, the exposure assessments conducted indoors usually use light spectrometers or other non-filter based exposure assessments (Mu L, et al. 2013). In our study, we measured 24-hour readings of indoor particulate matter in 15 unique households within Taiyuan, China. We used two stationary air pump monitors to collect particulate matter on Teflon filters in both the kitchen and the bedroom for each household. Furthermore, although some studies have looked at the chemical characteristics of air pollution in China and in Taiyuan specifically, none have looked at exposures within households (Wang Q et al. 2013). Our study, to the best of our knowledge, is the first X-ray fluorescence chemical analysis of indoor air pollutants in Taiyuan, China.

Materials and Methods:

This exposure assessment was conducted in fifteen households located in the city of Taiyuan, within the province of Shanxi, China. All fifteen households were located in urban areas within 5 miles of the city center. Households were selected based on feasibility and availability in coordination with Shanxi Medical University's School of Public Health. In total, sixteen households had measurements taken, with one household (Household 8) being dropped because they preemptively shut off the airflow pump before 24 hours of measurement were complete.

Exposure assessment and analysis were conducted in two phases a) indoor PM 2.5 monitors collected PM on filters and then b) x-ray florescence analysis was conducted on the particulate matter captured on the filters. Sampling was conducted between July 2013 and August 2013. During this summer season, households commonly would open windows, use their air conditioning (if owned), and did not use heating fuel. Therefore, our results can be attributed to outdoor air exposure and cooking fuel exposure for individuals living in each household. PM 2.5 monitoring occurred within each household for a period of 24 hours (1440 minutes). Stationary monitors were placed in both the kitchen and the bedroom.

All households had both adults and children living within the home. Adults were asked to complete a questionnaire under the guidance of researchers from the Shanxi Medical University's School of Public Health. Each participant gave verbal consent to participate in the study, not to tamper with research equipment, and complete the questionnaire to the best of their knowledge. The sampling period covered both weekdays, during which some individuals would be at work or school, and during the weekends, when many individuals were home. Outside monitoring of PM 2.5 was not assessed, however crude estimates were taken by recording PM 2.5 levels from one monitoring station from the *Air Pollution in China: Real Time Air Quality Index Visual Map* (http://aqicn.org/map/china/). These estimates were only taken for 9 households in our study as recording data during the late night hours became difficult.

Air sampling PM 2.5 monitors:

Air sampling pumps were procured from Harvard University School of Public Health Department of Environmental Health. Two air-sampling pumps were shipped to Taiyuan, China and were placed in 16 bedrooms and 16 kitchens in various households. Prior to indoor air samples being measured, thirty-two 37mm Teflon filters were pre-weighted and shipped to China in sealed and secured petri dishes. A unique filter was used for each room, for a total of two filters per household. Prior to starting the measurement, filters were placed in each pump. For each air-sampling pump, airflow was measured using a Buck soap-bubble flow meter before and after every 24-hour measurement. After the filter was placed and initial flow was measured, the pumps were placed at an average height of 1-1.5 meters in both the kitchen and bedroom. Each pump was placed facing the center of the room with a safe distance from windows and air conditioners, in order to avoid bias readings. Other factors such as availability of an outlet for electricity, safety of equipment, and convenience of the participant were also considered when placing the air pumps. Particulate matter was collected continuously in each room for an average of 23 hours and 32 minutes (1412.4 minutes) with one household measuring for only 17 hours. Each air-sampling pump would continuously collect particulate matter through an inlet tube, which would lead down to the filter. After the study was conducted in a household, the airflow was checked again and the filter was removed, stored safely, and then shipped back to Harvard University for post study weighing. For all measurements the average airflow was measured at

1798.8 ml/min (1774.0, 1834.5).

Questionnaires:

After the 24-hour period of conducting the air sampling measurement the principal researcher, with the assistant of native Mandarin speaking researchers from Shanxi Medical University's School of Public Health, would collect information through questionnaires. Information about cooking activities of the study participants, home structure and improvements, ventilation, and smoking is assessed. To better orient the participants and researchers, questions were separated into two categories: 1) questions dealing with the home and 2) questions dealing with specifically the kitchen. The questionnaire was used to further analyze and understand the data and look for either confounders or correlations. Two questions from the questionnaire are shown below, the full questionnaire can be found in the appendix.

您家测量当日家中是否有人吸烟：
In the day of measuring, does anyone smoke in your home?

0.否　　1.是，______小时　_____ 吸食香烟
0. no　　1. Yes ______hours　_____# of cigarettes

您家厨房使用的排烟系统，目前：___________
The ventilation and smoke exhaustion system for your kitchen, current:
(1) 无 (2) 抽油烟机 (3) 排风扇 (4) 开窗 (5) 其它___________
(1) no (2) exhaust ventilator (3) ventilating fan (4) window (5) other

Data Analysis:

Data analysis was conducted on all thirty Teflon filters from all fifteen households. Total PM2.5 measurements were calculated by subtracting the pre-study filter weights from the post study filter weights (shown in part a below). The weighted measurements were converted from milligrams to micrograms. Then total sample volume for each filter was calculated by taking the average flow rate measured and multiplying it by the sampling time period (shown in part b).

The average flow rate over the entire sampling period is converted from liters into cubic meters. Finally, the mass concentration of PM2.5 particulate matter was calculated by dividing the total mass of fine particulate collected during the sampling period by the total volume of air sampled (shown in part c) (Dwelle T et al 2003).

a)

$$M_{2.5} = (M_f - M_i) \times 10^3$$

$M_{2.5}$ = total mass of fine particulate collected during sampling period (μg)
M_f = final mass of the conditioned filter after sample collection (mg)
M_i = initial mass of the conditioned filter before sample collection (mg)
10^3 = unit conversion factor for milligrams (mg) to micrograms (μg)

b)

$$V = Q_{avg} \times t \times 10^{-3}$$

V = total sample volume (m^3)
Q_{avg} = average flow rate over the entire duration of the sampling period (L/min)
t = duration of sampling period (min)
10^{-3} = unit conversion factor for liters (L) into cubic meters (m^3)

c)

$$PM_{2.5} = \frac{M_{2.5}}{V}$$

$PM_{2.5}$ = mass concentration of $PM_{2.5}$ particulates (μg/m^3)
$M_{2.5}$ = total mass of fine particulate collected during sampling period (μg)
V = total volume of air sampled (m^3)

X-ray florescence of elements:

After measuring the amount of fine particulate matter upon each Teflon filter in the study, X-ray fluorescence spectrometry analysis was conducted on each filter in order to identify the chemical makeup of the material on the filters. X-ray fluorescence uses a high-energy wavelength of x-ray and gamma ray radiation in order to dislodge an electron from an inner shell of the element, allowing an outer shell electron to move into its spot. This movement from the outer shell to the inner shell is referred to as fluorescence and follows with a release of energy from the atom. Each atom has a unique thumbprint for the energy that is released, therefore allowing the researcher to identify what elements are present and at what quantity (Dwelle T et al 2003). In our study we looked at 48 elements for each of the thirty unique filters. The results of our x-ray fluorescence analysis were divided by their likely sources and then their levels were compared to a study of heavy metals conducted in 8 cities in China, including Taiyuan. Analysis of variance of the concentrations and exposures of both the PM2.5 and chemicals were done using EXCEL and SAS.

Results:

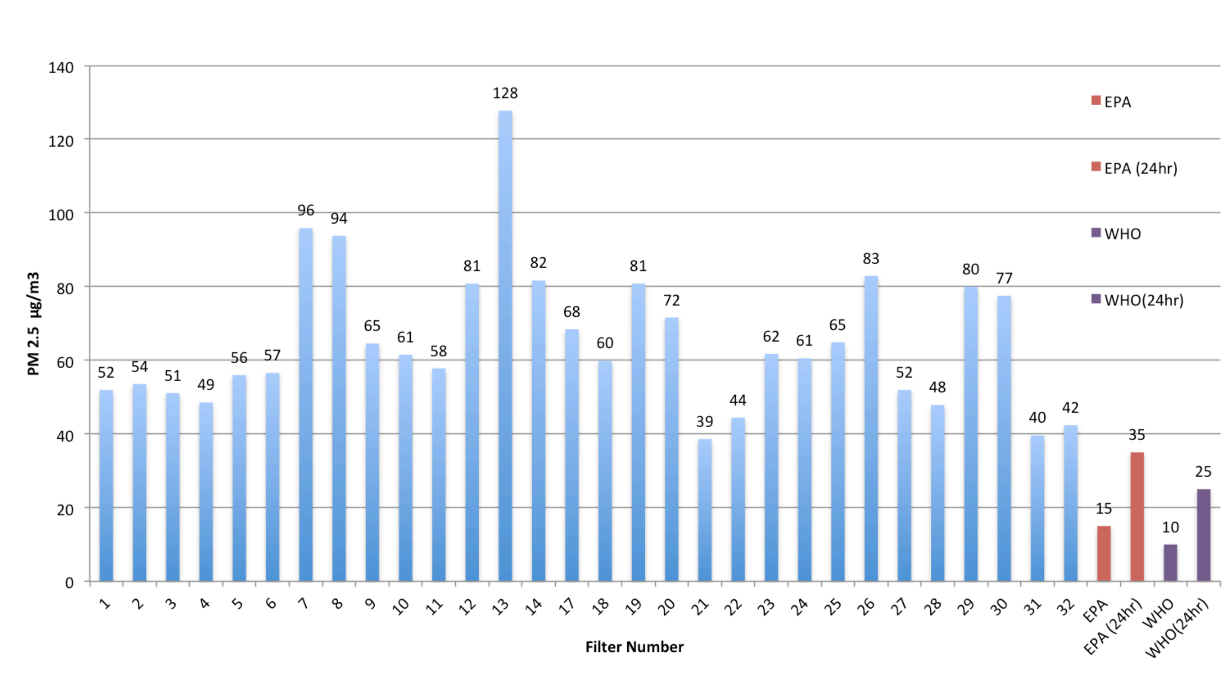
Mass concentrations of 32 filters from Taiyuan, China ranged from 38.6 μg/m^3 to 127.7 μg/m^3, with a mean of 65.1 μg/m^3 (Table1). The PM2.5 levels varied greatly between each home and even between each room within a household. The highest concentrations were found in household 7 which had a concentration of 127.7 μg/m^3 in the bedroom. There are many factors, which may contribute to this large range of exposures, these factors are shown in Table 2 and further described in the discussion section. The lowest concentration of PM 2.5 was found in the bedroom of household 11 which had a reading of 38.6 μg/m^3 in the bedroom. As shown in Figure 2, all of the

