



Urinary concentrations of heavy metals in pregnant women living near a petrochemical area according to the industrial activity

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ABSTRACT

Background: The progressive industrialization has resulted in an increase in heavy metal pollution in the environment, which has a dangerous impact on human health. Prenatal exposure to heavy metals, even at very low concentrations, may be especially harmful to pregnant women and their children. Different industrial activities can contribute to heavy metal pollution in a specific area.

Objective: 1) To explore the concentrations of heavy metals in urine samples of pregnant women, and 2) to evaluate the potential effect of different industrial activities in Tarragona (Spain).

Methods: Urinary levels of four heavy metals (nickel (Ni), cadmium (Cd), mercury (Hg), and lead (Pb)) from 368 pregnant women recruited in the ECLIPSES study were analyzed. Home addresses and all the industries potentially releasing heavy metals were geo-referenced. Buffer zones were established within a 1.5, 3, and 5 km radius at the center of each industry. Subsequently, the number of participants living in and out of each buffer zone was recorded.

Results: Urinary levels of Ni and Cd, but not those of Hg and Pb, were obviously increased in pregnant women living near most of the industrial sites. After adjustment for potential co-variables, only Cd showed notable differences according to the industrial activity. Compared to women living outside the buffer, Cd levels were increased in those living within 1.5 and 3 km of chemical industries, within 5 km of energy industries, within 1.5, 3, and 5 km of mineral industries, and within 3 and 5 km of metal processing industries.

Conclusion: Among the analyzed heavy metals, Cd showed an increasing trend in urinary concentrations in women living near chemical, energy, mineral, and metal processing industries. This study highlights the need to develop legislative measures to minimize Cd exposure, especially by sensitive populations. Moreover, additive or synergistic effects of co-exposure to other air pollutants should not be disregarded.

1. Introduction

Heavy metal pollution is one of the most serious environmental issues worldwide (Zhang et al., 2022). To date, the detrimental impact of heavy metals on human health is increasingly acknowledged due to their toxic potential, even at trace concentrations (Wu et al., 2019). Heavy metal pollution is one of the most serious environmental issues worldwide [1]. To date, the detrimental impact of heavy metals on human health is increasingly acknowledged due to their toxic potential, even at

trace concentrations [2]. Heavy metals exposure can result in organ impairment, nervous system damage, memory deterioration, cardiovascular diseases, and even cause cancer in humans [3], [4]. Notably, pregnancy is a special period in that women become especially vulnerable to environmental pollution, in general, and heavy metals, in particular [5], [6]. The detrimental health effects of prenatal exposure to these toxic trace elements include, but are not limited to, spontaneous abortion, premature delivery, infertility, and disturbance of hormone levels [7], [8]. Apart from that, prenatal exposure to heavy metals can

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Table 1
Basic characteristics of participants.

Characteristics	Pregnant women (N = 368)
Maternal age (years), No. (%)	
<25	43 (11.7%)
25–29	82 (22.3%)
>29	243 (66.0%)
Baseline pregnancy BMI (kg/m ²), mean (SD)	24.88 (4.33)
Educational status, No. (%)	
Primary studies	100 (27.2%)
Secondary studies	130 (35.3%)
University studies	138 (37.5%)
Smoking status, No. (%)	
No smoker	260 (70.7%)
Smoker or ex-smoker	108 (29.3%)
rMedDiet adherence score, No. (%)	
Low: 0–6 points	123 (33.4%)
Medium-high: 7–18 points	245 (66.6%)

BMI, body mass index; SD, standard deviation; rMedDiet, Mediterranean diet.

Table 2
Urinary concentrations of heavy metals in pregnant women living in Tarragona.

	Median	Percentile			GM	IQR
		25th	50th	75th		
Unadjusted (µg/L)						
Ni	1.63	1.08	1.63	2.45	1.45	1.37
Cd	0.21	0.12	0.21	0.36	0.19	0.24
Hg	0.53	0.26	0.53	0.94	0.39	0.67
Pb	0.37	0.14	0.37	0.82	0.27	0.68
Adjusted (µg/g of creatinine)						
Ni	1.62	1.09	1.62	2.43	1.63	1.33
Cd	0.23	0.13	0.23	0.23	0.22	0.20
Hg	0.58	0.29	0.58	0.95	0.48	0.66
Pb	0.37	0.16	0.37	0.70	0.27	0.54

Ni, nickel; Cd, cadmium; Hg, mercury; Pb, lead; GM, geometric mean; IQR, interquartile range.

also affect the offspring due to placental transfer, which is reflected by growth retardation, immune dysregulation, and neurodevelopment impairment (Guo et al., 2022; Karunanidhi et al., 2022). Notably, pregnancy is a special period in that women become especially vulnerable to environmental pollution, in general, and heavy metals, in particular (de Assis Araujo et al., 2020; Iglesias-Vázquez et al., 2022). Prenatal exposure to these toxic trace elements may have several adverse health effects, including spontaneous abortion, premature birth, infertility, and disruption of hormone levels, among others (Dutta et al., 2022; Gómez-Roig et al., 2021). Apart from that, prenatal exposure to heavy metals can also affect the offspring due to placental transfer, which is manifested by growth retardation, immunological dysregulation, and impairment of neurodevelopment (Shah-Kulkarni et al., 2020; Tsai et al., 2019).

Heavy metals can be released into the environment from different sources. Although they occur naturally, anthropogenic emission sources are quantitatively more important, being industry and traffic the two most relevant (Brindhadevi et al., 2023; Hubeny et al., 2021). In recent years, there has been a considerable increment of heavy metal concentrations in air, water, soil, and plants in areas with heavy industries (Wei et al., 2022; Yang et al., 2021). Specifically, heavy metals can be released differently from distinct industrial activities including the production of chemical products, fossil fuel combustion, mining, electroplating, sewage discharges, etc. (Kladsomboon et al., 2020; Shah-Kulkarni et al., 2020; Zhao et al., 2022). Among the many ways that people might be exposed to heavy metals, including through air inhalation, skin absorption, and soil ingestion, food consumption is the most important one (González et al., 2019; Nadal et al., 2011). So far, a variety of epidemiological studies have explored the distribution and associated factors of heavy metals in industrial areas (Fan et al., 2022;

Huang et al., 2022). Moreover, some of these investigations point out that residents living near petrochemical industrial complexes have a higher cancer incidence and mortality, with special incidence of leukemia and other hematological malignancies, as well as lung and bladder cancer (Domingo et al., 2020). Furthermore, living close to petrochemical industry is linked to negative health outcomes other than cancer, including a higher prevalence of asthma and other respiratory conditions as well as a rise in negative pregnancy and delivery outcomes (Marqués et al., 2020). Nevertheless, most of these studies lack to explore how different industrial activities affect heavy metals exposure (Interdonato et al., 2014; Shah-Kulkarni et al., 2020).

