Lead and cadmium levels in raw bovine milk and dietary risk assessment in areas near petroleum extraction industries

Authors

Reza Norouzirad[a]; Jose-Ramiro González-Montaña[b]; Felipe Martínez-Pastor[c]; Hedayat Hosseini[d]; Ali Shahrouzian[e]; Mehdi Khabazkhoob[f]; Fardin Ali Malayeri[g]; Haniyeh Moallem Bandani[g]; Mohsen Paknejad[h]; Behrouz Foroughi-nia[i]; Atefeh Fooladi Moghaddam[j]*

[a]. Department of Biochemistry, School of Paramedicine, Dezful University of Medical Sciences, Dezful, Iran; and Endocrine Physiology Research Center, Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran. norouzirad@sbmu.ac.ir

[b]. Department of Medicine, Surgery and Veterinary Anatomy, Universidad de León, León, Spain. jramirogonzalez@unileon.es

[c]. INDEGSAL (Institute for Animal Health and Cattle Development) and Molecular Biology (Cell Biology), Universidad de León, León, Spain. felipe.martinez@unileon.es

[d]. National Nutrition & Food Technology Research Institute (NNFTRI), Faculty of Nutrition & Food Technology, Shahid Beheshti University of Medical Sciences, Tehran, Iran. hedayat@sbmu.ac.ir

[e]. Dezful Polyclinic, Iranian Social Security Organization, Dezful, Iran. shzpnu@gmail.com

[f]. Department of Medical Surgical Nursing, School of Nursing and Midwifery, Shahid Beheshti University of Medical Sciences, Tehran, Iran. khabazkhoob@yahoo.com

[g]. Department of Clinical Biochemistry, Faculty of Medicine, Zabol University of Medical Sciences, Zabol, Iran. f_alimalayeri@zbmu.ac.ir

[g]. Department of Clinical Biochemistry, Faculty of Medicine, Zabol University of Medical Sciences, Zabol, Iran. hanimb150@yahoo.com

[h]. D.V.M. Khuzestan Veterinary Organization, Andimeshk, Iran. mohsenpaknejad@yahoo.com

[i]. Faculty of Pharmacy, Tabriz University of Medical Sciences, Tabriz, Iran; and Students Research Committee, Tabriz University of Medical Sciences, Tabriz, Iran. behrouz_119@yahoo.com

[j]. Technical University of Munich, Research Department Nutrition and Food Sciences, Chair of Analytical Food Chemistry, Freising, Germany. fooladi.atefeh@tum.de

Corresponding author

*Atefeh Fooladi Moghaddam. Technical University of Munich, Research Department Nutrition and Food Sciences, Chair of Analytical Food Chemistry, Maximus-von-Imhof-Forum 2, 85354, Freising, Germany; e-mail: fooladi.atefeh@tum.de

Abstract

Oil fields are a source of heavy metal pollution, but few studies have evaluated its impact on the intake of these contaminants through milk, an important food especially for children. From February 2015 to 2016, 118 samples of raw cow's milk, 14 of fodder and 8 of water in Southwest Iran were collected from farms close to oil fields or related industries. Lead (Pb) and cadmium (Cd) levels were evaluated by graphite furnace atomic absorption spectrometry. Mean±SE in milk and fodder were 47.0±3.9 and 54.0±6.9 μg/kg for Pb, and 4.7±1.0 and 3.5±1.3 μg/kg for Cd. No Pb or Cd was detected in water. Most milk samples (82.2%) for Pb were above the permissible limits (20 μg/kg). Exposure to Pb and Cd from milk consumption was calculated in two scenarios: mean and maximum exposure for the age range of 2-90 years. The intake of an average Iranian adult (25 years, 60 kg b. w., 0.14 kg milk/day) would be 6.6 μg Pb and 0.66 μg Cd/day (WI of 46.2 and 4.6 μg, respectively), well below the risk values proposed by some international organisations, even in the maximum exposure scenario. However, Pb exposure for infants and toddlers may be closer to the risk values, since milk and milk products could be the main contributor to Cd and Pb, and small children consume 2-3 times more food than adults relative to their body weight. The risk of Pb and Cd exposure through milk close to oil fields should be considered and a monitoring plan for these contaminants is strongly recommended.

Key words: raw cow milk, lead, cadmium, heavy metals, exposure assessment.

Abbreviations: CONTAM: Panel on Contaminants in the Food Chain; EFSA: European Food Safety Authority; EPA: Environmental Protection Agency; IARC:

International Agency for Research on Cancer; JECFA: Joint FAO/WHO Expert Committee on Food Additives; MI: monthly intake; PTMI: provisional tolerable monthly intake; TWI: tolerable weekly intake; WI: weekly intake.

1. Introduction

Milk is an important nutritious food, especially for children, in many parts of the world. The risk of milk contamination increases in the vicinity of highly polluted areas. Oxidants, nitrates, agricultural pesticides, industrial chemicals, and heavy metals could be potential contaminants of milk (Swarup et al., 2005; Patra et al., 2008).

Sources of heavy metal contamination include combustion of fuels, the proximity of roads, mining and industrial areas, and specifically, iron and steel plants (Swarup et al., 2005; Singh et al., 2011; Tunegová et al., 2016). Plants from land irrigated with contaminated water allow heavy metals to pass into the atmosphere, land, water and then to animal feed. Through this route it enters the trophic chain and is finally ingested by animals and people (Patra et al., 2008; Singh et al., 2010; Perween, 2015).

