Mercury Concentration in Hair Due to Environment on Two Populations in Mexico

Isela Martínez Fuentes and Rocío García Martínez

Abstract The study of mercury pollution has been intensified through the last decades due to the high toxicity of this heavy metal and its increasing availability in the environment; since mercury is produced by both natural and anthropogenic processes. Mercury is an element naturally present in air, water and soil, leading to its accumulation in all living beings without being essential for any biological process. The measurement of the corporal mercury load in humans is made through the use of different biological markers such as nails, teeth, bones, saliva, urine, blood and hair. Our objective was to quantify total mercury in hair of two populations: one rural population (miners of the region of San Joaquin, Queretaro, Mexico) and one urban population of the Metropolitan Area of Mexico, and to compare the results of a population potentially exposed by the explotation of mercury in mines and a community not affected by mercury emissions. Each participant provided a hair sample and completed a questionnaire assessing potential exposures and health outcomes. We found average mercury concentrations of 32.07 μg g^{-1} and 2.62 μg g^{-1} in the rural and urban population, respectively. The great difference between these values is probably due to a difference in the time of exposure for each population. In both cases, the populations studied exceeded the maximum allowable limit established in standards and by national and international agencies, mainly due to the direct exposure of mercury vapors in miners and by anthropogenic sources in the urban population.

Keywords Mercury · Hair · Toxicity · Analysis · Bioaccumulation

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I. M. Fuentes (✉)
Posgrado en Ingeniería Ambiental, UNAM-IMTA. Blvd,
Paseo Cuauhnáhuac 8532, Progreso, 62550 Jiutepec, Morelos, Mexico
e-mail: ise_la19@yahoo.com.mx

R. G. Martínez
Centro de Ciencias de la Atmósfera, UNAM. Cd. Universitaria,
Circuito Exterior s/n, 04510 Mexico, CDMX, Mexico
e-mail: gmrocio@atmosfera.unam.mx

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1 Introduction

Mercury is an element that cannot be destroyed and is a global threat to human and environmental health. In Latin America and the Caribbean, artisanal and small-scale gold mining represents the main source of mercury emissions, releases, and consumption. However, another source of concern is the primary production of mercury. In the case of Mexico, in the past 2 years the informal production of mercury mining has increased 10-fold. Considering this scenario, an intervention program was initiated to reduce health risks in the mining communities. The program's final goal is to introduce different alternatives in line to stop the mining of mercury, but introducing at the same time, a community-based development program. This increased concern about the health of persons exposed to very low environmental mercury concentrations is because mercury causes subclinical effects at low concentrations.

In 2003, after having performed a global assessment, the United Nations Environment Program (UNEP) found that there was sufficient evidence of significant global adverse effects from mercury and its compounds to warrant further international action to reduce the risks to human health and the environment from the release of mercury and its compounds to the environment. In January 2013, an intergovernmental negotiating committee agreed on the text of the Convention on Mercury, and in October 2013 the Convention was signed in Minamata, Japan, by 128 countries. In its first article, the Minamata Convention states that its objective is to protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds (UNEP 2013). Mercury (Hg) is a toxic chemical element widely used by humans and produced consequently in vast quantities as a result of industrial processes, mining, and international trading.

Hg possesses several physical and chemical states (elemental/inorganic/organic), each with its own intrinsic toxic properties. In term of toxicology, organic Hg and specially methylmercury (CH_3Hg^+) has a higher toxicity than elemental Hg (Hg^0) and inorganic compounds (HgS, HgO, $HgCl_2$, among others). Even a low quantity of Hg may cause serious health problems: Hg exposure leads to diseases of the nervous, digestive and immune systems as well as damage to the lungs, kidneys, skin and eyes (Ramírez 2008).

The distribution and toxicity of mercury depend on various factors, including the hydrodynamic characteristics and the physico-chemical conditions of the area, the assimilation of mercury by living organisms and its interactions with other constituents of the environment which can modify its form in the water, soil, air or within the bodies of living organisms. Hg occurs naturally in a wide variety of organic and inorganic compounds not only in the solid state, but also dissolved in water and, exceptionally, in the atmosphere due to its high vapor pressure (Fig. 1).