The most important industrial complex in Spain and one of the largest in Southern Europe is located in Tarragona County (Catalonia, Spain) (Domínguez-Morueco et al., 2018; Rovira et al., 2021). The zone contains a wide variety of potential emission sources, such as a big oil refinery, a chlor-alkali plant, several plastic manufactures and two waste incinerators, among others. Most of these have been established for more than 50 years. Several roads that cross the area also contribute to the generation of air pollutants due to their heavy traffic.

The current study aimed to explore heavy metals exposure and associated factors, including sociodemographic status, lifestyles, dietary factors, and industry types, among pregnant women living in Tarragona (Spain).

2. Methods

2.1. Study design and participants

The current analyses were based on the sub-data of the ECLIPSES study, which is large-scale research focused on pregnant women in Tarragona (Spain) [15]. The enrolled 791 women were contacted during the first routine visit with midwives in their primary care center and urine samples were collected from 368 women based on the principle of voluntariness. The inclusion criteria were as follows: (i) women were older than 18 years old with ≤ 12 weeks gestation; (ii) being able to comprehend the official State languages (Spanish or Catalan) and the study features to sign the informed consent; (iii) no anemia indication was discovered before 12 weeks of gestation. Reasons for loss of follow-up were as follows: (i) voluntary abandonment; (ii) miscarriage or appearance of complications among women during the gestational period.

2.2. Maternal baseline data collection

Baseline maternal features were gained by questionnaires among all participating women during a face-to-face interview at the enrollment, which contained maternal age (years), maternal weight and height and body mass index (BMI, kg/m²), educational status (primary studies, secondary studies, and university studies), Mediterranean diet adherence score (low, middle, high) [16], and residential address during pregnancy. The coordinates in UTM of the participants' homes were obtained by geolocation.

2.3. Urine sampling and metal determination

Maternal urinary samples were homogenized and then aliquoted from all the enrolled women at the 12th gestational week. Aliquoted urinary samples were stored in polypropylene tubes at $-20\text{ }^{\circ}\text{C}$ for nickel (Ni), cadmium (Cd), mercury (Hg), and lead (Pb) analysis and measurement of urine creatinine levels.

Before sample analysis, urinary samples were thawed at room temperature and diluted 1:10 in the same diluent as the corresponding calibration standards with 2% nitric acid (suprapur 65%). Lypochek Urine Metal Control for trace elements Level I and II (Bio-rad) was used for internal quality control. Recovery percentages for Ni, Cd, Hg, and Pb were between 90.6% and 102.1%. Observed values fell within the range



Fig. 1. Tarragona location in Spain.

of certified values. Urinary concentrations of nickel (Ni), cadmium (Cd), mercury (Hg), and lead (Pb) were determined by Triple quadrupole inductively coupled plasma tandem mass spectrometry (ICP-MS/MS) (Agilent 8800 triple quadrupole ICP-MS, Agilent Technologies, Santa Clara, CA, USA); the detailed information of metal determination was presented elsewhere (Anual et al., 2021; Lozano et al., 2022). The blanks for the analysis were prepared with 2% nitric acid. The limits of detection (LOD) of Ni, Cd, Hg, and Pb were 0.2, 0.04, 0.04, and 0.2 $\mu\text{g/L}$, respectively. To correct the impact of variation in urine dilution, heavy metal levels in urine samples were adjusted by their respective creatinine levels. The urinary creatinine levels were measured by Reagents Sistema ADVIA 1800 Chemistry and Sistema ADVIA 2400 Chemistry (Warren et al., 2014). Urinary metal concentrations were expressed for descriptive purposes in $\mu\text{g/g}$ of creatinine to control for differences in urine dilution (Lozano et al., 2022).

2.4. Industrial activity assessment

The locations (latitude and longitude) of all the industries in the province of Tarragona that had the potential of releasing Ni, Cd, Hg, and

Pb were acquired by accessing the Spanish Register of Emissions and Pollutant Sources (<https://prtr-es.es/>) and classified into 5 industrial categories: “chemical”, “energy”, “mineral”, “metal processing”, and “waste management”. The latitude and longitude of all selective industries were converted to the UTM reference frame. Finally, UTM of all related industries and residential addresses of enrolled pregnant women were imported into QGIS software (QGIS Desktop 3.22.11). Buffer zones were established with a 1.5 km, 3 km, and 5 km radius at the center of each industry. Subsequently, the location and count of homes where pregnant women were living, inside and outside each buffer zone, were recorded.

2.5. Statistical analysis

To describe the population, categorical variables were expressed as numbers (%) and quantitative variables as mean \pm standard deviation (SD) and median (95% confidence interval (CI)). Because the distribution of urinary heavy metal concentrations was not normally distributed, the geometric mean and median of unadjusted and creatinine-adjusted urinary heavy metal concentrations were estimated. To