Heavy metals such as lead (Pb) and cadmium (Cd) have negative effects on livestock health (Rahimi, 2013; Lane et al., 2015), as well as harmful effects on human health (Perween, 2015). This problem is more important for children, who consume large amounts of milk, and are the most vulnerable population.

Pb and Cd are not essential for animals and plants. These metals are potentially toxic, causing hematologic, neurotoxic, and nephrotoxic effects even at low concentrations. Human exposure to these heavy metals has a negative effect on specific organs that may lead to metabolic disorders, fatigue, heart failure, and cancer. Furthermore, both chronic and acute exposure to Pb can result in encephalopathy (vomiting, depressed consciousness and lethargy), and it also decreases the learning ability in childhood (EFSA, 2010; JECFA, 2011; EFSA, 2012). Thus, Pb and Cd monitoring in milk must be considered as a fundamental part of public health and product quality (Rahimi, 2013; Tunegová et al., 2016).

The concentration of heavy metals in milk produced in some areas varies greatly, due to the differences in the contamination source (Swarup et al., 2005; Ataro et al., 2008). To the best of our knowledge, no studies have been carried out on the concentration of heavy metals in milk from livestock living close or exposed to contamination from oil extraction activities, not only pumping but also transport and processing, perhaps a consequence of dominant winds. Because oil fields are a source of Pb, Cd and other heavy metal contamination, our objective was to estimate the level of Pb and Cd contamination in cow's milk, as well as water and fodder, by studying an area of Southwest Iran exposed to contamination not only from nearby oil fields, but also to contaminated areas because of the Iran-Iraq war, and oil-related facilities (pipelines, and refineries). By studying that area, we aimed at testing the hypothesis that Pb and Cd levels are elevated in the water and fodder produced locally, as well as elevating heavy metal pollution in milk. In addition, we estimated the population's exposure to these two heavy metals from milk consumption, in order to assess the risk level in these areas.

2. Materials and Methods

2.1. Characteristics of the studied area

Southwest Iran has differential characteristics from the rest of the country (Kameli et al., 2013). Oil and gas extraction, transport, processing and distribution of their derivatives are sources of contamination (Lane et al., 2015). Moreover, the fine dust entering from Iraq and Saudi Arabia transfers many contaminants to these areas, with war and political-military conflicts making things worse (Ashrafi et al., 2014). Dez river, which flows through eight provinces of Southwest Iran moves contaminants downstream, significantly increasing the risk of contamination in some areas.

2.2. Sampling design

Convenient sampling was performed on 15 dairy farms located in 14 different regions of Southwest Iran (Khuzestan province), including industrial or traditional farms. Samples of milk, food and water were obtained based on the existing most representative livestock in the investigated area. Most farms were located in the Dezful area, except for two farms in the Shirin Ab-Dez region (Figure 1, farms A and B). Figure 1 shows farms are North or North-East relative to many oil fields and their facilities, and to current or former war areas (Iraq/Saudi Arabia). Therefore, these areas are exposed to contaminants not only by proximity to contamination sources but also because of the predominant South/ Southwest winds.

Immediately after milking, 200 ml raw cow milk was collected in pre-acid wash sterile screw-topped bottles. Before sampling, all the dishes were kept in 10% nitric acid for 24 hours, then washed with deionized water for 48 hours and dried in an incubator. The same method was used to collect water samples and fodder samples. All samples were kept at -80°C until the time of measurement. This study included 118 milk samples distributed as shown in Tables 1 and 2, eight water samples, and 14 fodder samples.

2.3. Pb and Cd analyses

All reagents were purchased from Merck KGaA Laboratories (Darmstadt, Germany). According to Iranian National Standard Determination of Food Pb and Cd Content (INS method No. 9266 and AOAC official method 999.11 standards), the samples were dried and then ashed at 450ºC under a gradual increase in temperature. 6M HCl (1+1) was added, and the solution was evaporated to dryness. The residue was dissolved in 0.1M

HNO_3, and Pb and Cd were measured with a graphite furnace atomic absorption spectrometer (Varian-SpectrAA 600), equipped with a platform graphite tube and a deuterium background corrector. A blank digestion solution was made for comparison.

To check the accuracy of the analytical method, a multi-element standard solution (Merck) with different concentrations of Cd and Pb (0.2, 1, 10, 50 and 100 μg/kg) was used for calibration. The standard curve was performed with a concentration range of 5, 10, and 30 μg/kg for Pb and 0.5, 1.0, and 1.5 μg/kg for Cd.

The precision of the method was expressed as recoveries close to 100% (95-110% for Pb and 80-97% for Cd), with a standard deviation (SD) of the recoveries lower than 0.010, and with a relative standard deviation (RSD) lower than 10% for both metals. Limit of detection (LoD) and limit of quantification (LoQ) was 3 and 9 μg/kg, respectively for Pb measurement and 0.4 and 1.2 μg/kg, respectively for Cd measurement. Duplicate analysis was performed for all samples.

2.4. Exposure assessment

The European Union recommends maximum Pb levels of 20 ppb (20 μg/kg w. w., wet weight) in raw milk, heat-treated milk and milk for the manufacture of milk-based products (European-Union, 2006, 2015).