Table 1

Household	Square Meters	PM 2.5 µg/m^3	Location
1	65	51.9	Bedroom
		53.6	Kitchen
2	70	51.1	Kitchen
		48.5	Bedroom
3	104	56.0	Bedroom
		56.6	Kitchen
4	100	95.8	Bedroom
		93.8	Kitchen
5	121	64.5	Kitchen
		61.5	Bedroom
6	55	57.8	Bedroom
		80.8	Kitchen
7	60	127.7	Bedroom
		81.6	Kitchen
9	50	68.4	Kitchen
		59.8	Bedroom
10	100	80.8	Kitchen
		71.6	Bedroom
11	135	38.6	Bedroom
		44.4	Kitchen
12	120	61.7	Bedroom
		60.5	Kitchen
13	215	64.9	Bedroom
		82.9	Kitchen
14	75	51.9	Kitchen
		47.8	Bedroom
15	60	80.0	Bedroom
		77.5	Kitchen
16	108	39.6	Kitchen
		42.4	Bedroom

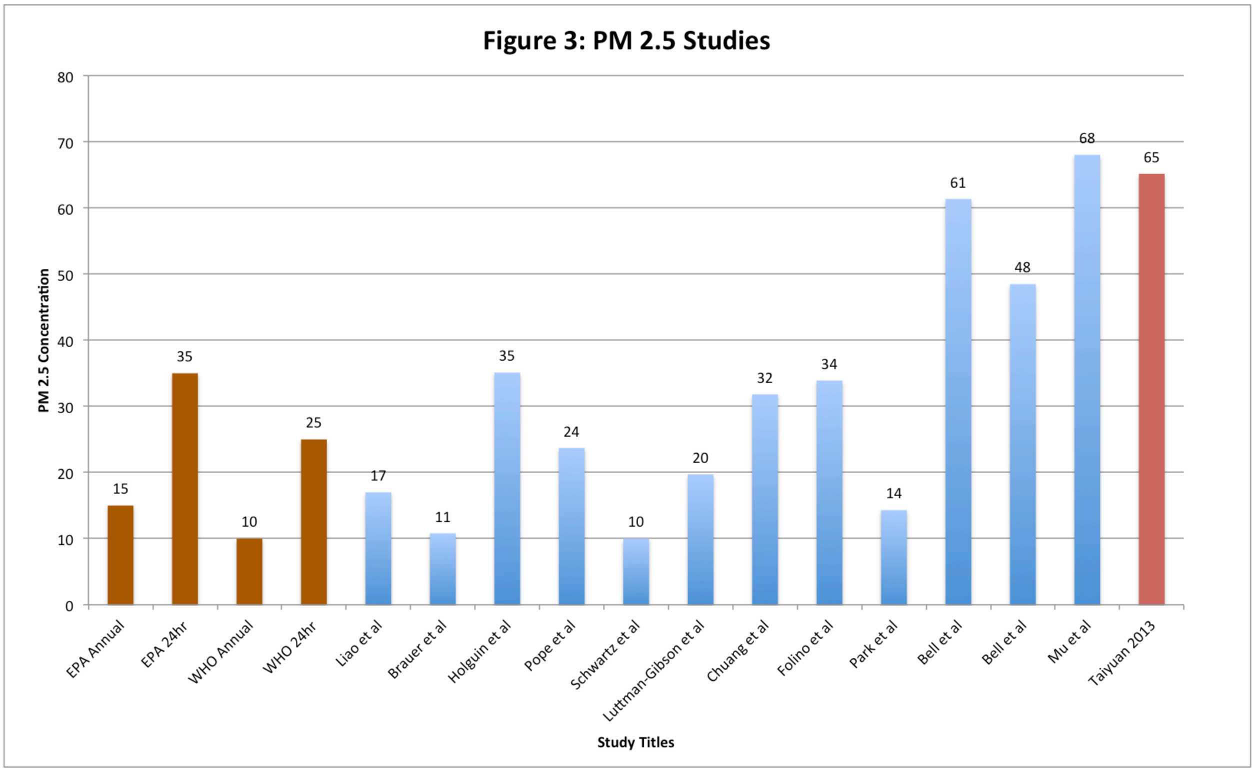
*Household 8 was dropped from the study for lack of compliance concentrations exceed both the United States Environmental Protection Agency (EPA) 24 hour PM2.5 standard of 35 $\mu g/m^3$ and the World Health Organization (WHO) 24 hour PM2.5 standard of 25 $\mu g/m^3$ (EPA 2012, WHO 2006). The EPA and WHO standards are set for outdoor particulate matter levels and do not regulate indoor air pollution.

Figure 2: PM 2.5 µg/m3



Furthermore when compared to other 24 hour PM2.5 studies (Figure 3) the concentrations measured in our study were higher than many other studies (EPA 2012, WHO, Liao et al 1999,Brauer et al 2001, Holguin et al 2003, Pope et al 2004, Schwartz et al 2005, Lutmman-Gibson et al 2006, Chuang KJ et al 2007, Folino et al 2009, Park SK et al 2010, Jiang et al 2008, Mu et al 2013.) The study by Jiang et al looked at particulate matter in the city of Shenyang, China over 10 hour sampling periods (Jiang et al 2008). Our results are shown to be consistent with the Mu et al study, which measured mean indoor PM2.5 concentrations of 68 $\mu g/m^3$ in

Taiyuan, China (Mu et al).



Questionnaire Results:

All 15 participating households in the study completed the questionnaire; they had an arithmetic mean of 65 $\mu g/m^3$ PM2.5 for both the kitchen and the bedroom.

Apartment:

Of the 15 households that participated in our study, 13 had renovations that were completed on their home and 2 households had no renovations. The materials used to complete the renovations included: paint (10 homes), wallpaper (5), artificial slabs or panels added (8), wood (5), oil painting (8), rubber (8), marble (2), and granite (2). Seven households had air conditioning and used it during the 24-hour study while another eight households did not use it. Households that used air conditioning during the study had an arithmetic mean concentration that

Table 2:

Questionnaire Variable:	# of Households	Arethmetic Mean of PM2.5 μg/m^3
ALL	15	65
Renovations		
Yes	13	63
No	2	77
If yes:		
a) Paint	10	
b) Wallpaper	5	
c) Artificial slabs/panel	8	
d) Wood	5	
e) Oil Paint	8	
f) Rubber	8	
g) Marble	2	
h) Granite	2	
Air Conditioning		
Yes	7	70
No	8	61
Smoking		
Yes	2	68
No	13	65
Kitchen		
Open	5	55
Closed	10	71
Type of Fuel/Stove		
Gas	10	66
Induction Cooker	5	66
Cooking Method		
Deep Fried	1	81
No DF		65
Braised	1	52
No B		67
Pan fried	13	65
No P		47
Steamed	9	65
No St		67
Simmer	10	70
No Si		57
Exhaust Ventilator		
Yes	13	66
No	2	65

was 9 μg/m^3 higher than those who did not. As table 3 shows, the highest PM 2.5 reading was taken in the household that used their air conditioning the longest. Thus it may be possible that those who circulate outside air indoors through the air conditioner may expose themselves to even a greater amount of particulate matter, however as this study only employees 15 households, we can not conclude that this correlation is certain. 2 out of the 15 households had someone who smoked during or before the time of studying. There was no significant different between the arithmetic means of PM2.5 for households who smoked and those who did not, however a larger sample set would be needed for further analysis.

Kitchen:

10 households had a closed kitchen, which was its own standalone room and closed off from the rest of the house by a door or a wall. 5 households had an open kitchen that allowed air to flow

freely from the kitchen to the rest of the home. Those households that had an open kitchen showed a significantly lower PM 2.5 level (55 9 μg/m^3) than those who had a closed kitchen (71 μg/m^3). Furthermore, 10 households used a gas stove to cook their food while 5 households used an induction cooker. Of the cooking methods used by the participants, deep frying, braising, pan frying, and simmering all showed a significant different between the arithmetic mean PM2.5 levels in the kitchen of those who employed that cooking method versus those who did not. Participants used multiple cooking methods during the study, thus making it necessary to set up a controlled experiment with a larger sample size to further understand these differences. Finally, in the kitchen 13 out of 15 households used exhaust ventilation while they were cooking. The two households that did not have use exhaust ventilation did not see any significant difference in PM2.5 levels within their kitchen.