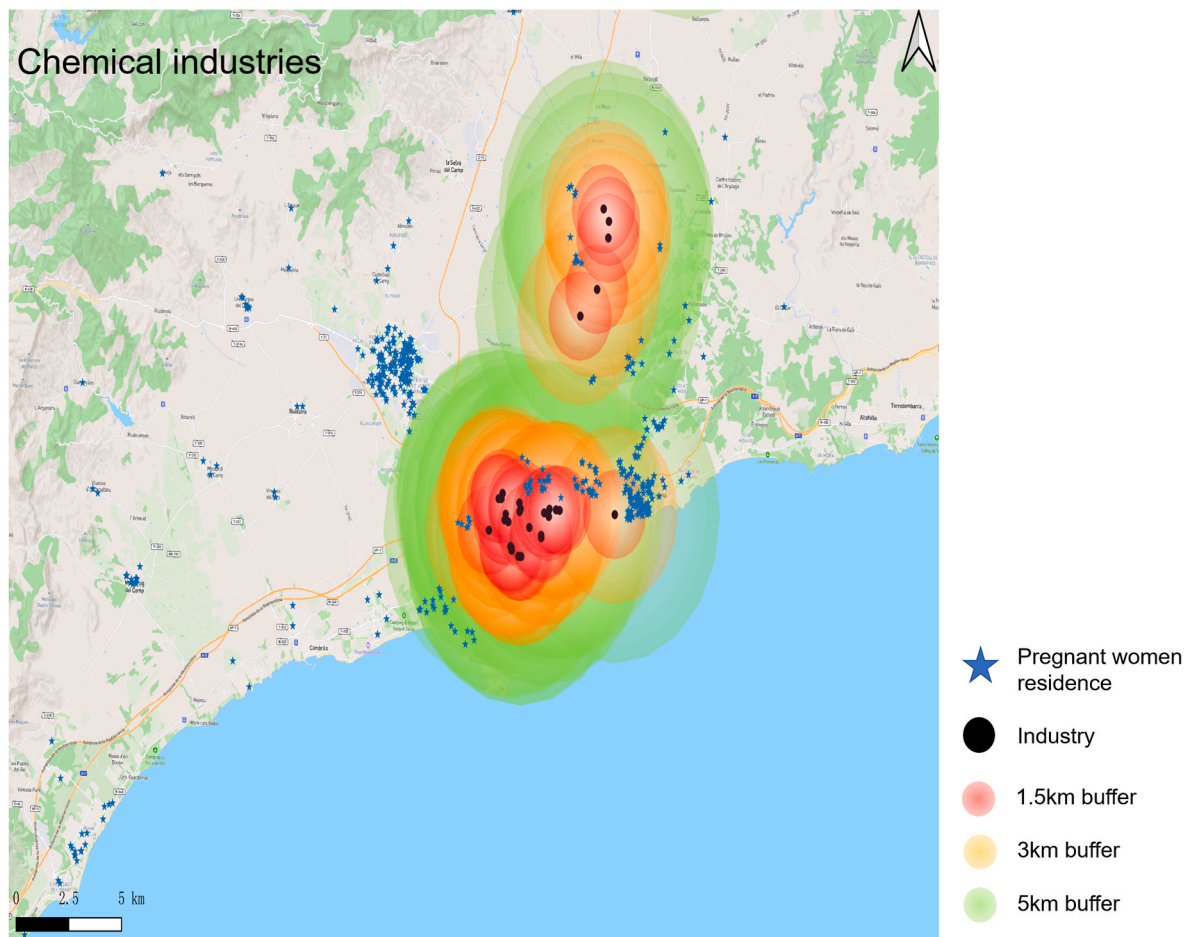


Fig. 2. Distribution of pregnant women residences and buffer zones within a 1.5 km, 3 km, and 5 km radius at the center of chemical industries in Tarragona.

understand the relationship between urinary creatinine-adjusted heavy metal concentrations and industrial activity, the Student's T-test was used to compare the averages among pregnant women living near different types of industry at different distances. Multiple linear regression models were applied to explore the correlation between urinary creatinine-adjusted heavy metal concentrations with industry type, sociodemographic characteristics, and lifestyles under industry buffers of 1.5, 3, and 5 km. The analyses were conducted by QGIS software (QGIS Desktop 3.22.11) and SPSS v28.0 (IBM Corp., USA).

3. Results

3.1. Basic characteristics of pregnant women

Among 368 pregnant women from ECLIPSES, there were 43 (11.7%), 82 (22.3%), and 243 (66.0%) women aged <25, 25–29, and >29 years, respectively. Meanwhile, the mean (\pm standard deviation) baseline pregnancy body mass index was 24.88 (4.33) kg/m². Regarding education status, 100 (27.2%), 130 (35.3%), and 138 (37.5%) women possessed primary studies, secondary studies, and university studies, respectively. In terms of smoking status, 260 women (70.7%) had never smoked, while the remaining 108 women (29.3%) were smokers or ex-smokers. As for the Mediterranean diet adherence score (rMedDiet), there existed 123 (33.4%) women with a low score and 245 (66.6%) women with a medium-high score (Table 1).

3.2. Heavy metals concentrations and distributions of pregnant women

The concentrations of unadjusted and creatinine-adjusted heavy

metals among pregnant women were summarized in Table 2. The geometric mean (GM) (interquartile range) of creatinine-adjusted levels of Ni, Cd, Hg, and Pb were 1.63 (1.33), 0.22 (0.20), 0.48 (0.66), and 0.27 (0.54) μ g/g of creatinine, respectively.

3.3. Change of heavy metals in different industry types with different distances among pregnant women

The location of Tarragona in Spain was presented in Fig. 1. Pregnant women's residences and buffer zones within a 1.5 km, 3 km, and 5 km radius from chemical industries (Fig. 2), energy industries (Fig. 3), mineral industries (Fig. 4), metal processing industries (Fig. 5), and waste management industries (Fig. 6) were depicted. Heavy metals concentrations among pregnant women living within the buffer and those living outside of the buffer were compared.

The T-test analysis showed that Ni mean concentrations were higher in pregnant women living within 1.5 km of chemical industries ($P = 0.015$), within 5 km of energy industries ($P = 0.039$), and within 1.5 km of metal processing industries ($P = 0.020$) compared to those living outside of the same type industries with the same distance. Moreover, Cd mean concentration was higher in pregnant women living within 1.5 km ($P = 0.041$) and 3 km ($P = 0.018$) of chemical industries, within 5 km of energy industries ($P = 0.042$), within 3 km ($P = 0.042$) and 5 km ($P = 0.042$) of metal processing industries compared to those living outside of the same type industries with the same distance. Furthermore, Pb concentrations were only increased in pregnant women living within 5 km of waste management industries compared to those living outside of the same type of industries within the same distance ($P = 0.016$). Finally, urinary levels of Hg did not significantly differ, regardless of the home's