Lead is absorbed more in children than in adults. It accumulates in soft tissues, and over time in bones, and above all, for its long half-lives in blood and bone. The Panel on Contaminants in the Food Chain (CONTAM Panel) of European Food Safety Authority (EFSA) and the Joint FAO/WHO Expert Committee on Food Additives (JECFA) identified developmental neurotoxicity in young children and cardiovascular effects and nephrotoxicity in adults as critical effects for risk assessment.

In 1972, JEFCA established a Provisional Tolerable Weekly Intake (PTWI) of 3 mg of lead per person, equivalent to 50 µg/kg b. w., stating this did not apply to infants and children. In 1978, the committee retained the PTWI for adults, noting that establishing a PTWI for children was not yet possible owing to the lack of scientific data. In 1987, the PTWI for infants and children was established at 25 µg/kg b. w.; this value was extended to all age groups. However, JEFCA, based on dose-response analysis, considered that the previously established value (PTWI of 25 µg/kg b. w.) could not be considered protective of health and withdrew it (JECFA, 2011). Moreover, they stated that it was not possible to establish a new PTWI. The CONTAM indicated that the PTWI of 25 µg/kg b. w. was no longer appropriate as there was no evidence for a threshold for critical lead-induced effects (EFSA, 2010).

It is recommended to use margin of exposure (MOE), which is calculated by dividing the benchmark dose lower confidence limit (BMDL) values derived from human data for the end points of dietary exposure (EFSA, 2010). MOEs apply to different age groups (infants, <3 months; toddlers, 1-3 years; children, 4-7 years, and adults), and is also considered for medium and high consumers (EFSA, 2010).

The JECFA reaffirmed that foetuses, infants and children are subgroups that are most sensitive to lead. Therefore, protection of children and women of childbearing age against the risk of neurodevelopmental effect, is sufficient to protect all age groups from harmful effects of lead (JECFA, 2011). The mean dietary exposure estimated for children aged 1–4 years ranges from 0.03 to 9 µg/kg b. w. per day, and for adults from

0.02 to 3 μg/kg b. w. per day. In addition to the dietary contribution, other sources of exposure to lead also need to be considered (JECFA, 2011).

The European Union initially did not propose a maximum value for Cd in raw milk (European-Union, 2006), although it suggested maximum amounts between 5 and 10 μg/kg in infant formulas (liquid formulae or powdered formulae) manufactured from cow's milk proteins or protein hydrolysates (European-Union, 2014). The Codex Alimentarius does not report permissible levels of Cd in milk (Codex-Alimentarius-Commission, 2011).

With respect to Cd, and because of the long half-life in living organisms, exposure over a longer period of time should be considered to ensure safe and appropriate levels of exposure throughout life with no appreciable risk to the consumer (Codex-Alimentarius-Commission, 2011; EFSA, 2011; JECFA, 2011; EFSA, 2012).

Therefore, in 1988, a PTWI of 7 μg/kg b. w. for cadmium was established by JECFA. Later in 2009, and subsequently confirmed in 2011, the CONTAM adopted an opinion on cadmium in food. It was recommended that the PTWI should be reduced to a tolerable weekly intake (TWI) of 2.5 μg/kg b. w. in order to ensure a high level of protection of all consumers, including exposed and vulnerable subgroups of the population (EFSA, 2011; 2012).

In 2010, the JECFA reviewed its previous evaluation and established a provisional tolerable monthly intake (PTMI) of 25 μg/kg body weight, corresponding to a WI of 5.8 μg/kg b. w. (JECFA, 2011).

The EFSA decided to review its assessment of exposure in the European population to cadmium, showing up-to-date information on the consumption of different foods, including milk and milk products. It sought to ensure a high level of protection of all consumers, including exposed and vulnerable subgroups of the population, such as children, vegetarians or people living in highly polluted areas. It pointed out that total exposure is the result of not only a few main contributors, but the sum of the contributions of different food groups (EFSA, 2012).

In this study, we used the occurrence data for Cd and Pb contamination in milk and mean milk intake in the studied area and calculated the exposure of these two heavy metals from milk. These values were then used to compare the exposure to Cd and Pb from milk with the TWI set by JECFA and EFSA.

2.5. Data analysis

Data were analyzed by using SPSS (IBM) version 20 and the R statistical environment v. 3.4.2. Results are reported as Mean ± SE. We also reported the proportion of milk samples with Pb concentrations above the 20 μg/kg w. w. (European-Union, 2006, 2015). To compare Pb and Cd levels among all sampled locations (milk, water and fodder) we carried out an ANOVA test with Tukey post-hoc multiple comparisons.

Exposure assessment was calculated using the equation below in two scenarios: mean and maximum Pb and Cd occurrence.

$$\text{Exposure to contaminant} = \frac{\text{Contaminant occurence } (\mu\text{g/kg}) \times \text{milk consumption (kg/day)}}{\text{average body weight in Iran (kg)}}$$

This exposure (μg/day/kg b. w.) was used to calculate weekly exposure, in order to compare it with the published TWI. So as to obtain a complete figure of the relative risk in the sampled zones, we carried out a bibliographic research to get an estimation of both average body weight and milk/dairy consumption at different ages (from toddlers to seniors) (Ghassemi et al., 2002; Haghdoost et al., 2008; Abdollahi et al., 2014; Esfarjani et al., 2015; Singh et al., 2015).