The analytical diagnostic of Hg poisoning is difficult: urinary excretion of this element is not an assessable index since organic Hg is stably absorbed, and in the highest concentration, in red blood cells. Blood tests thus indicate the mineral concentration at the cellular level. In both cases, it only reflects Hg concentration in

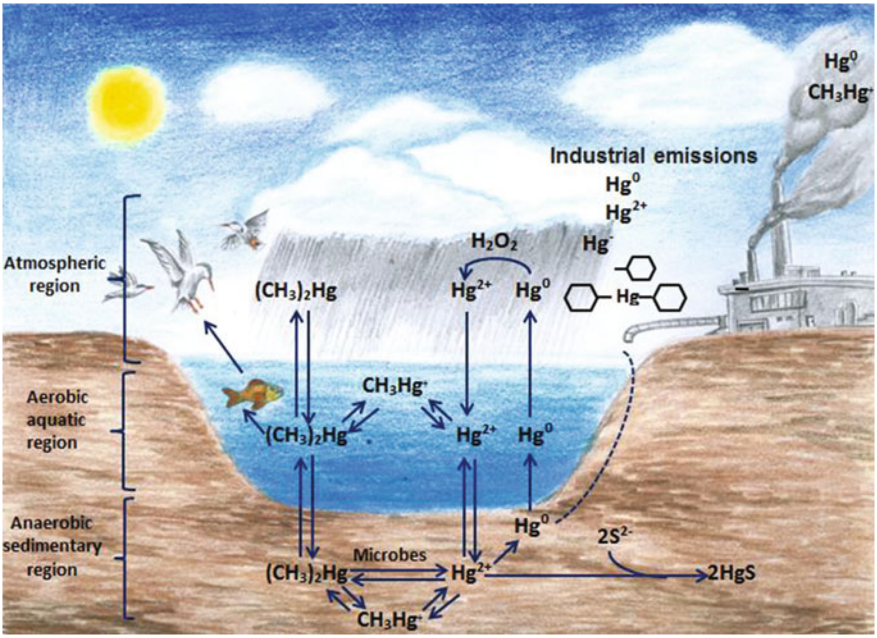

Fig. 1 Biogeochemical mercury cycle. Realized by Daniel Ramírez

the body at the moment the sample is taken. It is thus necessary to uncover other biomarkers that will allow early detection of mercury contamination, particularly in high-risk populations.

Hair is the best indicator of Hg exposure because it is affected by the diet, the environment and the profession of the individual. Analyses of hair samples enable to precisely evaluate the mineral concentration inside the body, since it accumulates in proteins rich in sulfhydric groups. Therefore, hair works as a dosimeter and the detected quantity is proportional to the concentration of mercury in the organism (Echegaray and Gómez 1984). It also allows the evaluation of the levels of pollution through time. It is possible to tell how much mercury a person has been exposed to by testing their hair, blood and urine. According to The World Health Organization, Dental amalgam has been identified as the largest single source of continuous Hg exposure for members of the general population who possess amalgam fillings (WHO 2000).

The principal advantages of hair as a biomarker are the following: (1) it is a non-invasive method of analysis, (2) the sample is stable at room temperature, easy to transport and to store for long periods of time and (3) it does not require a specialized training to collect. However, it is important to consider that hair doesn't grow evenly and the substances remain according its growth at an approximated rate of 1.20–2.0 cm/month, exposed to external pollution.

Hg exposure in non-exposed populations often happens through dental amalgams, polluted food (mainly fish and seafood) and the use of personal hygiene products containing this metal (hair dyes, creams and clarifying soaps). Except some outstanding cases, human health is not in danger because of Hg present in nature. The higher risk to human health derived by the natural abundance of mercury is due to the occupational exposure, because it is obtained in the mining industry as a principal product or byproduct in the extraction and refining of other metals and minerals, as well as in iron and steel industry and some other activities (Cespón 2001). For these reasons, it is important to develop exact and precise techniques that will provide reliable results when applied in a complex matrix such as hair.

Research suggests that Hg and its derived chemical species enter the organism by different pathways, as for example, inhalation, ingestion, absorption through skin and placenta (Fig. 2). The toxic effects of organic and inorganic Hg are due to the fact that they bind to the cellular organic constituents rich in sulfhydryl groups, affecting various metabolic and enzymatic systems of the cell and its wall. The toxic action of Hg on enzyme systems occurs because it precipitates the proteins synthesized by the cell, mainly the neurons, and because it inhibits the groups of several essential enzymes (Ramírez 2008).