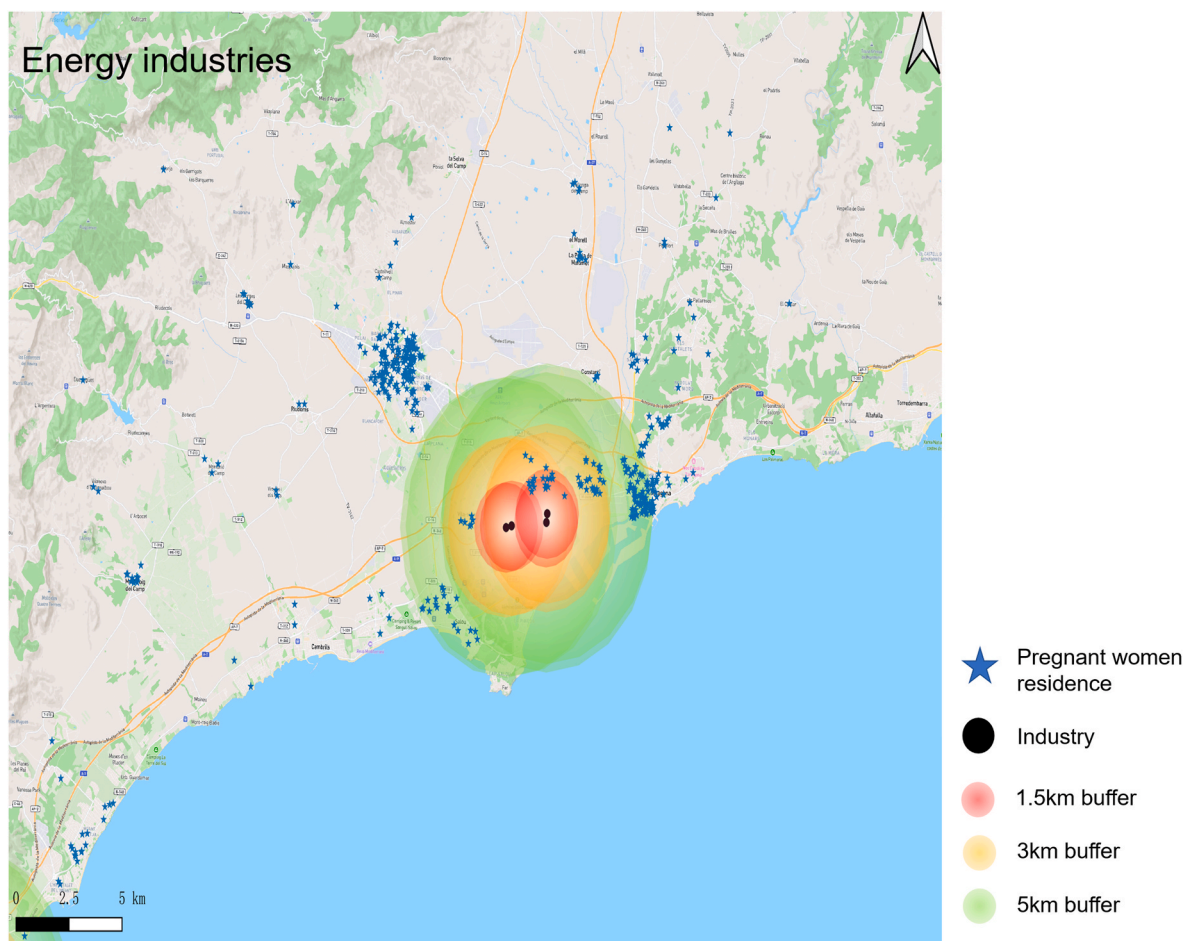


Fig. 3. Distribution of pregnant women residences and buffer zones within a 1.5 km, 3 km, and 5 km radius at the center of energy industries in Tarragona.