Outdoor Air Pollution:

Table 3:

Household	PM 2.5 µg/m^3	Smoking	Air Conditioning	AC Use (Hours)	Open Window (hours)	Average Outside PM2.5 µg/m^3
1	51.9 53.6	No	Bedroom	0	24	-
2	51.1 48.5	No	No	0	24	-
3	56.0 56.6	No	No	0	24	-
4	95.8 93.8	No	Bedroom/Common	1	5	-
5	64.5 61.5	Yes	Bedroom/Common	2	14	-
6	57.8 80.8	no	no	0	24	137.2
7	127.7 81.6	no	Bedroom	7	24	117.1
9	68.4 59.8	no	No	0	12	147.1
10	80.8 71.6	no	No	0	8	134.3
11	38.6 44.4	no	Common Room	0	7	124.6
12	61.7 60.5	no	Bedroom/Common	0.5	5	117.1
13	64.9 82.9	yes	Bedroom	0	3	142.0
14	51.9 47.8	no	No	0	10	119.6
15	80.0 77.5	no	No	0	24	124.8
16	39.6 42.4	no	No	0	24	-

In this study we had two stationary air pumps capture particulate matter in both the kitchen and the bedroom but did not have a stationary air pump outside of the home. Therefore for 9 households we wrote down outdoor PM2.5 reading from one monitoring station in Taiyuan, China, which was published on *Air Pollution in China: Real Time Air Quality Index Visual Map* (http://aqicn.org/map/china/) Table 3. The readings from the 9 days showed that outdoor air pollution played a role in determining the PM2.5 levels indoors, however there are only a limited number of observations with great variability in location and time that a correlation can not be made. We did observe that the household with the highest indoor PM2.5 levels (household 7) used the air conditioning for the longest time in their bedroom and had a window open somewhere in the home for 24 hours. Further research would need to include a pump outdoors while measuring indoor exposures to PM.

X-Ray Fluorescence:

As stated earlier, this is most likely the first study to conduct X-ray fluorescence on indoor particulate matter in Taiyuan, China. 48 elements were analyzed from the 32 Teflon filters used in the study. The full list of elements and their concentrations are attached at the end of paper in the appendix. In this paper we analyzed and calculated concentrations in nanograms per cubic meter (ng/m^3) for 12 elements: mercury, arsenic, selenium, zinc, lead, manganese, copper, nickel, chromium, cobalt, vanadium, and sulfur. Graphs of all 12 elements can be found in the appendix. Significantly high levels of mercury, zinc, lead, manganese, copper, chromium and sulfur were found indoors of homes (Table 4). Within a 24-hour sample period, 3 filters recorded lead levels higher than the EPA's 3 month rolling average of 150ng/m^3, while all filters averaged a reading of 88 ng/m^3 (EPA 2012).

Table 4:

Element	µg/filter	ng/m^3
Mercury	0.067	26
Arsenic	0.005	2
Selenium	0.013	5
Zinc	0.610	242
Lead	0.220	88
Manganese	0.196	79
Copper	0.052	21
Nickle	0.032	13
Chromium	0.081	34
Cobalt	0.000	0.2
Vanadium	0.003	1
Sulfur	18.000	7091

Discussion:

The results of our research suggest that households living in Taiyuan, China are exposed to high levels (mean of 65 $\mu g/m^3$) of PM2.5 and heavy metals. The small sample size of 15 households limits our ability to generalize our interpretations for the entire population; however, our findings not only confirm what other studies have seen in urban China, including previous studies in Taiyuan (Jiang et al 2008, Mu et al 2013), but also for the first time characterize the chemical composition of PM households in Taiyuan are exposed to indoors. Our results show the mean PM 2.5 levels for all households were twice as high as the WHO standards for 24-hour indoor air pollution suggesting a greater burden of health risk for those living in Taiyuan (WHO 2006).

Our study focused on looking at indoor air pollution levels, which few studies in China have focus on in the past. Questionnaires were given at each household to give a unique understanding of all the factors that may attenuate PM exposure; factors such as outdoor air pollution, air conditioning, cooking methods, structure of the kitchen, and ventilation were all identified to have a potential impact on the exposure levels of individuals to indoor particulate matter levels. Furthermore, this research, to the best of our knowledge, was the first to conduct analysis using X-ray fluorescence on indoor exposure of particulate matter.

Particulate matter concentrations were higher in the kitchen for 10 households compared to bedrooms in 5 households. An explanation of this higher exposure maybe associated with the closed kitchen structures, which allow less PM to flow in and out of the room, the cooking methods, which have been linked to higher exposures of PM, and poor ventilation in the homes. The largest PM concentration was found in the bedroom of a home, which operated their air-conditioner for 7 hours during the night. Future studies could look at homes, which circulate air-conditioned air within the home versus pulling in air from the outside. Although PM levels were higher in the kitchen, the winter season may show higher readings in the common room or bedrooms where heating may take place.

Heavy metals in the air have been known to cause many diseases or adverse health effects such as cancer (Wang et al 2007). Although some heavy metals are endogenous in the soil and environment, anthropogenic activities add a significant amount into the atmospheric particulate matter. Studies have shown that certain heavy metals such as Cr, Mn, Ni, Zn, Mo, Cd, Se, and even Pb are linked to steel production while Ni and V are associated with fuel-oil combustion activities (Zhang 2013). Taiyuan is known for its large metal, machinery, chemical, and coal industries, which contribute a great deal of particulate matter into the ambient air. Compared to the study conducted by Wang et al, our indoor air analysis was consistent to the trend of metal concentrations found in outdoor samples of 8 cities in China, including Taiyuan (Wang et al 2013). Zinc levels were greater than lead which were greater than manganese, which was greater than copper, which was greater than nickel, which was greater than cobalt and vanadium (Zn > Pb > Mn > Cr > Cu > Ni > V > C) (Wang et al 2013). Chromium, which can be attributed to industrial activities, was found at high levels outdoors in all 8 cities studied by Wang et al, consistent with our findings indoors. The mean chromium concentration indoors, 0.034 $\mu g/m^3$ is over ten times higher than the WHO standard (0.0025 $\mu g/m^3$) (Wang et al 2013, WHO 2006).

Concentration diagrams in the Wang et al study confirms that heavy metals were introduced into the atmosphere by anthropogenic activities beyond those found naturally; thus the large concentrations we observed indoors in our study most likely originate from those same anthropogenic activities. From our study, we can conclude that as long as industrial activities occur in and around Taiyuan, individuals will be exposed to heavy metals both outdoors and indoors.

The first limitation of our study was the lack of outdoor air pollution samples during the same study period for each household. Having a better understanding of outdoor air pollution would give our study a complete understanding of where the particulate matter originated. Furthermore, having a daily dairy of timed activity would have allowed us to attribute exposure concentrations to individuals and their activities. Finally, this research study looked at exposure levels during a 24-hour period in the summer season of Taiyuan, China, but the climate and anthropogenic activities can change significantly within days and months, thus possibly impacting the exposure assessment.

As rapid migration shifts individuals from rural areas of China to cities, an increase in urban air pollution and air pollution exposure is eminent (Aunan K et al, 2014). An increase in adverse health effects are being seen in China every year due to the population exposure to outdoor and indoor particulate matter (Zhang Y. et al, 2013). Studies have shown that individuals spend significant amounts of times indoors, including within their home (Briggs 2003). Our study focused on assessing the amount of particulate matter Taiyuan citizens are exposed to and the chemical composition of the pollution. Our findings show that high levels of PM and heavy metal exposure are experienced by all households in our study and most likely all households in Taiyuan. Further research and action should be taken to increase knowledge and decrease the risk of exposure of PM and heavy metals for individuals living in Taiyuan, China.