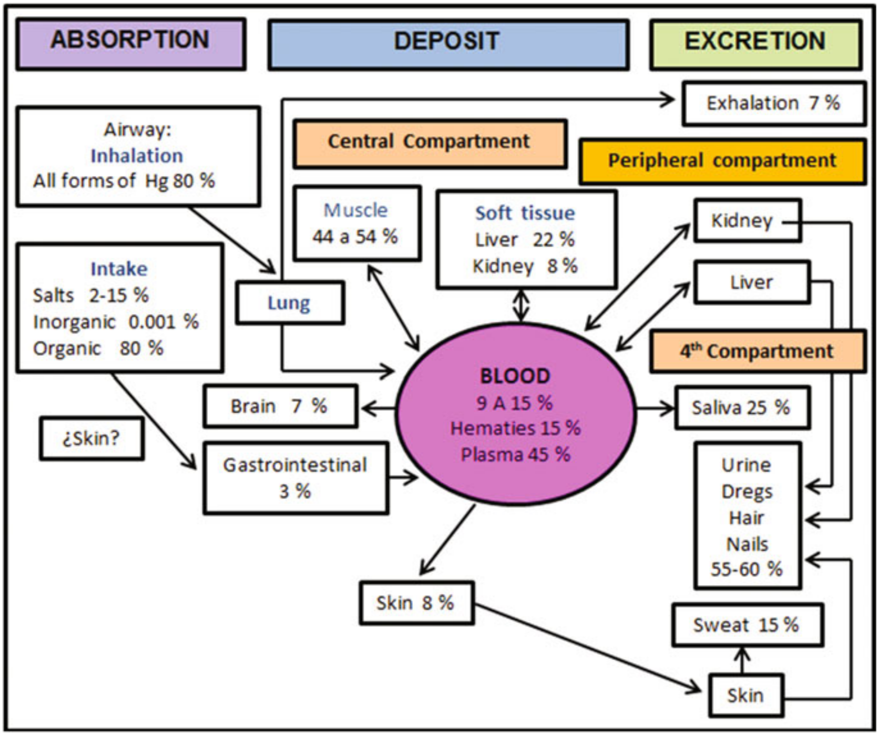

Fig. 2 Toxicokinetic model of inorganic mercury (Ramírez 2008)

International Agencies like the United Nations Environment Programme (UNEP), the Food and Drug Administration (FDA), the World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) stablish the maximum allowable limit of Hg for non-exposed people's hair as 1–2 $\mu g\ g^{-1}$, for people that have a diet rich in contaminated fish as 10 $\mu g\ g^{-1}$ and for occasionally exposed people during odontological activities as 7 $\mu g\ g^{-1}$ (UNEP 2002).

Because the importance of its effects, Hg is a chemical product of global awareness, especially for its transport at long distance in the atmosphere, its persistence in the environment after being anthropogenically introduced, its capability of bioaccumulation in ecosystems and its effects against human health and the environment (Carretero and Pozo 2007) Minamata Convention on Mercury was created to take actions on the environmental storing of Hg and waste control, to set expiry dates and stablish manufacture, importation and exportation protocols of Hg for 2020 to utilize economically feasible techniques and to produce new products that lack this metal in their composition. Some exceptions have been made for some products without any reliable substitution and also, the Hg content has been limited for some applications like low-energy lamps. The Convention committed to devise new strategies to identify and evaluate Hg polluted locations for and appropriate management, focusing in human health (MEJ 2013).

In Mexico, there are few studies, and even fewer regulations, that indicate the maximum limits of exposure to this metal. A few references can be found about exposure by odontological activities (analyses of hair and urine), but none about Hg exposure in high polluted areas. In this study, we performed hair analyses on two different populations: a rural, high-risk population and an urban one.

The first population is located in the mining region of San Joaquín, Querétaro. This is considered a partially exposed population because of the explotation of inorganic Hg mines (HgS, cinnabar), in which the informal Hg exploiting represents the principal economic income for the inhabitants. The importance of the study in this area relies in the Hg exposure by different pathways (absorption through skin and inhalation) that workers must endure because of the lack of the necessary safety equipment, affecting severely their health through continuous exploitation and handling of HgS. Other consequence of this industry is the production of hazardous waste that continuously damages the ecosystems and people in the area, due to the capacity of mercury to remain in the environment for decades, centuries and even thousands of years.

The second population of interest is located in the urban area (Metropolitan Area of Mexico City) in which the principal sources of mercury pollution are anthropogenically produced by industrialization, the use of products with high content of Hg (hair dyes, clarifying soaps and creams) and the possible consumption of contaminated seafood.

In large cities like the Metropolitan Zone of Mexico City, air, water and soil composition has changed because of pollution with chemical products and powder from excessive use of cars, factories and lack of vegetation, asphalt of other kind of coatings on soils, as well as a variety of activities that use hazardous solvents and toxic substances as Hg. Because of these actions, common use products and even food have been polluted affecting human beings through several pathways engaging their health (ME 2012).

In Mexico there has not been a detailed evaluation about production, emission and spreading of Hg. In this work, we propose an assessment of the degree of Hg exposure in a population dedicated to Hg mining, which has affected for several years to the Terrestrial Systems (water, soil, air and plants).