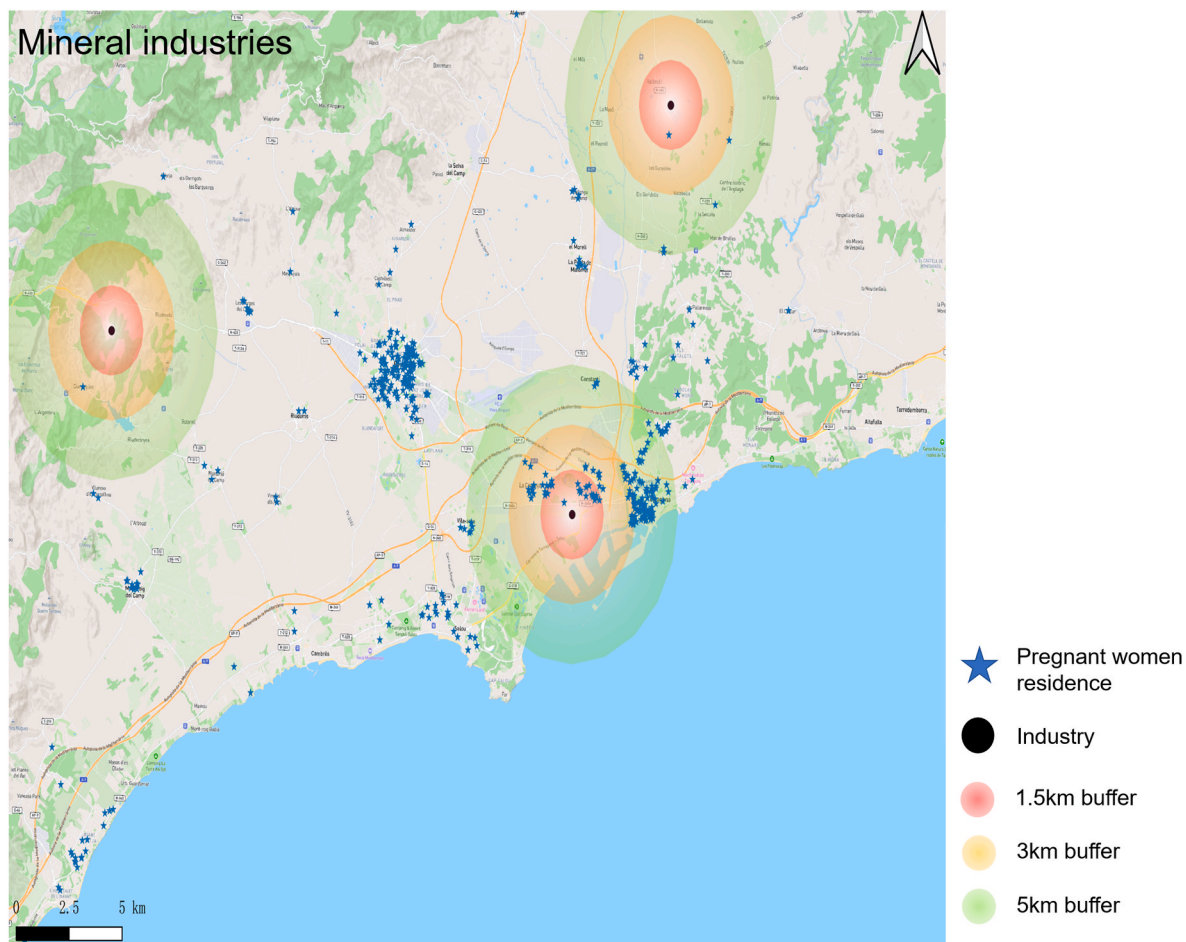


Fig. 4. Distribution of pregnant women residences and buffer zones within a 1.5 km, 3 km, and 5 km radius at the center of mineral industries in Tarragona.

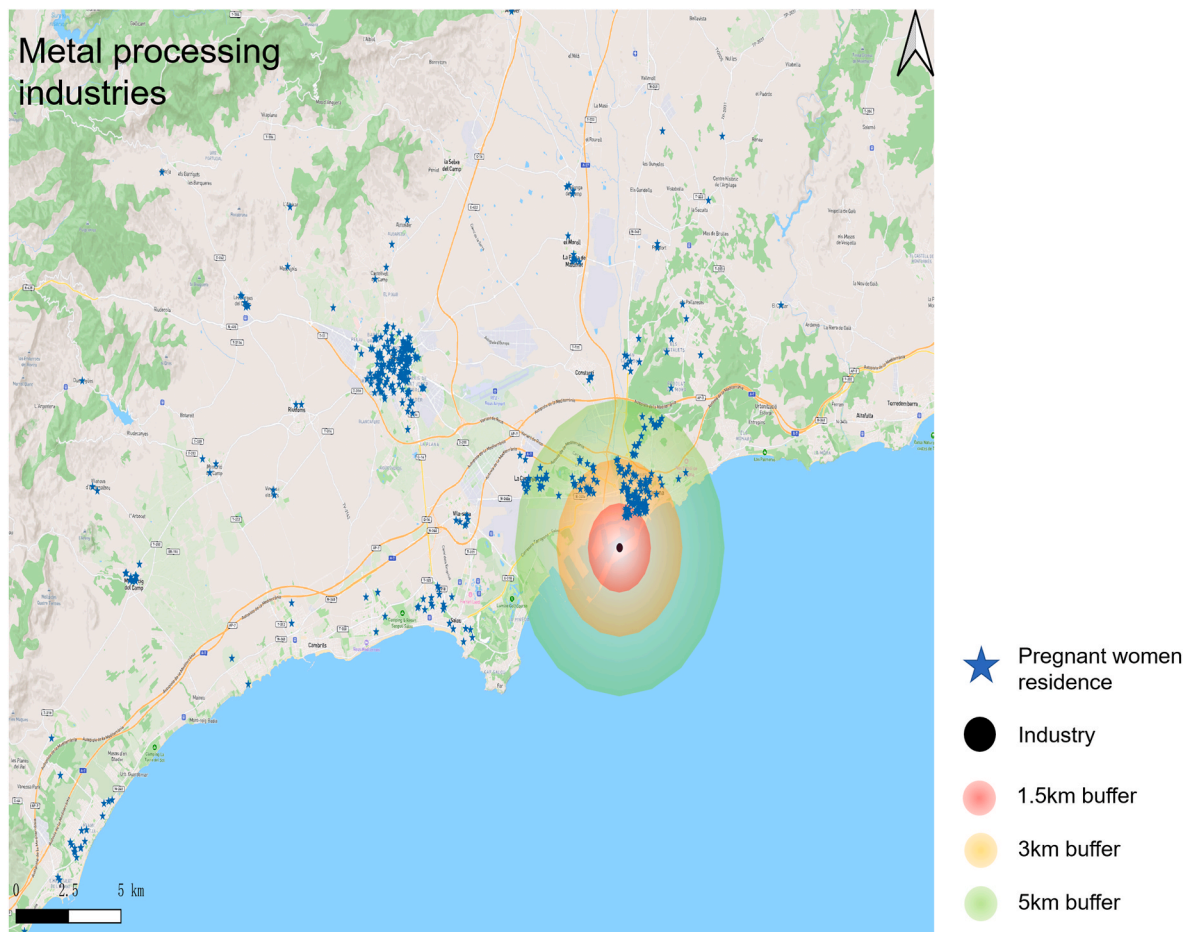


Fig. 5. Distribution of pregnant women residences and buffer zones within a 1.5 km, 3 km, and 5 km radius at the center of metal processing industries in Tarragona.

location in relation to any industry type ($P > 0.05$) (Table 3). Considering that Ni and Cd concentrations were significantly increased in pregnant women living near many of the industries, these two heavy metals were selected for further analysis.

3.4. Factors affecting the Cd concentration among pregnant women

To explore the role of many associated factors, a multiple linear regression analysis was conducted for Ni and Cd. The levels of Cd were increased in women living within 1.5 km and 3 km of chemical industries, within 5 km of energy industries, within 1.5 km, 3 km, and 5 km of mineral industries, and within 3 km and 5 km of metal processing industries. Furthermore, urinary Cd concentration was also affected by age, smoking, and education level (all $P < 0.05$) (Table 4). On the other hand, after exploring the correlation between Ni concentration and the outcome variables using multiple linear regression, the concentration of Ni did not have a substantial or significant impact on the outcome variables.