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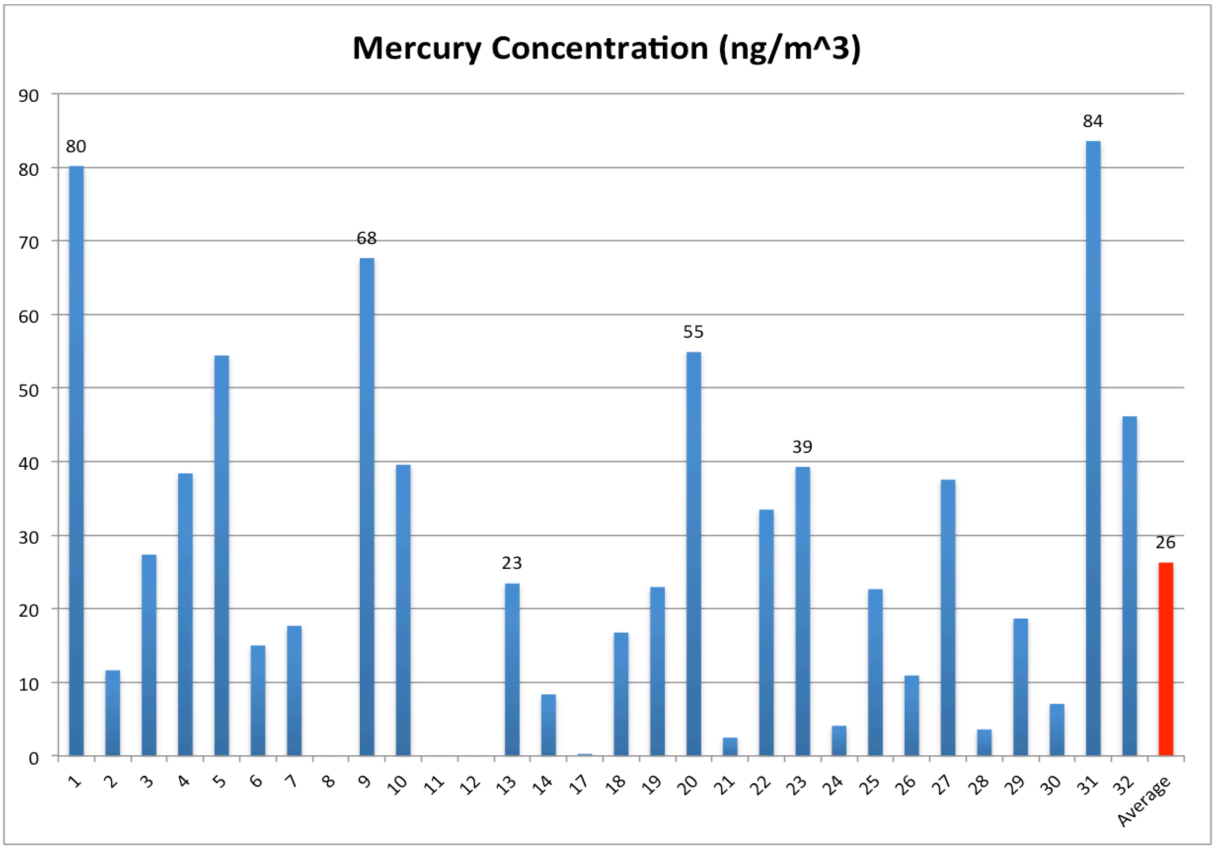
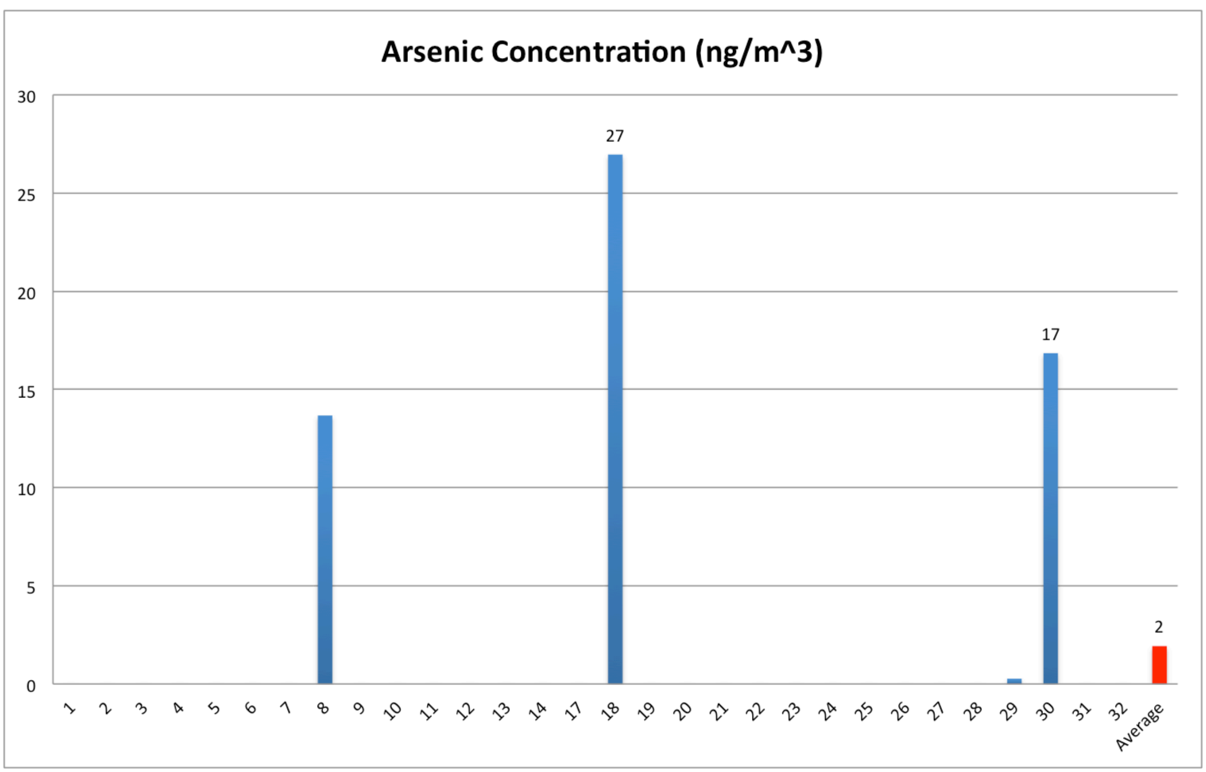
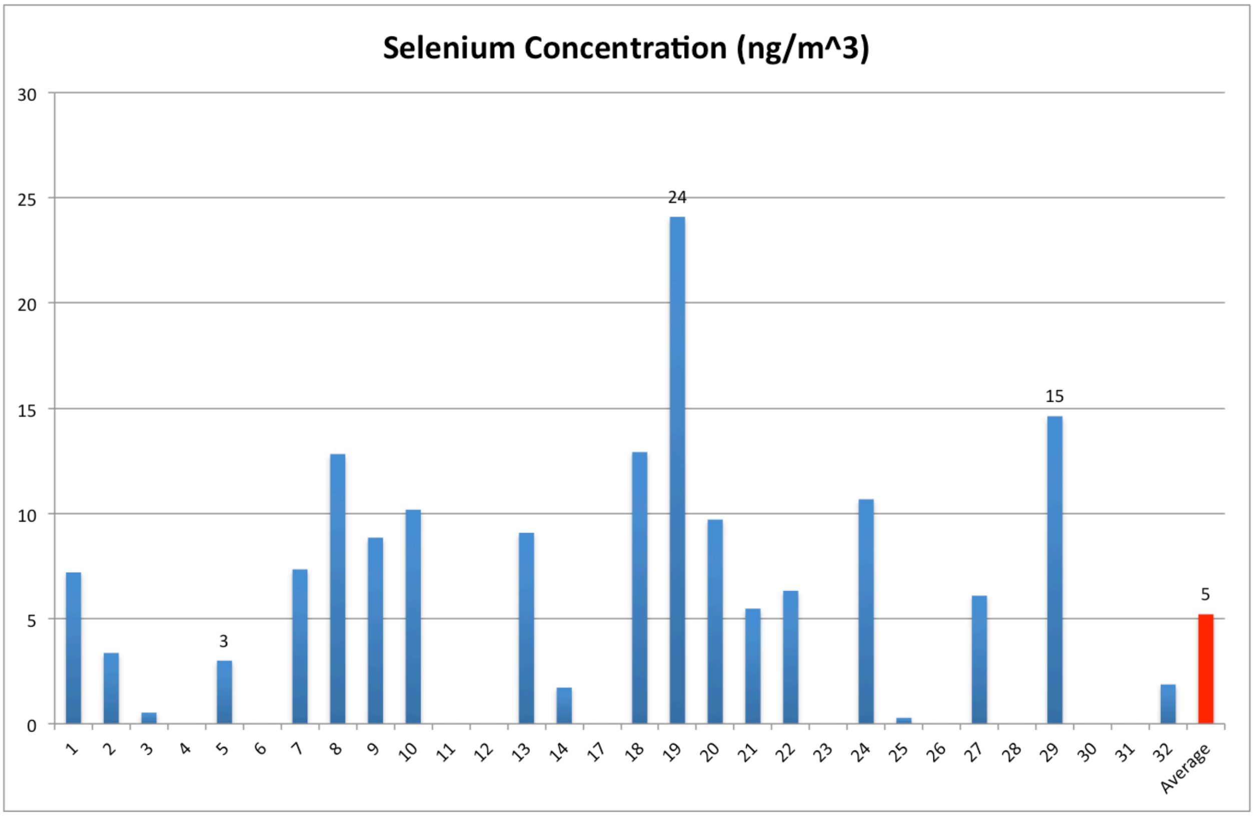
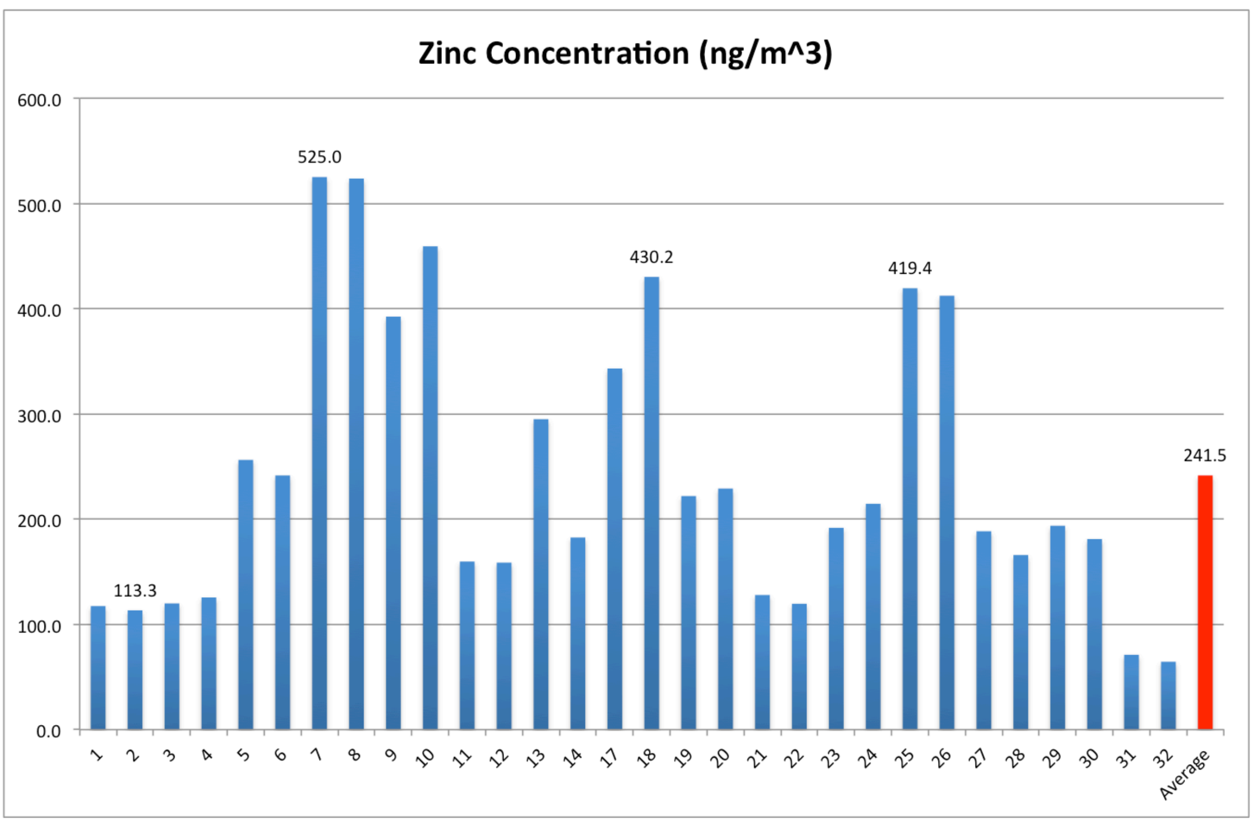
TAIYUAN PHOTO:
http://www.personal.psu.edu/lug129/blogs/serendipity/2008/09/27/Taiyuan.gif