2 Metodology

This study was performed to two different Mexican populations: one of them potentially exposed to Hg (miners) and living in the mining area of San Joaquín, Querétaro; and the other one in the southern part of the Metropolitan Zone of Mexico City (Ciudad Universitaria), an area that is not exposed to Hg by mining activity.

The present study is organized in two parts. The first stage corresponded to the diagnostic, the organization and the scheduling of the performed tasks. This was achieved by an activity-time survey answered by the participants, including personal details (age, profession, and geographic localization), diet, personal hygiene, use of cosmetic treatments on the hair and oral health.

The second stage corresponded to the recollection of the samples: hair samples of 24 miners that currently work in the mercury mines of la Poza, Rosario, Otatal, Atenea, la Fortaleza, la Maravilla and la Barranca, located in the region of de San Joaquín; and hair samples from 36 students of Ciudad Universitaria in Mexico City. This last group consisted of 18 men and 18 women around 21 to 25 years-old.

Hg has great affinity for sulfhydryl groups of keratin and other hair proteins. Hair is one of the favorite matrices used for Hg determination because it is a non-invasive procedure, provides a simple sample with an exposure profile inclusive over time and that can remain with little concentration changes for years. Furthermore, the main advantage of hair analysis is that once the Hg has been incorporated, it cannot return into the bloodstream.

The back of the head is the most highly recommended part of the scalp for sampling because it is the area the less sensitive to external pollution. 2–3 locks of hair from 1–2 cm long were taken from the back of the head of the volunteers (Cespón 2001).

The samples were then placed in polyethylene tubes, previously washed with a nitric acid solution and sterilized in order to avoid microbial contamination and possible pH variations.

After the determination of the elements of endogenous absorption, the washing procedure is the next fundamental part of the analysis. An ideal washing must eliminate only the external pollutants, leaving the endogenous elements untouched.

The International Atomic Energy Agency (IAEA) has examined different procedures of washing and has determined all the variables associated. As the incomplete eradication of exogenous pollutants and the partial elimination of endogenous elements is hard to control, the IAEA method suggests a sequential washing process of the hair samples with a mixture of water and acetone, with constant stirring, removing powder particles, sweat, fat and other external substances (López 2013).

After the hair samples were washed, they were decanted and dried at room temperature. Then the acid digestion of the samples was performed in a microwave oven. Each sample of dried Taraxacum officinale were weighed and placed in liner tubes. 10 mL of nitric acid and 5 mL of hydrogen peroxide were added. A control (blank) was performed for each digestion cycle, consisting of the mixture of reagents without hair reference material. Prior to chemical analysis, acid digestion of the samples was done with a MARS 5 analytical microwave oven, using 15 mL of 3 M nitric acid and 5 mL of hydrogen peroxide at 110 psi, for 45 min; after digestion, the solution was poured into a 25 ml volumetric flask, then deionized water was added to the mark and kept at 4 °C until the analyses were carried out.

The samples were analyzed by graphite furnace atomic absorption spectrometry (GFAAS) with a 932AA double beam GBC device, coupled with a 3000 graphite furnace accessory system, which consists on a GF3000 graphite power supply and a PAL3000 furnace auto sampler, both computer controlled.

Calibration was made using certified standards that were prepared within the expected concentration range for traceable samples according with the National Institute of Samples and Technology (NIST). Calibration curves with sample concentrations of 1, 2, 5, 8, 10 and 15 $\mu g\ L^{-1}$ and their respective blanks were used. Concentration of Hg was determined in a wavelength of 253.7 nm.

3 Results and Discussion

According to the Mexican Norm (NMX-EC-17025-IMNC-2006, General Requirements for the Competence of Test and Calibration Laboratories), the validation of the analytical methods used is a fundamental requirement before realizing an analytical measurement, because analytical method performance vary between laboratories. Furthemore, analytical methods are specific of the matrix with which they were developed, and then validated, in the first place. They cannot be used to measure in any given matrix.

In this study, the analyses were performed by Spectrophotometric Tests by Atomic Absorption, in which the performance parameters are: linear range, detection limit, limit of quantification, sensitivity and percentage of recovery.

Linearity. To ensure quality control/quality assurance during sampling and analysis only plastic and glassware were used. Mercury National Institute of Standards and Technology standard (NIST; $Hg(NO_3)_2$ in 2 mol L^{-1} HNO_3, 1000 mg L^{-1} Hg was used to obtain calibration curves and for validation, 10 calibration curves were realized, observing at which point these curves lose linearity. Quality controls (QC) were evaluated from the calibration curves (Table 1), where the equipment recorded a concentration of Hg concentration and absorbance for the blank of 0 μg L^{-1}. In Graph 1, the correlation was (R^2) de 0.9993, the good line were 0 a 15 μg L^{-1} (Table 1).