4. Discussion

Different industrial activities are important emission sources of heavy metals to the environment. Tarragona has a long history of industrial activity (Domínguez-Morueco et al., 2017, 2019), supposing a long-lasting influence on heavy metal pollution (Nadal et al., 2004, 2006). Human exposure to heavy metals takes place through different pathways (e.g., diet, air inhalation, etc.) (Kladsomboon et al., 2020; Rahman and Singh, 2019). Pregnant women is a particularly fragile group, as not only themselves but also their offspring face the adverse

health effects caused by exposure to heavy metals (Gómez-Roig et al., 2021; Sabra et al., 2017). Based on the above-mentioned information, the exploration of heavy metals exposure among pregnant women according to different industry types and distances in Tarragona is crucial.

Nickel, Cd, Hg, and Pb, all detrimental heavy metals even in a low concentration (Rahman and Singh, 2019), were detected in urinary samples in our studied pregnant women. Interestingly, in the current study, increases in urinary Ni and Cd concentration were found for pregnant women living nearer to industrial areas compared to those residing farther. Differences according to the type of industry were also noted. This finding was consistent with the results of previous studies, which have shown that populations in the vicinity of industrial sites are exposed to heavy metal contamination to a greater extent than those located far from industrial areas (Jo et al., 2021; Kim et al., 2017; Xu et al., 2022). The mean urinary Ni level (GM: 1.63 $\mu\text{g/g}$) was comparable to those found previously in pregnant women living in the similar industrialized Spanish cities of Valencia, Gipuzkoa, Sabadell, and Reus (ranging from 1.58 to 1.7 $\mu\text{g/g}$) (Bocca et al., 2020; Lozano et al., 2022). In turn, our urinary Ni values were clearly lower than those reported in several industrial cities of China, such as Wuhan, Macheng, and Ezhou (2.76 $\mu\text{g/g}$) (Sun et al., 2018). A similar trend was noted for Cd, as the current urinary Cd concentration (GM: 0.22 $\mu\text{g/g}$) was similar to those previously found in the same aforementioned Spanish industrialized cities (0.28 $\mu\text{g/g}$) but higher than those found in pregnant women participating in the New Hampshire Birth Cohort Study (0.005 $\mu\text{g/g}$) (Lozano et al., 2022; White et al., 2018). These differences might be caused by demographics, lifestyle, diet, different industry types around the residence, and living distance from industries. The fact that so few studies have focused on Spanish pregnant women as a study group and

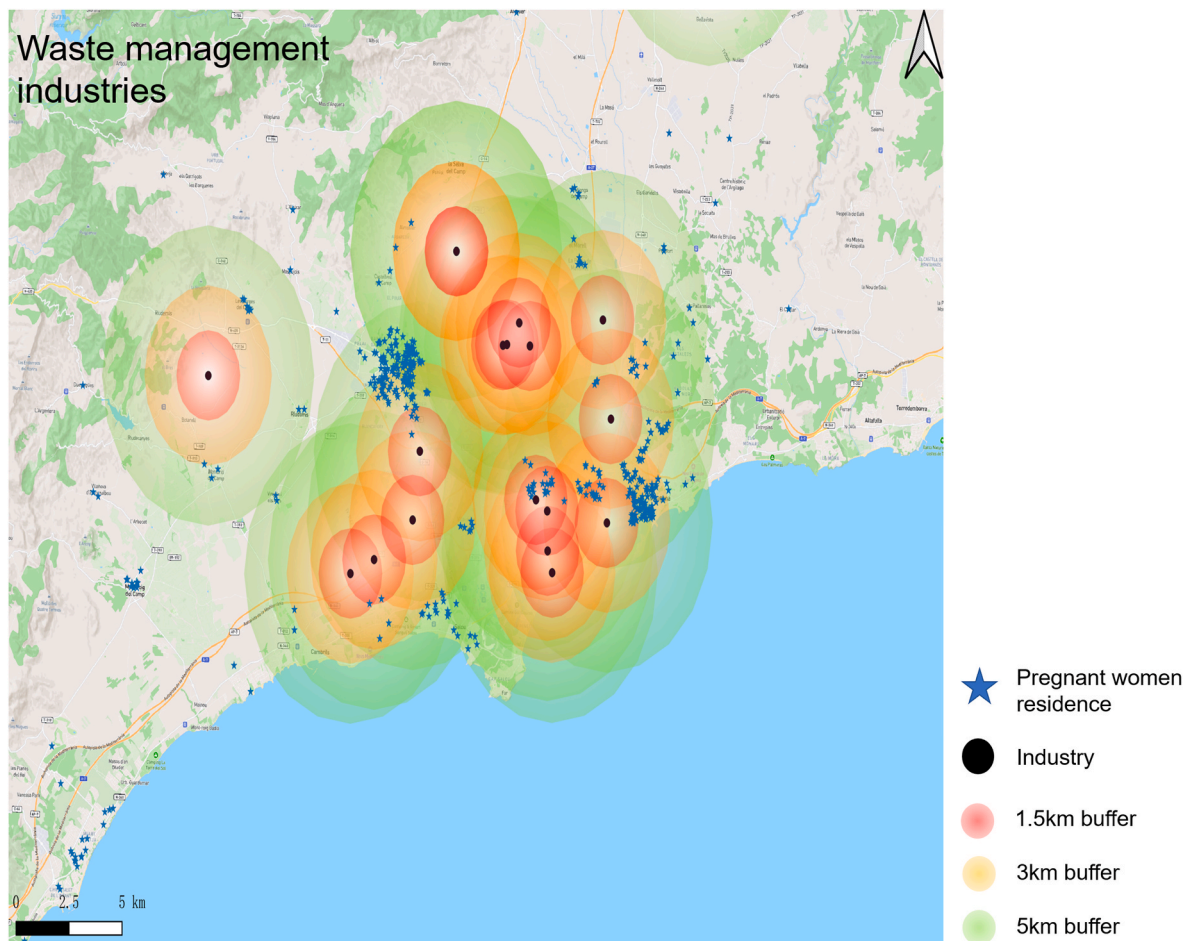


Fig. 6. Distribution of pregnant women residences and buffer zones within a 1.5 km, 3 km, and 5 km radius at the center of waste management industries in Tarragona.

that no prior research has examined the various industrial activities makes it challenging to completely compare the current results to earlier findings. Compared to the general population, our Ni concentration was lower than that in Malaysian (4.37 $\mu\text{g/g}$) while our Cd level was comparable to their data (0.32 $\mu\text{g/g}$) (Anual et al., 2021); meanwhile, Ni and Cd concentrations in the current study were similar to those population living in France (Ni: 2.00 $\mu\text{g/g}$ and Cd: 0.37 $\mu\text{g/g}$) (Nisse et al., 2017). Nevertheless, data on urinary metal concentrations in the general population of Tarragona are very scarce. However, an important reduction has been noted when comparing the current results with previous information on the baseline levels of Ni and Cd in urine from workers of the hazardous waste incinerator of Constantí (Tarragona), before starting its operations. Arithmetic mean concentrations of Ni and Cd in urine from those workers were 14.8 and 0.45 $\mu\text{g/g}$ of creatinine, respectively (Domingo et al., 2001). This temporal trend is also in agreement with the reduction of Cd found in samples of autopsy tissues from subjects who had been living in the same area of study (García et al., 2020).