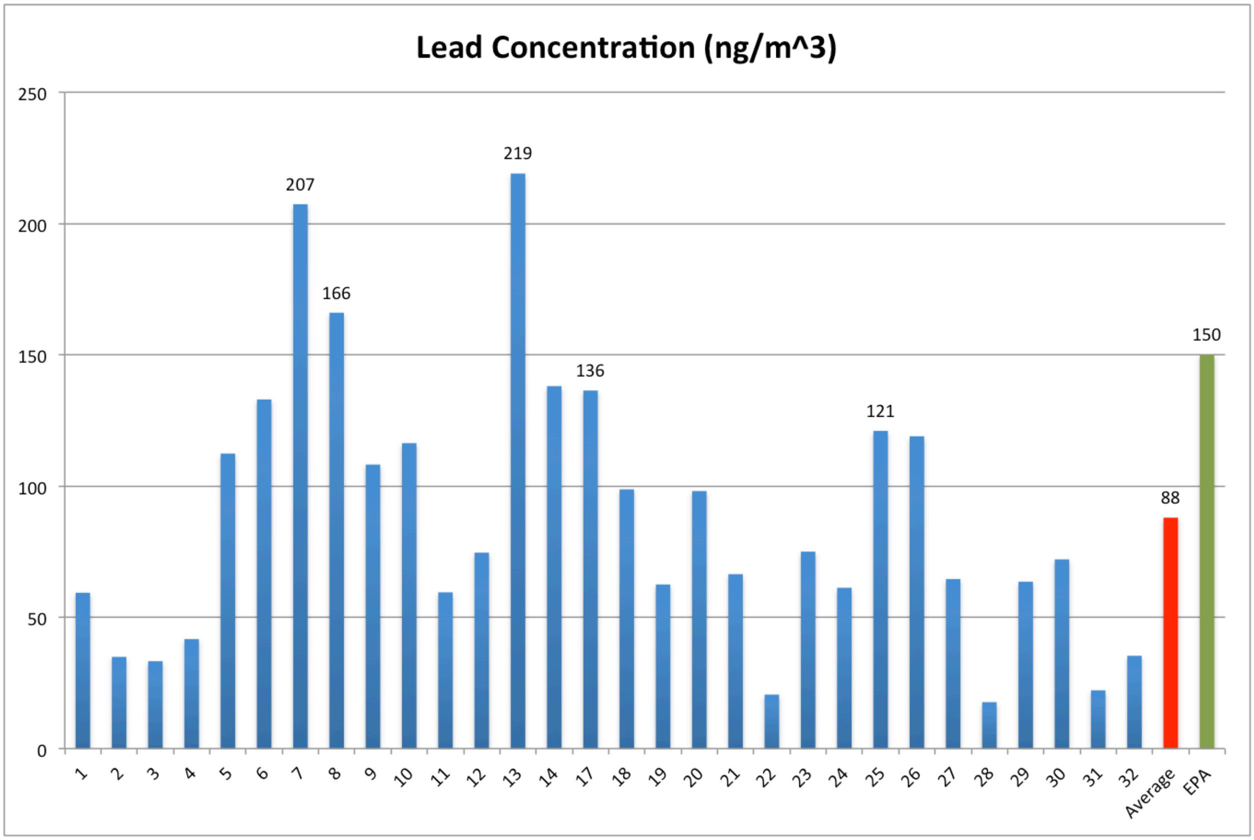
APPENDIX:


Mercury Concentration (ng/m^3)
90
80
70
60
50
40
30
20
10
0
80
68
55
39
23
84
26
1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Average

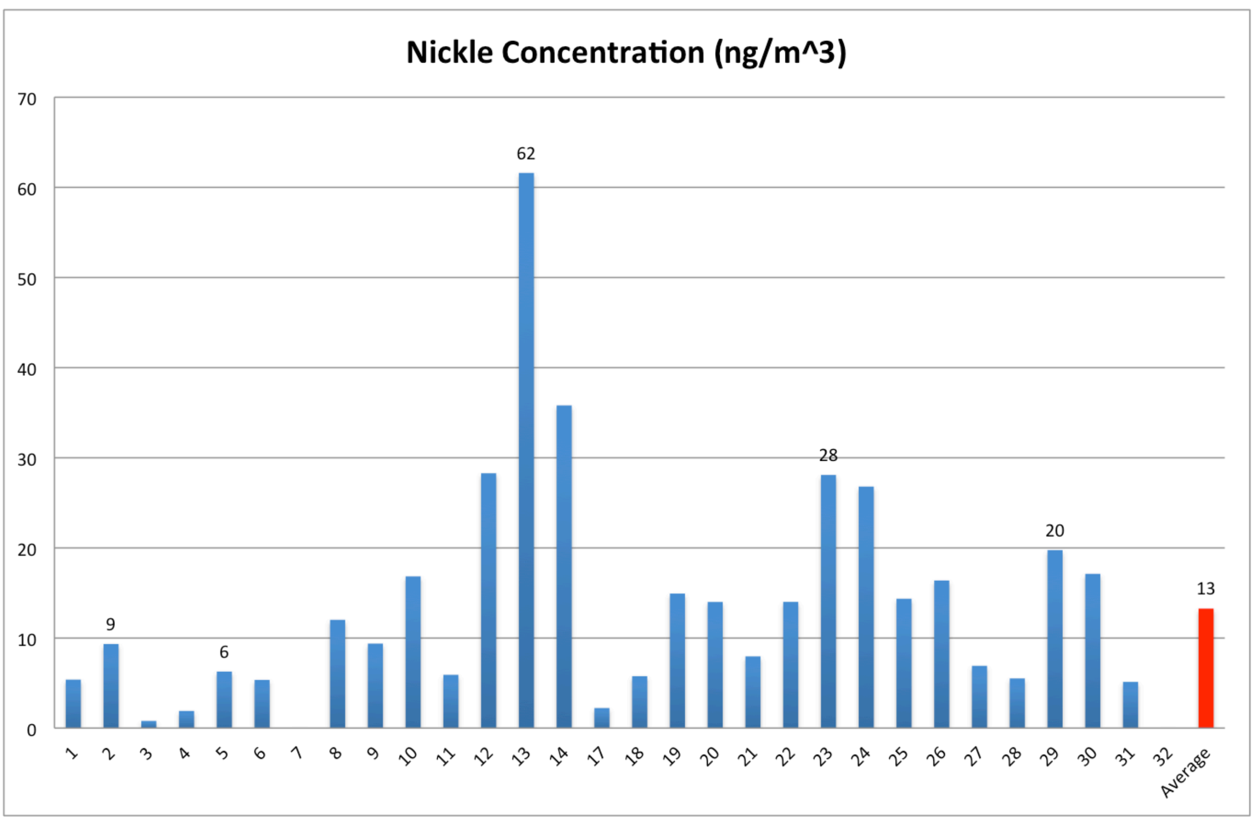

Arsenic Concentration (ng/m^3)
30
25
20
15
10
5
0
27
17
2
1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Average


Selenium Concentration (ng/m^3)
30
25
20
15
10
5
0
24
15
3
5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Average