3. Results

3.1. Pb and Cd in raw cow milk

The concentrations (mean ± SE) of Pb and Cd in the 118 milk samples are summarized in Table 3. The Pb concentration was 47.0 ± 3.9 µg/kg and the Cd concentration was 4.7 ± 1.0 µg/kg. Since the permissible limit for Pb in European Union is set at 20 µg/kg (European-Union, 2006; 2015), 82.2% of the samples were above this limit. Pb and Cd levels in milk segmented by sampling areas (Figure 1) are shown in Tables 1 and 2. Most of the regions (11 of 14) showed values above the permissible limit for Pb. The Hamzeh area showed the highest average value (almost twice as much the next highest value). However, for Cd, only the average level of Tanour Boland region was well above the average value of the rest of the sampled areas (Table 1). No apparent clustering was detected in the sampled areas for either Pb or Cd.

3.2. Levels of lead and cadmium in water and feed samples

Pb and Cd were not detected in any of the 8 water samples. Pb level in fodder samples (mean ± SE) was 54.0 ± 6.9 µg/kg, with a range of 30.0 to 130.0 µg/kg. Cd in fodder samples (mean ± SE) was 3.5 ± 1.3 µg/kg, with a range of 3.0 to 20.0 µg/kg.

3.3. Exposure assessment of lead and cadmium from milk consumption

The exposure to Pb and Cd coming from milk consumption in the region was calculated in two scenarios: mean scenario and max scenario. We estimated both weekly intake (WI) and TWI for a range of ages from 2 to 90 years old, taking into account the average body weight and milk intake in Iran. Results are summarized in Figure 2. The intake for an average Iranian adult (25 years old, 60 kg b. w., 0.14 kg milk per day) would be of 6.6 µg Pb and 0.66 µg Cd per day. That is, an exposure of 0.11 and 0.011 µg/kg b. w./day, respectively. The WI would be 46.2 and 4.6 µg, respectively. These figures are far from the 1500 µg Pb/week and 348 µg Cd/week currently defined, or at some point advised (by Codex Alimentarius, EFSA and JECFA) as TWI for a 60-kg person. However, in the maximum exposure scenario, the WI would be of 244.9 µg Pb and 97.9 µg Cd.

While the WIs for an adult person are far from the respective TWIs, even in the maximum exposure scenario, Figure 2 shows a much higher exposure for infants, toddlers and young adolescents. In fact, due to a higher milk intake in infants, WI increases considerably (indeed, due to lower body weight, the exposure is much higher at these ages). In the case of the mean scenario, WIs are still much lower than the limits defined by the TWIs. However, in the maximum scenarios, the WIs for Pb are close to the TWIs for infants and young adolescents, and the maximum WIs for toddlers (up to 5 years old) could be higher than the corresponding TWIs. The situation is even worse for Cd, with ages 2–15 having maximum WIs clearly above the corresponding TWIs.

4. Discussion

Concerns regarding Pb and Cd on human health have arisen from accumulation of these metals in the environment, especially in agricultural and livestock production, increasing the potential to enter products aimed at human consumption (Lane et al., 2015). Therefore, monitoring of milk, as one of the potential sources of these heavy metals, is necessary (Singh et al., 2011).

In this research, Pb concentration in raw cow's milk, was higher than the permissible limit in most of the sampling areas. These results are in agreement with others considering areas near contamination sources, such as roads (Simsek et al., 2000; Perween, 2015), mining areas (Giri et al., 2011; Gonzalez-Montaña et al., 2012), coal-fired power plants (Gonzalez-Montaña et al., 2012; Tunegová et al., 2016) dumps, metropolitan areas and industrial units (Simsek et al., 2000; Swarup et al., 2005; Patra et al., 2008; Hyseni and Musaj, 2014; Perween, 2015).

Our results showed the values of lead in the cow milk samples were in agreement with those reported from Turkey (Simsek et al., 2000; Ayar et al., 2009), Croatia (Pavlovic et al., 2004; Bilandzic et al., 2011), and several times higher than those reported from India (Tripathi et al., 1999; Dhanalakshmi and Gawdaman, 2013), Thailand (Parkpian et al., 2003), Italy (Licata et al., 2004), South Africa (Ataro et al., 2008), Spain (Gonzalez-Montaña et al., 2012), Greece (Gougoulias et al., 2014), and Iran (Najarnezhad and Akbarabadi, 2013; Najarnezhad et al., 2015; Mostafidi et al., 2016). Although they are inferior, to those investigated in Italy (Coni et al., 1995; Caggiano et al., 2005; Anastasio et al., 2006), India (Swarup et al., 2005), Romania (Serdaru et al., 2001), Pakistan (Javed et al., 2009), France (Maas et al., 2011), Sudan (Abdalla et al., 2013), Kosovo (Hyseni and Musaj, 2014), Pakistan (Iftikhar et al., 2014) and Egypt (Meshref et al., 2014).