The numerical value of the detection limit (LD) and the quantification limit (LC) were calculated from the absorbance reading value of the reactive targets of the 10 calibration curves performed.

Detection Limit. The limit of detection (LD) is defined as the lowest concentration at which the analityc can be detected, but not necessarily quantified under the established experimental conditions (García 2010).

$$\textit{Limit detection}(LD) = 2.1\ \mu g\ L^{-1}$$

Quantification Limit (QL). The limit of quantification is defined as the lowest concentration at which the analytic can be quantified with acceptable established experimental conditions (García 2010).

$$\textit{Quantification Limit}(QL) = 3.1\ \mu g\ L^{-1}$$

Sensibility. Sensibility is understood as the change in instrument response in relation to a change in analytic concentration, as visualized by the slope of the average curve obtained (Graph 1). The sensitivity is 0.016. To evaluate the confidence interval we applied a t-Student distribution test for 95% confidence with n = 10, following Eq. 1.

Graph 1 Average calibration curve

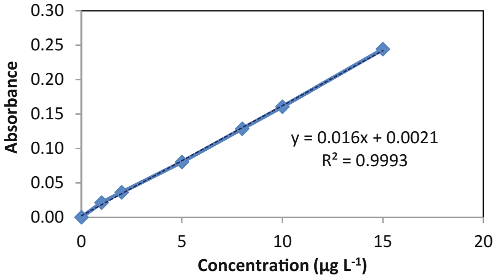

Table 1 Average calibration curve

Sample	Conc (μg L^{-1})	Abs
Blank	0	0.0000
Standard 1	1	0.0211
Standard 2	2	0.0362
Standard 3	5	0.0800
Standard 4	8	0.1285
Standard 5	10	0.1604
Standard 6	15	0.2441

$$\mathbf{Inter.\ de\ confianza} = \mathbf{t}_9 * \frac{\mathbf{typicalerror}}{\sqrt{10}}$$

Where:
$t_9 = 54.64$
Typical error = 0.0002

$$\textit{Sensibility} = (\mathbf{0.016} \pm \mathbf{0.0035})\mathbf{L}\ \mu g^{-1} \tag{1}$$

Recovery rate: the recovery is defined as the analytic fraction added to a test sample (added or fortified sample) prior to the analysis, whose concentration is effectively determined by the method.

According to Rangel (2015), the percentage of recovery obtained in the validation of the method is 98.41%.

3.1 Non-exposed Population by Profession (Student Population in the Southern Area of Mexico City)

This population is comprised of 36 people, including 18 men and 18 women. The identification code of the samples was assigned according to the gender (H: for men and M: for women), followed by a number from 1 to 18, corresponding to the number of the participant (Table 2).

Table 2 Concentration of Hg according to gender

Men				Women			
Code	Conc (μg g^{-1})	Code	Conc (μg g^{-1})	Code	Conc (μg g^{-1})	Code	Conc (μg g^{-1})
H1	2.20	H10	1.99	M1	2.64	M10	1.78
H2	0.83	H11	1.39	M2	2.31	M11	3.21
H3	1.49	H12	0.94	M3	6.16	M12	1.70
H4	3.41	H13	1.39	M4	1.15	M13	2.22
H5	1.09	H14	7.76	M5	0.99	M14	1.72
H6	1.25	H15	7.96	M6	2.27	M15	2.09
H7	8.50	H16	1.72	M7	4.40	M16	1.99
H8	2.24	H17	2.00	M8	2.87	M17	0.61
H9	5.43	H18	0.33	M9	2.87	M18	1.67

The statistical parameters (mean, maximum, minimum and standard deviation) obtained from the samples of this population are shown in Table 3.

The obtained data were statistically analyzed with central tendency measures and variability degree in order to observe the data location, its dispersion with respect to the average and the possibility to present a normal distribution. Correlation tests (Spearman) were performed between the main variables (gender and age).

An increased dispersion of the obtained data is observed for male population, mainly from 23 years-old, followed by 22 and 21 years-old, whereas the rest does not show dispersion because of the number of participants of the same age. For female population, dispersion is only observed in 22 years-old volunteers (Fig. 3). Spearman correlation coefficient was used as statistical tool to verify the independence between total Hg concentrations in the whole sampling campaign and to identify the independence between two variables (age and Hg concentration). The principal objective of this technique is to recognize if there is a common source of gender and if there exist any correlation.