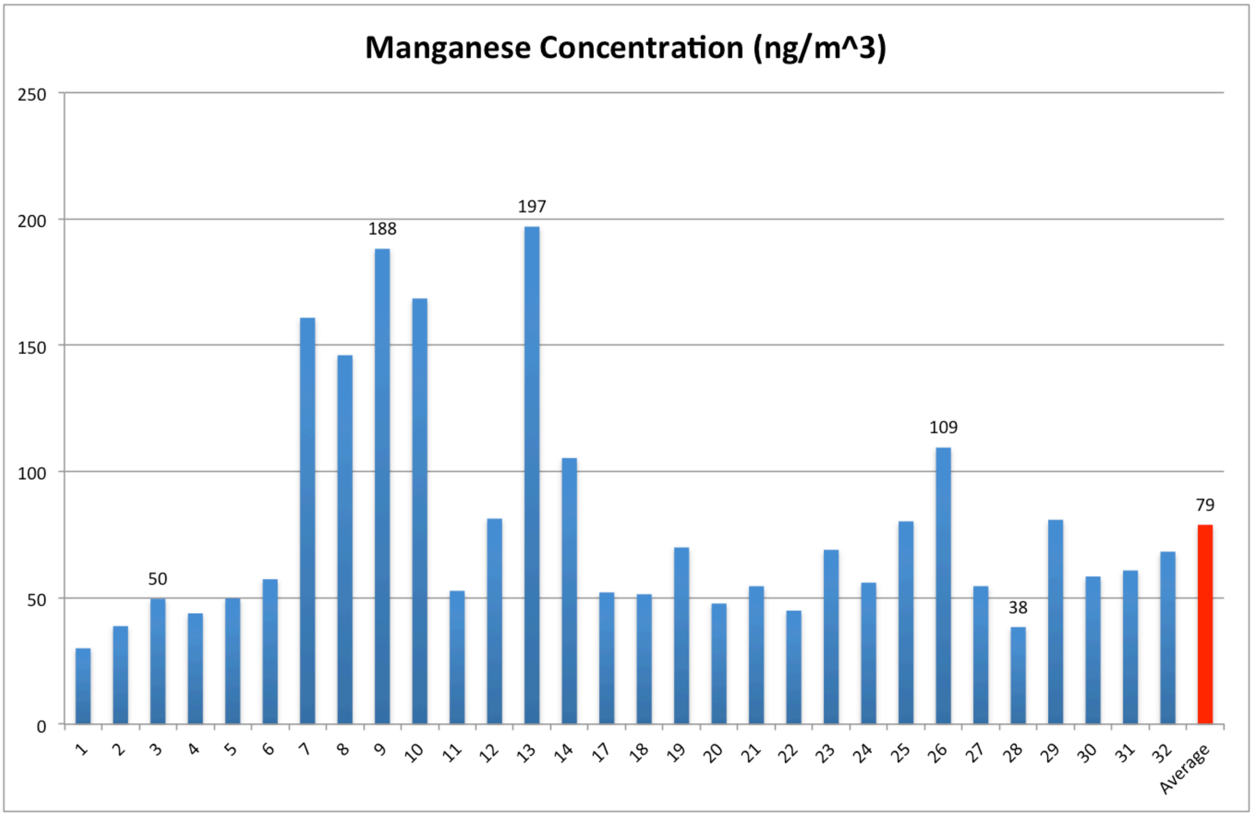

Zinc Concentration (ng/m^3)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
525.0
430.2
419.4
241.5
113.3
1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Average

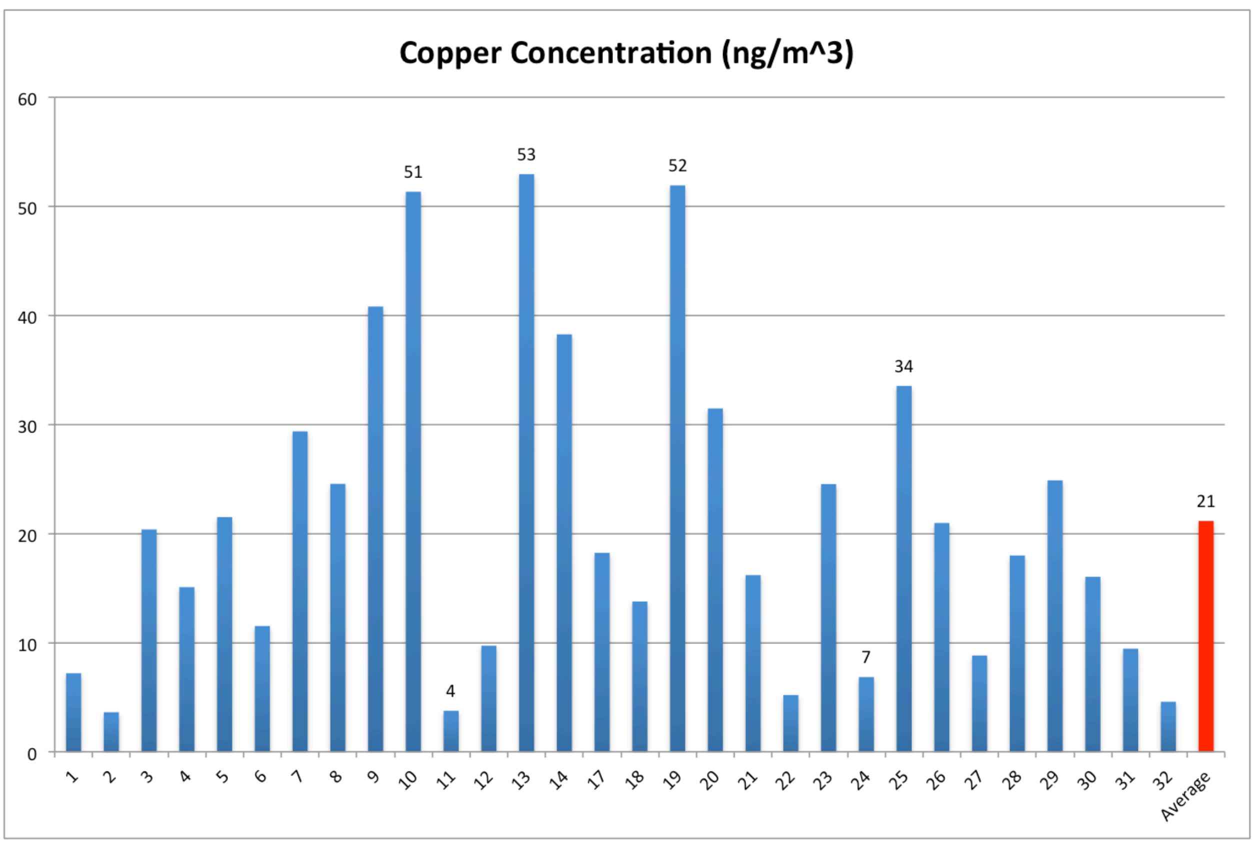


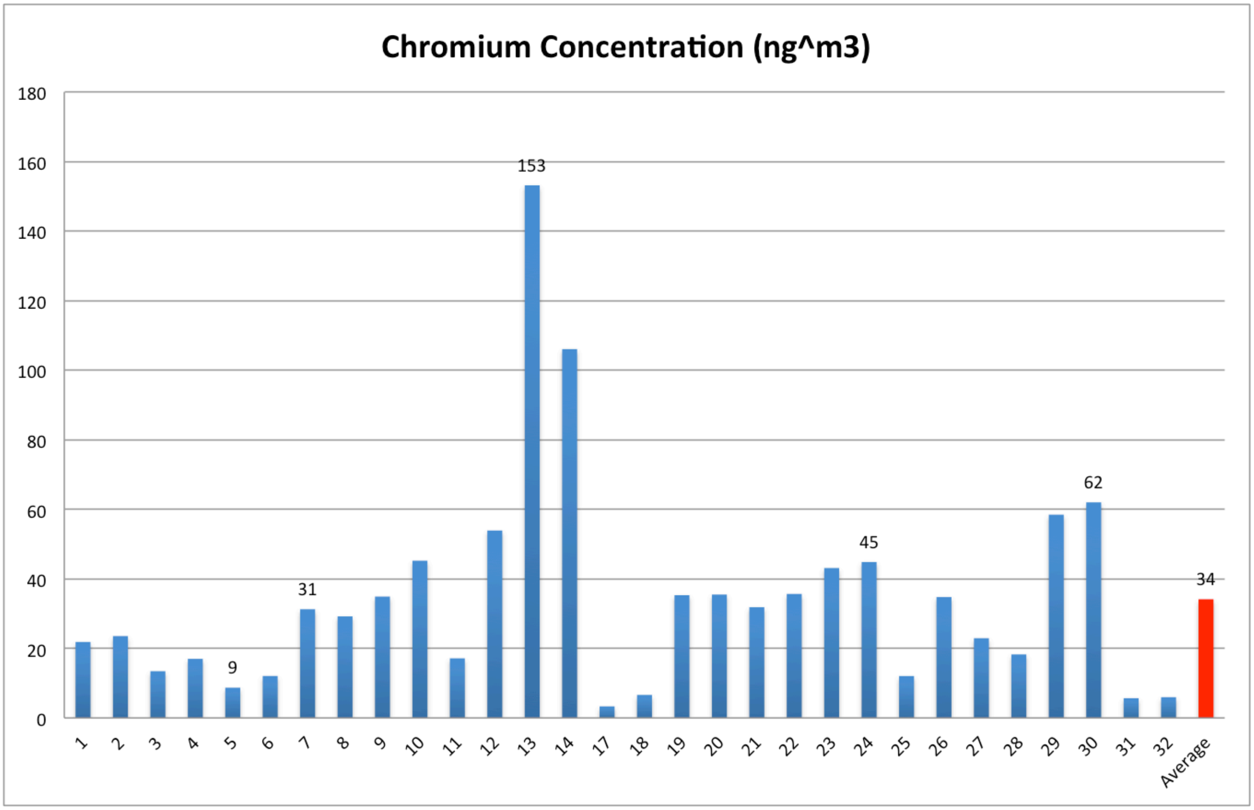
Lead Concentration (ng/m^3)
250
200
150
100
50
0
207
219
166
136
121
150
88
1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Average
EPA