Mean concentrations of the cadmium found were lower than those cited in Romania (Serdaru et al., 2001), Croatia (Pavlovic et al., 2004), Poland (Baranowska et al., 2006), Italy (Caggiano et al., 2005; Anastasio et al., 2006), Turkey (Ayar et al., 2009), Egypt (Meshref et al., 2014), Kosovo (Hyseni and Musaj, 2014), but are similar to those reported from Italia (Licata et al., 2004), Croatia (Pavlovic et al., 2004), Chile (Muñoz et al., 2005), Greece (Gougoulias et al., 2014), and Iran (Najarnezhad et al., 2015). Whereas most values are higher than cadmium levels reported from Argentine (Rubio et al., 1998), India (Tripathi et al., 1999; Dhanalakshmi and Gawdaman, 2013), Thailand (Parkpian et al., 2003), Brazil (Santos et al., 2004), South Africa (Ataro et al., 2008), Spain (Sola-Larrañaga and Navarro-Blasco, 2009), France (Maas et al., 2011), Sudan (Abdalla et al., 2013), Iran (Najarnezhad and Akbarabadi, 2013; Mostafidi et al., 2016) and Pakistan (Batool et al., 2016).

To date, only one study assessed the Pb level in raw cow milk in the Southwest of Iran (Tajkarimi et al., 2008) and none have analysed Cd. This is a region of special interest because of its proximity to conflict areas and contamination sources (especially those related to oil extraction and processing). Tajkarimi et al. (2008) sampled 14 milk factories in different provinces of Iran and they found lead mean residues of 2.4±1.4 μg/kg in Shoosh (Khuzestan), one order of magnitude lower than the values indicated here. Compared to other studies (Najarnezhad et al., 2015) carried out in the Northwest of this country (West Azerbaijan province), we have reported higher exposure (μg/kg, 47.0 Pb and 4.7 Cd vs. 7.0 and 10.0, respectively). Whereas both provinces are in the West of Iran, Khuzestan is closer to polluted areas and more exposed to dominant winds carrying pollution from zones related to oil or conflict.

Other authors have reported Pb and Cd in cow's milk from other areas in Iran. Najarnezhad and Akbarabadi (2013) reported Pb and Cd in cow's milk from the other side of the country, the Khorasan-Razavi province in North-East Iran. They reported values of 12.9 ± 6.0 μg/kg for Pb and 0.3 ± 0.3 μg/kg for Cd. Tajkarimi et al. (2008) found average Pb values of 7.9 ± 0.98 μg/L, ranging from 1.5 ± 0.4 in Kerman province to 23.4 ± 1.7 in Isfahan. For this author, 90% of the samples were lower than the maximum limit (20 μg/kg), while the highest values were found in the areas of Tehran, Isfahan, and West Azerbaijan, the most industrialized regions in Iran. Therefore, the high levels of lead in milk may be the result of industrial air pollution in these regions (Baranowska et al., 2006; Patra et al., 2008; Tajkarimi et al., 2008). However, other possible causes have been cited, such as proximity of roads and highways, adding this metal to gasoline (Baranowska et al., 2006; Tunegová et al., 2016), contamination of food (Muñoz et al., 2005; Andjušić et al., 2012), prevailing winds in the area or use of pesticides (Baranowska et al., 2006). Nevertheless, even the values in these more polluted areas contrast with our results, indicating that Southwest Iran is an area of high interest due to its exposure to heavy metal contamination.

For many researchers, the main source of lead contamination is irrigation with contaminated water (Tajkarimi et al., 2008; Singh et al., 2010; Singh et al., 2011). Therefore, simultaneous evaluation of metals in water and fodder could provide a good estimation of environmental contamination sources (Bakary et al., 2015). Rather surprisingly, neither Pb nor Cd could be detected in the water samples. Thus, the role of water as a source of heavy metals, either by direct ingestion by the animals or indirectly by irrigation seems unlikely. In present study, elevated Pb and Cd levels were detected in all fodder samples, so cattle fodder should be considered as the major source of Pb and Cd in milk samples, despite the absence of a link with irrigation water. Air contamination seems to be a likely culprit here, either from the exhausts of oil extraction or processing activities or from dust being blown from contaminated areas (Dahshan et al., 2013; Bakary et al., 2015; Perween, 2015).

We have estimated the weekly intake (WI) of Pb and Cd for the Iranian population through consuming milk. The WI for Pb for a typical young Iranian adult of 60 kg is

46.2 µg. The values found are well below (%3.1 TWI) the previously stablished risk value of 1500 µg/week for a 60-kg person (EFSA, 2011; JECFA, 2011), which would indicate a low risk for consumers at the sampled regions. It is important to note that this research only refers to milk intake, which may have a very low contribution to the total intake of Pb in the regional population.

The estimated WI of Cd from ingested milk for a 60 kg-person was determined to be 4.6 µg. Taking into account the JECFA (2010) limit value of 25 µg/kg b. w./month, the maximum monthly intake of Cd for the average Iranian should not exceed 1500 µg, which is approximately 350 µg/week. If we use the WI of 2.5 µg/kg b. w., established by EFSA (2011), the scenario of maximum Cd concentrations in this research shows a weekly intake of 150 µg for a 60 kg- person. In both cases, the weekly intake of Cd in the investigated areas, due to ingestion of milk, is well below the risk values proposed, being 1.3 and 3%, respectively. It is important to take into account the contributions of lead in other sources and not only in milk.