Scatter plot and Hg variability (Fig. 4) show that the average values and the standard deviation are above the allowed values dictated by the WHE, EPA and other national and international agencies. These results indicate that random errors

Table 3 Statistic parameters of Hg concentration by gender (n = 36)

Gender	Average conc ($\mu g\ g^{-1}$)	Max conc ($\mu g\ g^{-1}$)	Min conc ($\mu g\ g^{-1}$)	D.E. ($\mu g\ g^{-1}$)
Men	2.88	8.50	0.33	2.64
Women	2.37	6.16	0.61	1.29

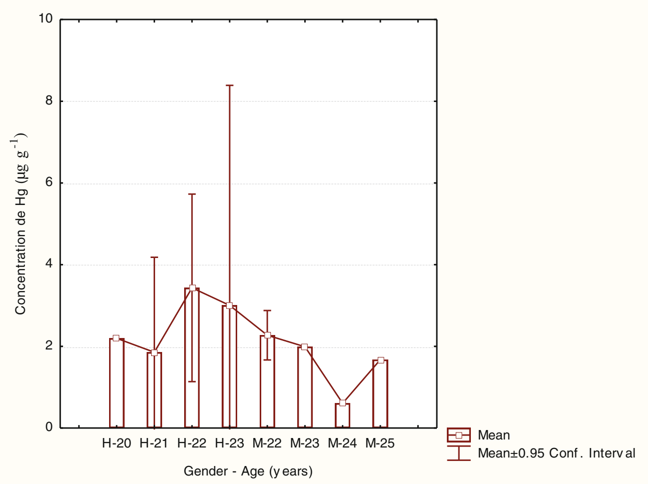

Fig. 3 Histogram of frequency of men and women with respect to age

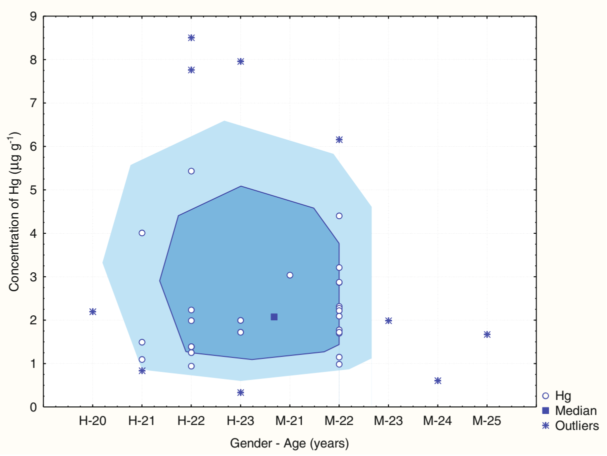

Fig. 4 Scatter plot and Hg variability for men and women with respect to age

Table 4 Hg concentration with respect to the frequency and percentage of participant distribution classified by geographical position (n = 36)

Location	Frequency	% frequency	Max conc (µg g^{-1})	Min conc (µg g^{-1})	Aver Conc (µg g^{-1})	D.E. (µg g^{-1})
Center	6	16.67	7.76	0.99	2.89	2.45
North	8	22.22	7.96	0.61	2.86	2.38
South	2	5.55	1.99	1.49	1.74	0.35
East	14	38.89	8.5	0.33	2.46	2.24
West	6	16.67	5.43	1.39	2.73	1.52
Total	36	100				

of age and gender are under control of mobility, inhabitation and food variables that are non-controlled variables.

The graphs also display that 86% of the population of interest is two times above the permissible limit (1 µg g^{-1}), considering that it is not a community with high consumption of seafood. The excess of Hg is due to environmental exposition and the use of hair products like hair dyes because at least two of the participants with the highest Hg concentration use to dye their hair in a regular basis, besides; the man with the highest amount of Hg is the only one that uses this type of products.

The excess of Hg observed must be linked to environmental exposition, such as the use of hair products like hair dyes for example, since at least two of the participants that exhibited the highest Hg concentration declare dyeing their hair on a regular basis. Furthermore, in the male group, the highest Hg concentration value correlates with the only individual making use of this type of products.

The Hg concentration measured was thus compared to the individual geographical position of each participant (Table 4), with Mexico City as the reference point and assigning coordinates as Center, North, South, East and West. The relations found by this analysis, with frequency and percentage of distribution, are summarized in Table 4.

The highest Hg concentration was found in participants living in the East of Mexico City, followed by those in the North, Center and West. The participants of the southern part of the city exhibited the lowest Hg concentrations.

3.2 Exposed by Profession Population (Mining Region, San Joaquin)

This population was comprised of 24 miners, who were all active at the moment of the analyses in one of the 6 mines that were included in this study in the mining region of San Joaquín.

The samples identification codes were assigned with the first letter of the name of the mine in which the participant worked (P: Pozas, R: El Rosario, O: El Otatal, A: Atenea, M: La Maravilla, F: Fortaleza y C: Carpintería), followed by a sequential number (1, 2, …,) depending on the number of volunteers for each of the location studied. The data collected and the statistical parameters for this population are shown in Table 5 and Table 6, respectively.