Only urinary Cd concentrations continued to differ obviously by industry activity after accounting for possible covariates. It might be

caused by the fact that emission limits are not the same for the four heavy metals, so emissions may notably differ (Kim et al., 2017; Poznanović Spahić et al., 2019). The half-life period of Cd is long, being able to remain in the human body for 26 years or longer (Xiao et al., 2021). It has been reported that the threshold limit of urinary Cd is 5.24 $\mu\text{g/g}$ creatinine in the general population (Satarug et al., 2020); nevertheless, even very low Cd concentrations (from 0.22 to 0.55 $\mu\text{g/g}$ creatinine) can affect the reproductive system of pregnant women, with abnormal birth anthropometrical and neurodevelopment outcomes among their offspring (Forns et al., 2014; Kipler et al., 2012; Politis et al., 2022; Yang et al., 2016). Thus, the exploration of related factors affecting urinary Cd concentration among pregnant women is extremely crucial. In the present study, we found that Cd concentration presented an increased trend along with living nearer (from 5 km to 1.5 km) to chemical industries, energy industries, mineral industries, and metal processing industries but not waste management industries. The potential explanation of no difference was found in Cd levels between living in a 1.5 km buffer and outside that radius in pregnant women living from energy industries and metal processing industries might be

Table 3
Differences in the levels of heavy metals in urine from pregnant women living inside and outside buffer zones according to the kind of industry types.

	Buffer distance [N (%)]	Ni						Cd						Hg						Pb					
		Inside buffer			Outside buffer			Inside buffer			Outside buffer			Inside buffer			Outside buffer			Inside buffer			Outside buffer		
		GM	IQR	P	GM	IQR	P	GM	IQR	P	GM	IQR	P	GM	IQR	P	GM	IQR	P	GM	IQR	P	GM	IQR	P
Chemical industry	1.5 km [78 (21.2%)]	1.88	1.48	1.57	1.30	0.015	0.25	0.21	0.21	0.19	0.041	0.52	0.61	0.47	0.70	0.395	0.33	0.68	0.25	0.53	0.176	0.25	0.68	0.33	0.395
	3 km [149 (40.5%)]	1.68	1.36	1.58	1.31	0.224	0.24	0.20	0.20	0.20	0.018	0.53	0.65	0.46	0.66	0.197	0.27	0.55	0.26	0.55	0.815	0.26	0.55	0.27	0.197
	5 km [186 (50.5%)]	1.67	1.45	1.59	1.23	0.522	0.23	0.19	0.20	0.21	0.084	0.49	0.66	0.47	0.65	0.705	0.24	0.50	0.29	0.56	0.239	0.29	0.50	0.24	0.705
Energy industry	1.5 km [14 (3.8%)]	1.42	1.49	1.63	1.33	0.466	0.17	0.15	0.22	0.20	0.212	0.52	0.55	0.48	0.66	0.768	0.18	0.72	0.27	0.54	0.322	0.27	0.54	0.18	0.72
	3 km [48 (13.0%)]	1.55	1.17	1.64	1.34	0.665	0.23	0.23	0.21	0.20	0.616	0.40	0.58	0.49	0.69	0.226	0.24	0.66	0.27	0.53	0.621	0.27	0.53	0.24	0.226
	5 km [112 (30.4%)]	1.83	1.38	1.55	1.32	0.039	0.24	0.20	0.21	0.20	0.042	0.54	0.73	0.46	0.60	0.151	0.28	0.60	0.26	0.50	0.800	0.26	0.60	0.28	0.151
Mineral industry	1.5 km [17 (4.6%)]	1.57	1.07	1.63	1.35	0.823	0.25	0.40	0.21	0.20	0.277	0.32	0.58	0.49	0.65	0.076	0.26	0.63	0.27	0.55	0.919	0.27	0.63	0.26	0.076
	3 km [52 (14.1%)]	1.84	1.74	1.60	1.31	0.183	0.24	0.18	0.21	0.20	0.250	0.47	0.69	0.49	0.66	0.755	0.22	0.62	0.28	0.53	0.322	0.28	0.62	0.22	0.755
	5 km [145 (39.4%)]	1.61	1.35	1.64	1.30	0.788	0.24	0.21	0.20	0.20	0.033	0.49	0.65	0.48	0.67	0.758	0.26	0.50	0.27	0.56	0.719	0.27	0.50	0.26	0.758
Metal processing industry	1.5 km [12 (3.3%)]	2.59	1.38	1.61	1.31	0.020	0.24	0.16	0.21	0.20	0.570	0.42	0.58	0.49	0.66	0.610	0.57	0.86	0.26	0.54	0.086	0.26	0.57	0.57	0.610
	3 km [92 (25.0%)]	1.78	1.41	1.58	1.13	0.159	0.26	0.22	0.20	0.19	0.002	0.50	0.72	0.48	0.59	0.783	0.26	0.59	0.27	0.54	0.855	0.27	0.59	0.26	0.783
	5 km [129 (35.1%)]	1.64	1.48	1.63	1.25	0.938	0.24	0.20	0.20	0.20	0.021	0.50	0.70	0.47	0.60	0.586	0.25	0.57	0.28	0.52	0.450	0.28	0.57	0.25	0.586
Waste management industry	1.5 km [47 (12.8%)]	1.73	1.95	1.62	1.28	0.556	0.25	0.21	0.21	0.20	0.139	0.43	0.55	0.49	0.67	0.357	0.24	0.56	0.27	0.55	0.552	0.27	0.56	0.24	0.357
	3 km [221 (60.1%)]	1.65	1.41	1.61	1.28	0.771	0.22	0.19	0.21	0.21	0.643	0.48	0.66	0.49	0.68	0.910	0.26	0.59	0.27	0.49	0.797	0.27	0.59	0.26	0.910
	5 km [333 (90.5%)]	1.66	1.34	1.38	1.07	0.143	0.22	0.19	0.21	0.25	0.821	0.49	0.66	0.44	0.62	0.534	0.26	0.52	0.41	0.57	0.016	0.41	0.52	0.26	0.534