However, considering the cumulative nature of Pb and Cd and the fact that children and especially toddlers mainly depend on milk for feeding, it might be of concern to this age group in the long term. For instance, an assessment on "cadmium dietary exposure in the European population" (EFSA, 2012), shows that the main contributors to Cd exposure, for adults, children and adolescents are starchy roots and tubers, grains and grain-based products, vegetables and derivatives. However, and not surprisingly, milk and dairy products are the main Cd sources for infants and toddlers. It is assumed that children's exposure would be 2–3 times that of the general population on a body weight basis (JECFA, 2011).

Both documents show that overall exposure is the result of not only a few main contributors but the addition of contributions of a number of different food groups (JECFA, 2011; EFSA, 2012), although the contribution of milk and dairy products varies between 6 and 8% (JECFA, 2011). Nevertheless, other age groups may be at risk, since exposure to Cd may be higher when other food batches are ingested.

Pb and Cd do not have a biological function, are toxic, and can be accumulated in the body (Liu, 2003; IARC, 2006: JECFA, 2011). The International Agency for Research on Cancer (IARC) has classified Cd and cadmium compounds as carcinogenic to humans (group I) on the basis of sufficient evidence in both humans and experimental animals (IARC, 1993; IARC, 2017). This same Agency, the IARC, has placed inorganic lead compounds as probably carcinogenic to humans (Group 2A) (IARC, 2006; IARC, 2017), while organic lead compounds are not classifiable as to their carcinogenicity to humans (Group 3) (IARC, 2006). However, the Environmental Protection Agency (EPA) classified lead and compounds (inorganic) at Group 2B “as probable human carcinogen", and to be considered "reasonably anticipated to be human carcinogens" (IRIS-EPA, 2004).

Considering the toxicity of these heavy metals, their probable carcinogenicity, the neurological and nephrotoxic effects, and the findings in the sampled areas (especially Hamzed), we strongly recommend to establish a continuous monitoring system in the areas affected by high levels of contamination, specifically in cattle ranches close to oil fields. Although the exposure seems to be far from those warned by the international organizations, our report puts Southwest Iran apart from the rest of the country and supports our hypothesis on the increased levels of Pb and Cd, and potentially other heavy metals and pollutants. The monitoring data can be used to assess the exposure and help the managers and policymakers to choose the best options for reducing human exposure and the related risk.

5. Ethical Approval

The proposal for this study was approved by the ethics committee of Dezful University of Medical Sciences, Dezful, Iran.

6. Conflicts of Interest

No competing interests are declared by the authors.

7. Authors' Contributions

R. Norouzirad and A. Shahrouzian designed the study; M. Khabazkhoob, F. Ali Malayeri, H. Moallem Bandani, M. Paknejad and B. Foroughi-nia carried out the samplings and analyses; M. Khabazkhoob, A. Fooladi Moghaddam carried out the data analysis; J.R. González-Montaña and F. Martínez-Pastor contributed to the analysis of the data. R. Norouzirad and A. Fooladi Moghaddam and H.Hosseini wrote the draft; J.R. González-Montaña and F. Martínez-Pastor contributed to the preparation of the manuscript and revised it critically. All authors contributed to the final version and have read and approved the final version of the manuscript.

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10. Tables and Figure

Table 1. Average Pb levels (µg/kg) in milk samples in each sampling area.

Regions	Pb					
	N	Minimum	Maximum	Mean		SE
Daste Lale	10	N.D	100.0	42.50	†	7.66
Tanour Boland	13	N.D	50.0	27.50	†	2.86
Golkhane	7	4.0	50.0	27.00	†	5.02
Cham Golak	11	10.0	50.0	33.33	†	2.81
Al-Mahdi	3	30.0	50.0	36.67	†	6.67
Shirin Ab-Dez	21	4.0	200.0	63.14	†	8.38
Hamzeh	15	1.0	250.0	114.20	†	14.69
Kolouli	3	10.0	20.0	15.00		2.89
Bande-Bal	3	30.0	40.0	35.00	†	2.89
Pirouzi	3	20.0	100.0	46.67	†	26.67
Behrouzi	5	0.5	50.0	16.70		8.65
Safiabad	3	2.0	60.0	30.67	†	16.75
Mianrrood	4	10.0	30.0	20.00		4.08
Pishineh	17	N.D	150.0	29.43	†	8.34

N.D: no detected.

† Mean Pb levels of these areas were above permissible limits (20 µg/kg).

Table 2. Average Cd levels (µg/kg) in milk samples in each sampling area.