The information gathered from the time-activity survey applied to this population indicate in general terms that the volunteers do not eat seafood and that their diet consists in balanced meals prepared at home. They also eat 3 fruits or vegetables daily and drink mainly milk as a detoxifying beverage.

In the first place, an exploratory analysis was performed in order to detect odd values caused by a wide data dispersion (Fig. 5), there are two atypical values are observed, among them the minimum value (0.80 μg g^{-1}) obtained, since this is too

Table 5 Hg concentration in miners (n = 24)

Code	Conc. (μg g^{-1})	Code	Conc. (μg g^{-1})	Code	Conc. (μg g^{-1})
P1	16.40	R5	11.05	A1	5.79
P2	16.57	R6	3.90	A2	28.20
P3	115.10	R7	121.60	M1	2.44
P4	65.29	R8	5.21	F1	4.00
R1	68.57	O1	40.38	F2	6.62
R2	2.88	O2	7.13	F3	3.15
R3	10.08	O3	142.56	F4	13.21
R4	62.24	O4	16.39	C1	0.80

Table 6 Statistic parameters of Hg concentration (n = 24)

Average conc (μg g^{-1})	Max conc (μg g^{-1})	Min conc (μg g^{-1})	D.E. (μg g^{-1})
32.07	142.56	0.80	41.89

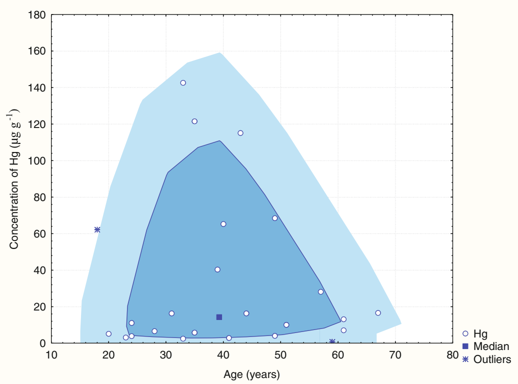

Fig. 5 Scatter plot and Hg variability with respect to age

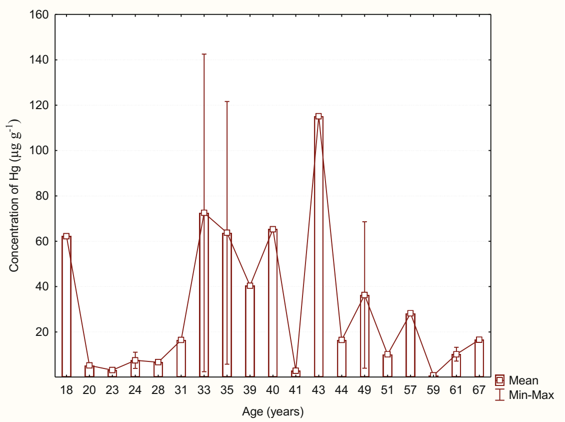

Fig. 6 Histogram of frequency with respect to age

far away from the subsequent value, which is 2.44 μg g^{-1}, which may possibly be related to the participant's age (18 years).

The frequency distribution of Hg histogram (Fig. 6) shows that more that 60% of the Hg concentrations are in the range of 0–20 μg g^{-1} with a frequency of 16; dismissing values of Hg concentration lower to a 10 μg g^{-1} 54% of the population is above the permissible value reported by UN, PAHO and others (10 μg g^{-1}) as the limit value for people that are exposed by profession, considering an odontological exposure because there isn't a reported value for mining activities.

4 Conclusions

According to the results of this research, Hg concentration on both populations is above the permissible limits established by National and International Agencies (USEPA, WHO, PAHO) that symbolizes a health risk which thus represents a real risk for human health.

The average values of Hg concentration in the non-exposed population are 1–2 times above the established limit, having a considerable dispersion of the obtained data for the population of interest. Hair Hg concentration of the population of Metropolitan Zone of Mexico City also shows important geographical variations probably because of anthropogenic local sources of mercury pollution in the northern areas of Mexico City.

The time-activity survey indicates that the utilization of hair treatments as hair dyes and clarifying products (creams and soaps) are important factors in the increase of Hg levels, but their use is independent of the gender and age. The research was relevant by showing that Hg levels are higher in men tan in women in the non-exposed by profession population which is attributed to diet habits, because men eat seafood in a more regular basis than women, who eat frequently fruits and vegetables. The factors that affect mercury levels are diet, occupation, age and sex; all have some effect on mercury levels in the hair, as mentioned above.