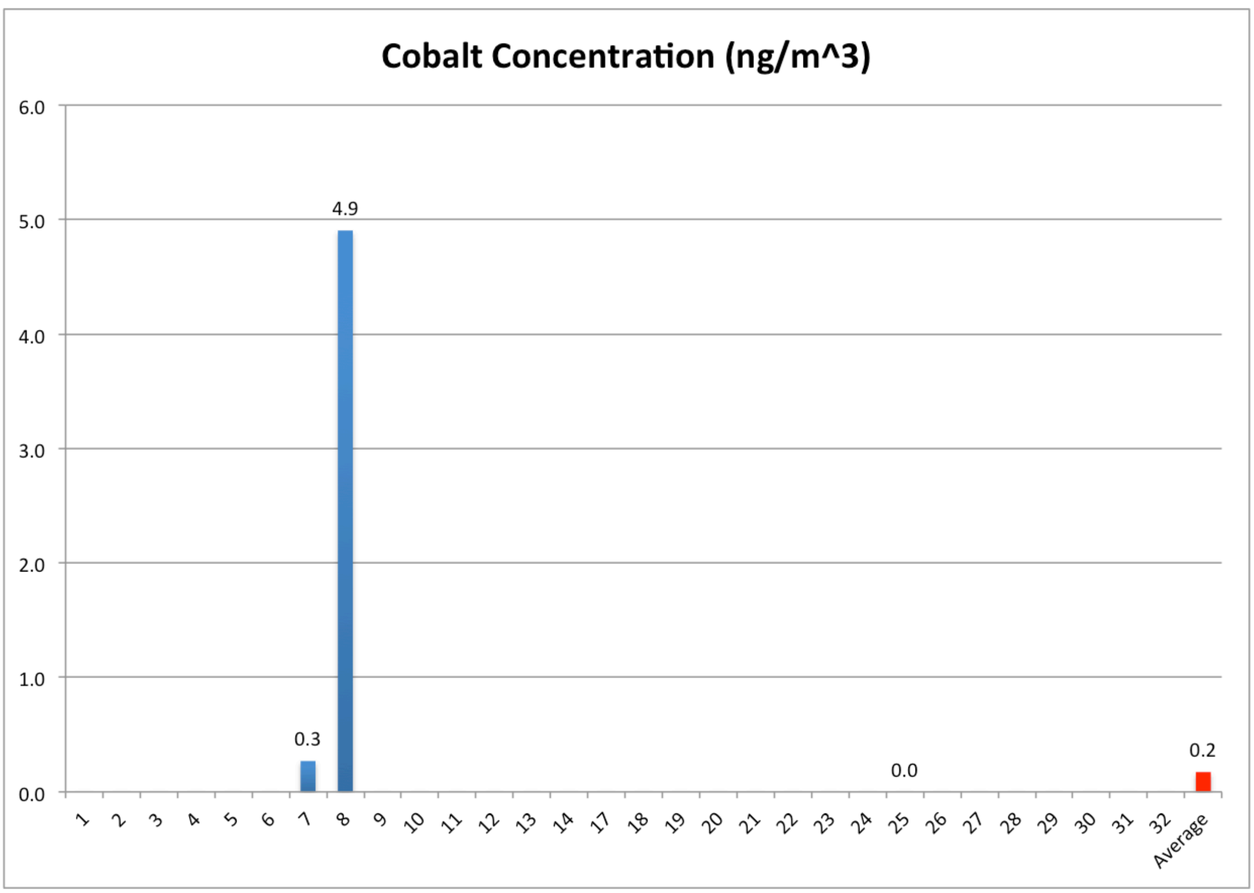
Nickle Concentration (ng/m^3)
70
60
50
40
30
20
10
0
62
28
20
9
6
13
1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Average


Manganese Concentration (ng/m^3)
250
200
150
100
50
0
188
197
50
109
79
38
1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Average


Copper Concentration (ng/m^3)
60
50
40
30
20
10
0
51
53
52
34
21
4
7
1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Average



Chromium Concentration (ng^m3)
180
160
140
120
100
80
60
40
20
0
153
62
45
31
34
9
1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Average



Cobalt Concentration (ng/m^3)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4.9
0.3
0.0
0.2
1
2
3
4
5
6
7
8
9
10
11
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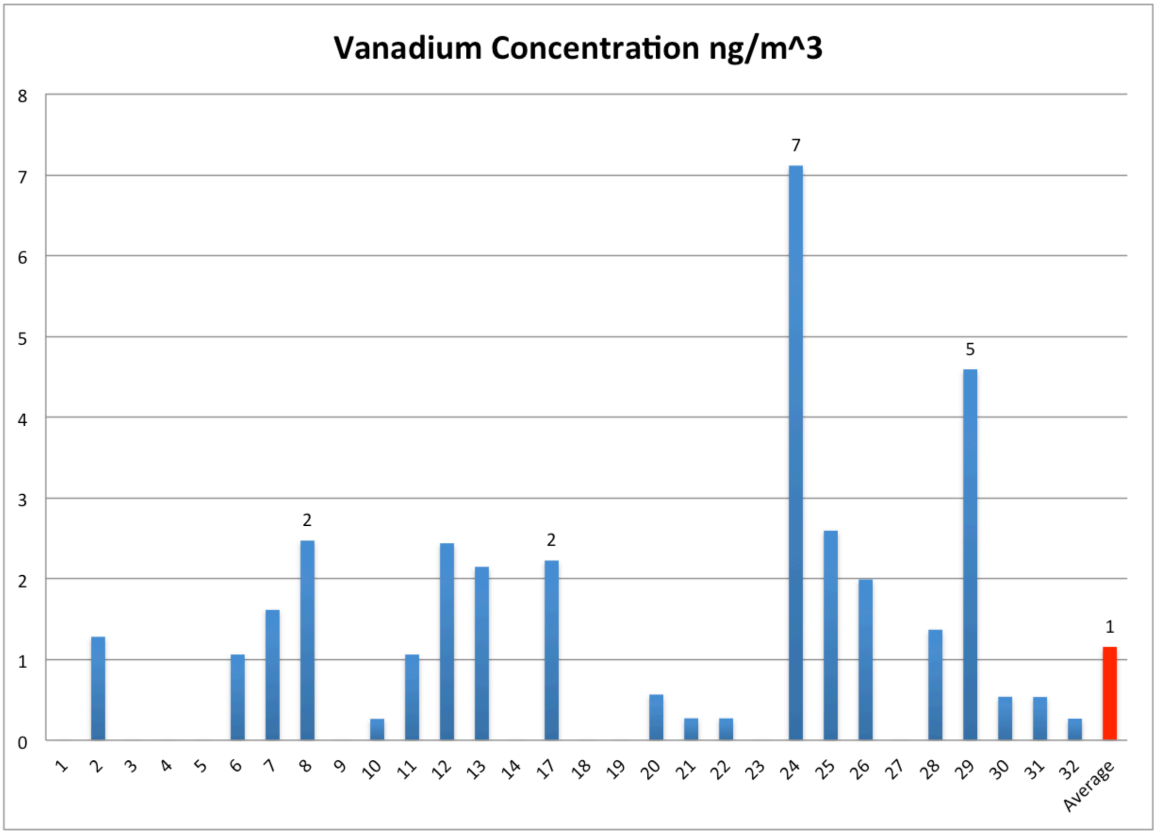
21
22
23
24
25
26
27
28
29
30
31
32
Average