Regions	Cd				
	N	Minimum	Maximum	Mean	SE
Daste Lale	10	1.0	2.0	1.50	0.23
Tanour Boland	13	N.D	100.0	26.75	6.78
Golkhane	7	1.0	3.0	2.00	0.46
Cham Golak	11	N.D	6.0	2.17	0.45
Al-Mahdi	3	N.D	1.0	0.47	0.29
Shirin Ab-Dez	21	0.8	4.0	1.83	0.18
Hamzeh	15	N.D	10.0	3.14	0.60
Kolouli	3	1.0	3.0	2.00	0.58
Bande-Bal	3	2.0	3.0	2.50	0.29
Pirouzi	3	N.D	1.0	0.33	0.33
Behrouzi	5	0.6	5.0	2.52	0.85
Safiabad	3	N.D	1.0	0.40	0.31
Mianrrood	4	0.5	3.0	1.50	0.54
Pishineh	17	N.D	10.0	1.49	0.57

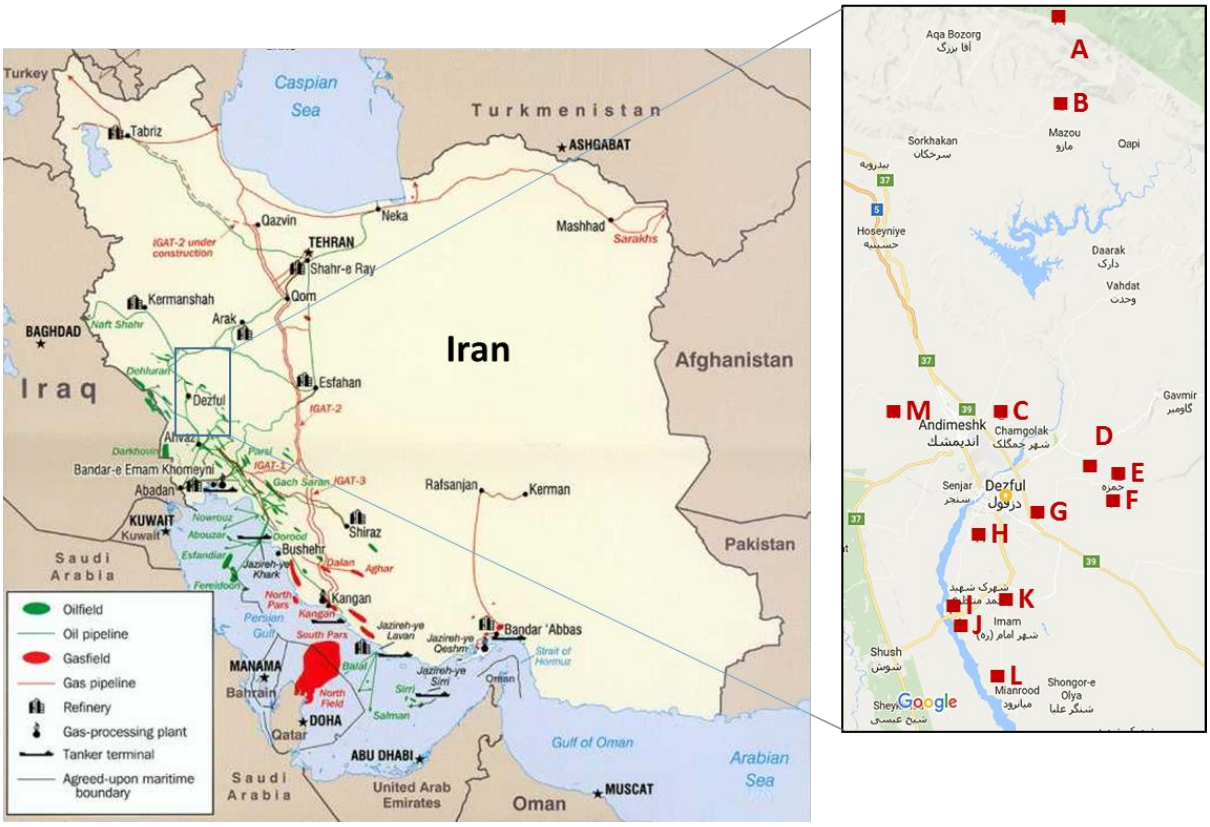
n.d: no detected

Table 3. Average Pb and Cd levels (μg/kg) in the 118 milk samples collected in the study, and proportion of samples above permissible limits (Pb: 20 μg/kg).

Metal	Mean ± SE	Minimum	Maximum	Samples above permissible limits
Pb	47.0 ± 3.9	N.D	250.0	97 (82.2%)
Cd	4.7 ± 1.0	N.D	100.0	†

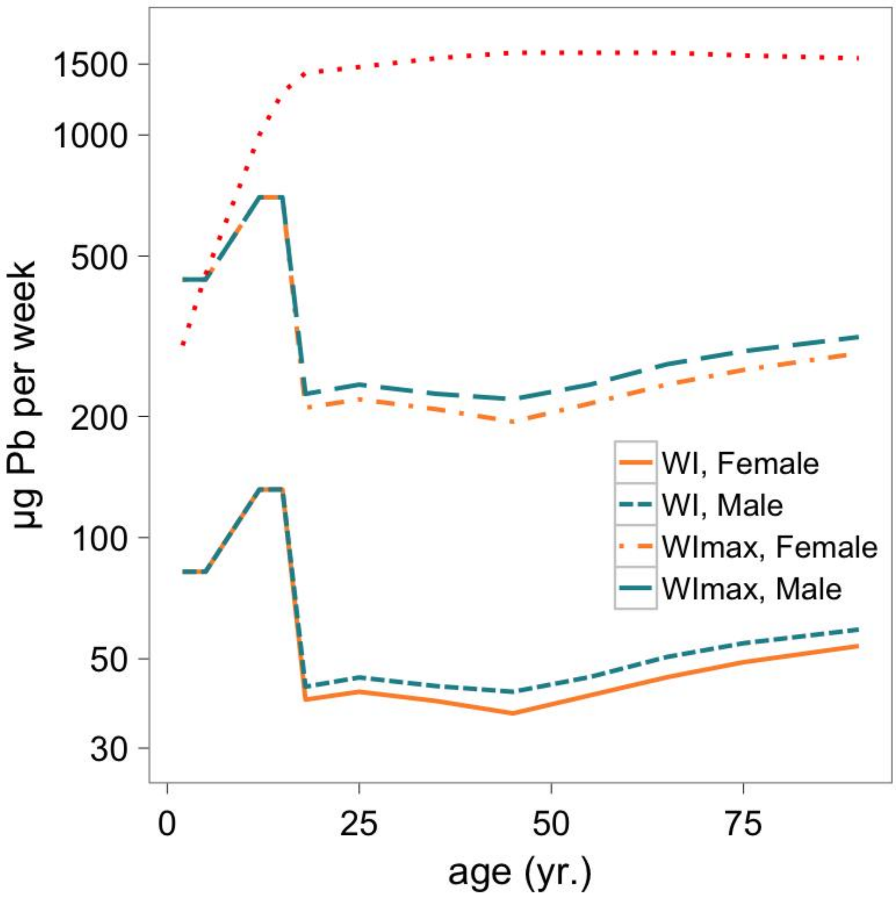
† There is not an established limit.