The advantages of hair Hg assessment include the fact that hair collection is non-invasive, and get good response rates in all population subgroups, where obtaining blood samples can sometimes be difficult from some of the subgroups, such as women for example. Additionally, hair is a time record marker of MeHg exposure in individuals and can be used to estimate Hg exposure over extended periods of time such as fetal exposure during gestation.

Even if both populations exceeded the permissible limits, it is important to note that there is a large gap the values of the concentration of Hg obtained since the student community (control population) is not rigorously exposed to contamination by Hg, the highest concentrations of Hg measured are 8.50 $\mu g\ g^{-1}$ in men and 6.16 $\mu g\ g^{-1}$ in in women, respectively. The lowest concentrations detected were 0.33 $\mu g\ g^{-1}$ and 0.61 $\mu g\ g^{-1}$. On the contrary, the highest concentration was 142.56 $\mu g\ g^{-1}$ and the lowest was 0.80 $\mu g\ g^{-1}$ in the population of the mining region. The wide interval observed between these last two values can be explained by the amount of time each miner has been working in a mine, which would influence the amount of time each individual would be exposed to the contaminant.

References

Carretero I, Pozo M (2007) Applied mineralogy: health and environment. Thomson, Spain, Madrid

Cespón M (2001) Development of automatic analytical methods for the determination of metals in the working environment. USC, Department of Analytical Chemistry, Nutrition and Bromatology, Barcelona

Echegaray R, Gómez M (1984) Determination of mercury in hair as an expression of mercury exposure. Public Health 6(31):87–92

García C (2010) Determination of mercury by cold vapor generation and detection via absorption and atomic fluorescence. Thesis of Degree in Chemistry. Sartenejas, Simon Bolivar University

López P (2013) Concentration of mercury in hair of a sample of the adult population of Yucatan, descriptive study. Thesis of master in Science. Merida Yucatan, Mexico. Unit Mérida, Department of Human Ecology. Cinvestav, IPN

Mexican Norm NMX-EC-17025-IMNC-2006 General requirements for the competence of the testing and calibration laboratories. Mexican Institute of Normalization and Certification

Ministry of the Environment (ME) (2012) Inventory of pollutant and greenhouse emissions. Metropolitan Zone of the Valley of Mexico. http://www.aire.cdmx.gob.mx/descargas/publicaciones/flippingbook/inventario-emisioneszmvm2012/#p=20. Accessed on 29 Nov 2014

Ministry of the Environment of Japan (MEJ) (2013) Teachings of Minamata disease and the management of mercury in Japan. Division of Environmental Health and Safety, Department of Environmental Health. https://www.env.go.jp/chemi/tmms/pr-m/mat01/es_full.pdf. Accessed on 10 Feb 2015

Ramírez A (2008) Occupational mercury poisoning. An Fac Med (69)1:46–51, Perú

Rangel M (2015) Quantification of Hg in water for human consumption from wells in the mining region of Taxco de Alarcón, Guerrero. Thesis of Degree in Chemistry. Mexico. Faculty of Chemistry, UNAM

United Nations Environment Program (UNEP) (2002) Global assessment on mercury. Chemical products. Geneva, Switzerland. https://noharm.org/sites/default/files/lib/downloads/espanol/Evaluacion_Mundial_Mercurio.pdf. Accessed 22 on May 2015

United Nations Environment Program (UNEP) (2013) Minamata convention on mercury. Geneva, Switzerland

World Health Organization (WHO) (2000) Environment Health Criteria 214, Human Exposure Assessment. International Programme on Chemical Safety (IPCS). Geneva, Switzerland

Author Biographies

Isela Martínez Fuentes, Bachelor B.S., graduated from the Faculty of Chemistry at the National Autonomous University of Mexico (UNAM), She worked at the Center of Atmosphere Sciences, UNAM in the quantitative analysis of heavy metals in environmental and biological matrices. Her research is focused in environment distribution of mercury, its interaction and its effects on urban and rural areas using Hydride Generation Atomic Absorption Spectrophotometry. She is currently working as a student in the Master in Environmental Engineering in the Mexican Institute of Water Technology in the wastewater treatment with nanoparticles and magnetic separation.

Rocío García Martínez, Earth Sciences Ph.D., graduated from the Earth Sciences doctoral program at UNAM. She is a Level I member of the National System of Researchers and a Level C member of the Incentive Program for Academic Performance at UNAM. She is also a member of the CONACYT list of Accredited Assessors in Physics, Math and Earth Sciences. Her research has been dedicated to: the isotopic characterization of rain and superficial water to identify sources of aquifer pollution recovery; the study of heavy metals and organic compounds over environmental bioindicators as atmospheric pollution indicators and the study of atmospheric mercury in rainwater and atmospheric sprays in urban, suburban and rural areas.