[N (%), number and percentage of women inside the buffer distance; GM, geometric mean; IQR, interquartile range; Ni, nickel; Cd, cadmium; Hg, mercury; Pb, lead.

due to the small sample size in 1.5 km buffer (n = 14 in energy industries and n = 12 in metal processing industry). Meanwhile, no correlation was found between Cd and waste management industries, despite the area being affected by the emissions of a municipal solid waste incinerator and a hazardous waste incinerator.

Maternal age and smoking were linked with increased urinary Cd concentrations. In contrast, the maternal education level was related to reduced Cd concentrations, which is partly consistent with previous studies (Jo et al., 2021; Wang et al., 2019). The reasons for this finding could be several. For instance, (1) Cd concentration in the body is continuously accumulated over time, and it leads to a higher Cd concentration in older women; (2) according to the US Food and Drug Administration, Cd is a constituent in tobacco products, so increased Cd burdens are expected in pregnant women who smoke or are ex-smokers compared to those who never smoke (Chang et al., 2017); and/or (3) pregnant women with a higher education level may have more awareness against environmental pollution and they tend to live and work in a healthier environment.

As one of its strengths, the present study owned important public health implications: pregnant women living in an industrial complex area were exposed to higher levels of Cd, leading to an increased body burden of this element. Therefore, their health status and the development of their children should be particularly monitored, and public health measures should be implemented to guarantee that the existence of these industries did not have a negative impact on their health. Nevertheless, there existed some limitations. According to the industries, three different buffer zones were taken into consideration; nonetheless, pregnant women might spend a big amount of time beyond the buffer zone on a regular basis. It was challenging to compare the results with earlier data from the scientific literature because urine was rarely utilized as a monitor to evaluate Pb exposure. Finally, it must be considered that food is a main source of heavy metal exposure, and only information on the rMedDiet score was provided. Consequently, the effect of more specific diet patterns on the body burdens of heavy metals should be investigated.

In conclusion, residential distance from industries that produce chemicals, energy, minerals, and metals has diverse effects on the body burdens of Cd among pregnant women. This emphasizes the necessity of continuing to increase awareness among industrial sources, with a focus on the creation of legislative measures to reduce the release of heavy metals and other dangerous chemical pollutants.

Credit author statement

Xiruo kou: Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Lucía Iglesias-Vázquez:** Conceptualization, Methodology, Investigation, Writing – review & editing. **Martí Nadal:** Investigation, Writing – review & editing. **Josep Basora:** Investigation, Writing – review & editing. **Victoria Arija:** Conceptualization, Data curation, Writing – review & editing, Funding acquisition, Project administration, Resources, Supervision

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Ethics approval

The study was designed in agreement with the Declaration of Helsinki/Tokyo. All procedures involving human subjects were approved by Clinical Research Ethics Committee of the Jordi Gol University Institute for Primary Care Research [Institut d' Investigació en Atenció Primària; IDIAP], the Pere Virgili Health Research Institute [Institut d' Investigació Sanitària Pere Virgili; IISPV] and of the Spanish Agency for Medicines

Table 4
Multiple linear regression for factors affecting Cd.

Cd																		
Industry type	Chemical industry			Energy industry			Mineral industry			Metal processing industry			Waste management industry					
Factors	Buffer distance																	
	1.5 km			3 km			5 km			1.5 km			3 km			5 km		
	β	β	β	β	β	β	β	β	β	β	β	β	β	β	β			
	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p			
Buffer																		
Out of buffer	Reference			Reference			Reference			Reference			Reference					
In the buffer	0.05	0.04	0.01	-0.03	0.05	0.05	0.09	0.05	0.04	-0.01	0.06	0.04	0.05	0.01	0.01			
	0.015	0.015	0.841	0.489	0.115	0.011	0.028	0.058	0.029	0.909	0.003	0.020	0.074	0.804	0.811			
Age (years)																		
<25	Reference			Reference			Reference			Reference			Reference					
25-29	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.05	0.05			
	0.068	0.07	0.108	0.117	0.081	0.058	0.057	0.079	0.07	0.108	0.078	0.083	0.102	0.104	0.108			
>29	0.13	0.13	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.13	0.13	0.12	0.12			
	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001			
rMedDiet score																		
Low	Reference			Reference			Reference			Reference			Reference					
Middle-high	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01			
	0.580	0.791	0.692	0.690	0.733	0.737	0.595	0.635	0.709	0.72	0.668	0.615	0.609	0.684	0.676			
Smoking																		
No smoker	Reference			Reference			Reference			Reference			Reference					
Ex-smoker or Smoker	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08			
	0.003	0.003	0.002	0.002	0.002	0.002	0.003	0.002	0.003	0.002	0.002	0.002	0.001	0.002	0.002			
Education level																		
Primary studies	Reference			Reference			Reference			Reference			Reference					
Secondary studies	-0.05	-0.06	-0.06	-0.06	-0.05	-0.06	-0.05	-0.06	-0.06	-0.06	-0.06	-0.06	-0.05	-0.06	-0.06			
	0.019	0.015	0.015	0.016	0.017	0.011	0.021	0.016	0.014	0.016	0.014	0.010	0.021	0.015	0.012			
University studies	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07			
	0.003	0.002	0.002	0.003	0.003	0.002	0.004	0.002	0.002	0.002	0.002	0.002	0.004	0.002	0.002			

Cd, cadmium; rMedDiet, Mediterranean diet.

and Medical Devices [Agencia Española del Medicamento y Productos Sanitarios; AEMPS]. Signed informed consent was obtained from all women participating in the study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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