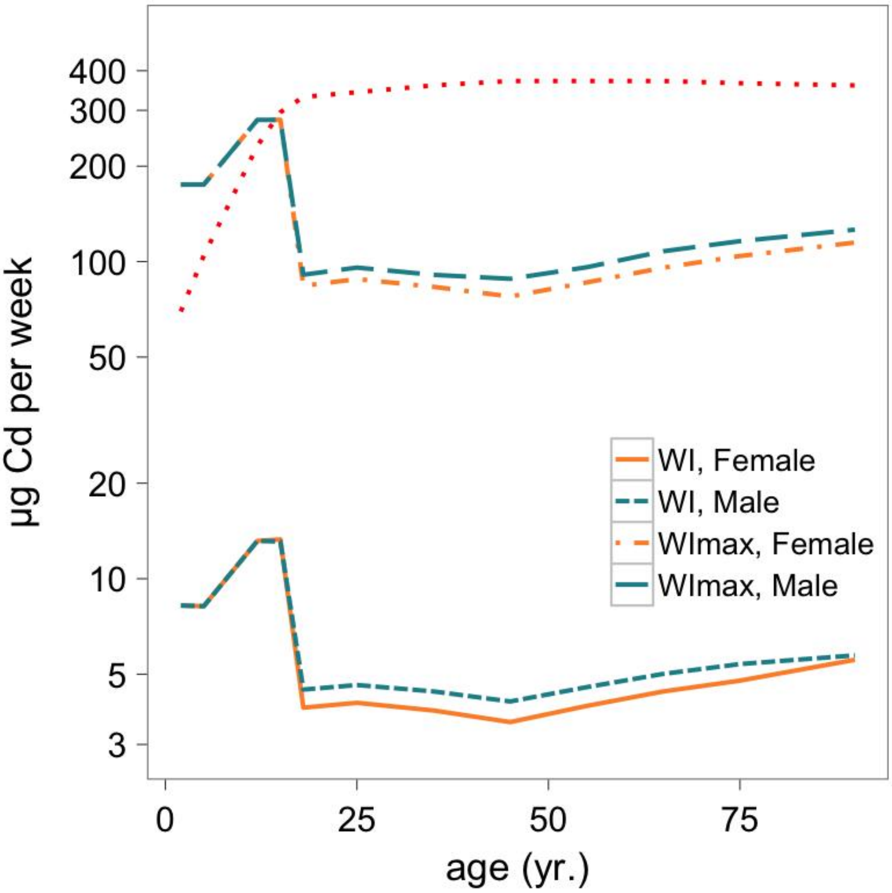
Figure 1. Sampled areas in this study.



A: Daste Lale; B: Tanour Boland and Golkhane; C: Cham Golak; D: Al-Mahdi; E: Shirin Ab-Dez; F: Hamzeh, G: Kolouli; H: Bande-Bal; I: Pirouzi; J: Behrouzi; K: Safiabad; L: Mianrood; M: Pishineh. Notice the position of the oil and gas fields and related facilities (refineries, pipelines, processing plants, tanker terminals) and the polluted areas by the Southwest Iran-Iraq border relative to these areas, considering also the predominant West and Southwest winds.

Figure 2. Weekly intake (WI) for Pb and Cd, calculated from 2 to 90 years of age, taking into account body weight and approximate milk/dairy intake at different ages in Iran.





WI was calculated according to our results, in a "mean exposure" scenario (WI; 47 µg/kg milk for Pb and 4.7 µg/kg milk for Cd) and in a "maximum exposure" scenario (WI max; 250 µg/kg and 100 µg/kg, respectively). Notice that the WI is in a logarithmic scale, in order to fit adequately both scenarios. Infants and young adolescents have a higher milk intake, thus the peak at young ages. From 1 years old, intake data is segmented by sex, with females having a slightly lower milk intake. The dotted line on the top is the tolerable weekly intake (TWI) for each age (averaged by sexes, because they are almost coincident in the logarithmic scale).