Vanadium Concentration ng/m^3
8
7
6
5
4
3
2
1
0
7
5
2
2
1
1
2
3
4
5
6
7
8
9
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11
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22
23
24
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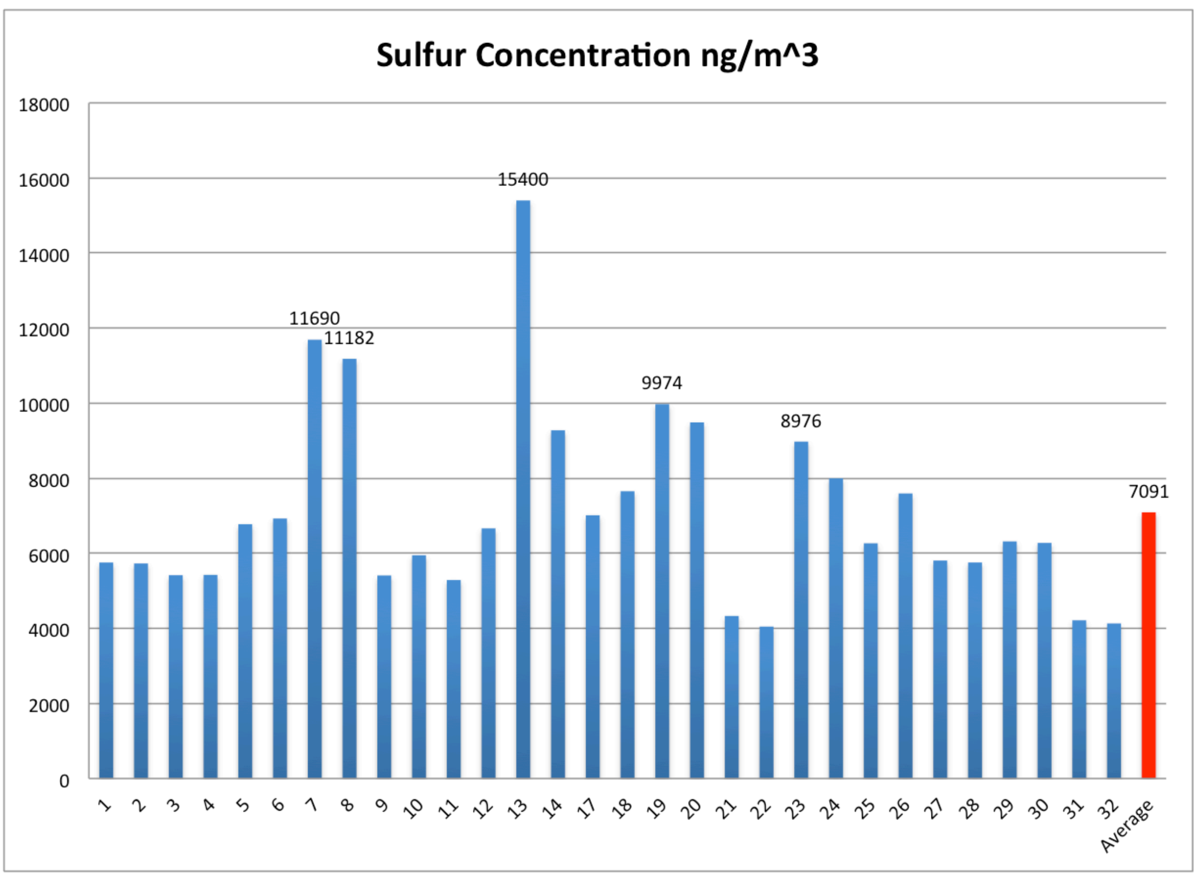
26
27
28
29
30
31
32
Average


Sulfur Concentration ng/m^3
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
15400
11690
11182
9974
8976
7091
1
2
3
4
5
6
7
8
9
10
11
12
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23
24
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26
27
28
29
30
31
32
Average

Questionnaire:

太原出生队列室内空气质量研究调查表 –
24 小时内室内环境调查

队列编号：__________　　姓名：_____________　　调查日期：__________
Respondent's ID　　Name　　Date
电话：______________　　住址：____
Phone　　Address

第一部分：家庭一般情况

Part 1: Family basic information

1.您家的房屋类型：______
The housing type of your home

（1）平房　（2）单元楼房　（3）独栋/别墅
(1) one-storey house　(2) apartment　(3) single-family house
居住面积：__________m^2（不包括院子面积）
Living area:　(not including garden area)

2.您家室内装修的时间：_______年______ 月（2006 年之前装修的不计）
When you decorate your home: year　month　(no need to fill if before 2006)

3.您家使用的装修材料：______
The decoration materials you used

（1）涂料（2）壁纸（3）人造板材（4）实木（5）油漆（6）胶（7）大理石（8）花岗岩（9）其它______________
(1) paint (2) wallpaper (3) artificial slabs/panel (4) wood (5) oil paint (6) rubber (7) marble (8) granite (9) other

4.您家装修完入住时能否闻到装修气味：______
Can you smell something about decoration materials after decoration

0.否　1.轻度　2.中度　3.重度
0, no　1, mild　2, moderate　3, severe

5.您家添置新家具日期：_______年______ 月（2006 年之前添置的不计）
when did you buy the new furniture in your home: year　month　(if after 2006)

家具材料：（1）人造板材　（2）实木　（3）玻璃　（7）其它______________
The materials: (1) artificial slabs/panel (2) wood (3) glass (7) other

6.开窗通风：

ventilation (open window)

目前：春秋季____小时/天　夏季____小时/天　冬季_____小时/天
Current: spring & fall: hour/day summer: hour/day winter: hour/day

6a.您家测量前 **24** 小时开窗通风___________小时
In the last 24 hours before measuring, opening window for ventilation in your home _________hour

您家测量当日开窗通风___________小时
In the day of measuring, opening window for ventilation in your home_________hour

7. 您家是否使用空调
Do you use air conditioning in your home?
1) Yes 是
2) No 否

7a:
如果是，空调放置在哪里
If Yes, where is the air conditioner?
1) Kitchen 厨房
2) Common Room 客厅
3) Bedroom 卧室

你家测量前 **24** 小时使用空调__________小时
In the last 24 hours before measuring, how many hours did you use the air conditioner _________hour

你家测量当日使用空调__________小时
In the day of measuring, how many hours did you use the air conditioner_________hour

8.您家测量前 **24** 小时家中是否有人吸烟：
In the last 24 hours before measuring, does anyone smoke in your home?

0.否　1.是，______小时
0. no　1. Yes ______hours

您家测量当日家中是否有人吸烟：
In the day of measuring, does anyone smoke in your home?

0.否　1.是，______小时　_____ 吸食香烟
0. no　1. Yes ______hours　_____# of cigarettes

9.您家测量前家中有**______**人

Before measuring, how many people stay in your home?

您家测量时家中有______人
In the day of measuring, how many people stay in your home?

KITCHEN 厨房:

10.您家厨房是____
The type of kitchen is:

（1）封闭式厨房 （2）开放式厨房 （3）独栋式厨房（厨房与居住空间分离）
(1) closed (2) open (3) detached with living area (living room, bedroom, etc)

11.您家用什么燃料做饭（可多选）， 目前：___________
What kinds of fuel do you usually use for cooking in this residence (multiple choices), current:

（1）天然气、煤气 、液化气等气体 （2）电炉 （3）电磁炉 （4）煤
（5）木材或生物质燃料 （6）其它________
(1) natural gas, coal gas, liquelied petroleum gas, etc (2) electric cooker (3) induction cooker
(4) coal/Briquettes (5) wood or biofuels (6) other

12. 如果您用电磁炉或电炉做饭，电磁炉或电炉的品牌名称，目前：___________
What is the brand name that you use above, current:

是否是新的：
Was it bought new?

0. 否 1. 是
0. no 1. yes

13.您家测量前 **24** 小时总共做饭次数_____次，持续时间______小时, 主要的烹调方式_____:
In the last 24 hours before measuring, cooking frequency: _____times, duration: ______hours, the main ways of cooking:

（1）油炸（___次） （2）红烧（___次） （3）煎炒（___次） （4）清蒸（___次）
（5）炖煮（___次） （6）其它________
(1) deep fried (___ times) (2) braised (___ times) (3) pan fried (___ times) (4) steamed (___ times)
(5) simmer (___ times) (6) other (___)

您家测量当日总共做饭次数_____次，持续时间_____小时, 主要的烹调方式_____:
In the day of measuring, cooking frequency: _____times, duration: ______hours, the main ways of

cooking:

（1）油炸（___次） （2）红烧（___次） （3）煎炒（___次） （4）清蒸（___次）
（5）炖煮（___次） （6）其它________
(1) deep fried (___ times) (2) braised (___ times) (3) pan fried (___ times) (4) steamed (___ times)
(5) simmer (___ times) (6) other (___)

您每周有多少次会做相似或同样的饭菜?
How often do you cook similar meals in a week?

(1）油炸（___次） （2）红烧（___次） （3）煎炒（___次） （4）清蒸（___次）
（5）炖煮（___次） （6）其它________
(1) deep fried (___ times) (2) braised (___ times) (3) pan fried (___ times) (4) steamed (___ times)
(5) simmer (___ times) (6) other (___)

13.您家厨房使用的排烟系统， 目前： ___________
The ventilation and smoke exhaustion system for your kitchen, current:

（1）无 （2）抽油烟机 （3）排风扇 （4）开窗（5）其它___________
(1) no (2) exhaust ventilator (3) ventilating fan (4) window (5) other

14. 您家测量前 24 小时排烟系统使用时间___________小时
In the last 24 hours before measuring, using time of smoke exhaustion system is_______hours

您家测量当日排烟系统使用时间___________小时
In the day of measuring, using time of smoke exhaustion system is _______hours

调查者：_______________
Interviewer:

审核者：_______________
Verifier:

调查者 To Fill out by interviewer:
空气采样器在厨房的位置 Location of air pump machine in Kitchen? _______________
是否靠近窗户 Was it near a window? ________________
卧室里空气采样器的位置 Location of air pump machine in Bedroom? ________________
是否靠近窗户 Was it near a window? _________________

采样开始时间 Time pump was plugged in: ______________ (am/pm)
采样结束时间 Time pump was disconnected: ______________(am/pm)

天气 Weather：
测量 24 小时内是否下雨？Did it rain in the 24 hour period of measurement?
测量 24 小时内温度_______℃ What was the temperature in the 24 hour period of measurement?