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ORIGINAL ARTICLE

High variability of mercury content in the hair of Russia Northwest population: the role of the environment and social factors

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Abstract

Purpose The purpose of this work is to study mercury levels in the hair of different social and demographic groups of the population of the Vologda region in Northwest Russia. This region is selected due to a heterogeneous distribution of rivers and lakes—a resource base for fishing.

Methods The mercury content was determined in the hair from the root with a length of about 2 cm. The concentration of total mercury in human hair was determined by the atomic absorption method without preliminary sample preparation using an RA-915M mercury analyzer and a PYRO-915 + pyrolysis unit.

Results The average level of mercury in the human hair was 0.445 µg/g (median 0.220 µg/g). The concentration of mercury in the hair of people older than 44 years (0.875 µg/g) was three times higher than in the hair of children under 18 years of age (0.270 µg/g). People who eat fish less than once per month had a hair mercury concentration of 0.172 µg/g, for 1–2 times a month 0.409 µg/g, once a week 0.555 µg/g, and several times a week 0.995 µg/g. The concentration of mercury in the hair of smokers (0.514 µg/g) was higher than in the hair of non-smokers (0.426 µg/g).

Conclusion Significantly higher concentrations of mercury were observed in the hair of participants from the western part of the region, where reservoirs are the main commercial sources of fish products. The data showed that the main source of people's mercury intake was fish.

Keywords Mercury · Hair · Fish consumption · Age · Smoking status · Northwest Russia

Introduction

Mercury (Hg) is a global pollutant (Driscoll et al. 2013). The main sources of the element in the atmosphere are emissions from natural sources (weathering of rocks, volcanic eruptions, and geothermal sources) as well as anthropogenic emissions (combustion of coal and other fossil fuels, production of non-ferrous metals and cement, artisanal and small-scale gold mining) (Pacyna et al. 2006; UNEP 2008, 2013; Sundseth et al. 2017). Most of the mercury emissions into the environment are elemental mercury gas (Hg) (Sprovieri et al. 2016, 2017; Travnikov et al. 2017). The global distribution of mercury is associated with its volatility and long residence time in the atmosphere (Lindberg et al. 2007). Mercury and its compounds are found in water bodies remote from industrial sources (Haines et al. 1995; AMAP 2008; Horowitz et al. 2014; Pacyna et al. 2016; Cohen et al. 2016; Sprovieri et al. 2016, 2017; Travnikov et al. 2017).

Mercury is a highly toxic metal for all living organisms (Clarkson and Magos 2006; Dietz et al. 2013; Ivanova et al. 2021; Porcella 1994) and it has unique physicochemical properties that lead to a higher degree of bio-magnification compared with other heavy metals (AMAP 2003). The negative impact of mercury on the human body has been studied in detail. Mercury has an adverse effect on the liver and kidneys (WHO 2007). Mercury compounds can pass through the placental barrier (Clarkson 2002) and have a negative impact on the development of the nervous system in the fetus (Grandjean and Landrigan 2014). Therefore, it is believed that mercury is a neurotoxin for a living organism (Rodier 1995; Andersen et al. 2000; Blake 2004). Even low doses of mercury compounds can cause a violation of brain function, probably the occurrence of neuropsychological disorders in

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the field of speech, attention and memory, and motor functions (Grandjean and Landrigan 2006). Mercury compounds are highly neurotoxic (Thapa et al. 2014).

Mercury has a high affinity for sulfhydryl groups, amino acids, and enzymes (WHO 1990; Salonen et al. 1995, 2000). Due to the physical and chemical properties of mercury, there is an increase in oxidative stress, which leads to cardiovascular diseases and cerebrovascular accident (CVA) or stroke (Salonen et al. 1995; Yoshizawa et al. 2002; Houston 2011; Dórea 2020). A study conducted in Finland found that among men with mercury levels in their hair > 2.0 µg/g, CHD (Coronary heart disease) and MI (Myocardial infarction) risks were increased two-fold, and cardiovascular death increased by 2.9 times (Salonen et al. 1995; Hu et al. 2020).

The main source of mercury in the human body is seafood derived from marine and freshwater fish (EFSA 2012; WHO 1990; Mozaffarian and Rimm 2006; Sheehan et al. 2014; USEPA 1997; Hightower and Moore 2003; Horvat et al. 2012; Rose et al. 2015; Tong et al. 2017) and also rice (Li et al. 2010; Zhao et al. 2016; Du et al. 2020). Rice plantations predominate in Asia among agricultural land (FAOSTAT 2020). In the Russian Federation, rice consumption is much lower (FAOSTAT 2020). Fish is the most prominent source of mercury in Russia for the human population. In Russia, including in the Vologda Region, as well as in Europe and the United States, high concentrations of mercury have been recorded in fish from lakes with a pH level below 5.0 (Haines et al. 1995; Nemova et al. 2000; Spry and Wiener 1991). In 2017, Russians consumed, on average, 21.5 kg of fish and fish products (ROSSTAT 2017) while residents of the Vologda region, on average, consumed 23.3 kg (ROSSTAT 2017). More than 90% methylmercury (MeHg) of the total mercury (THg) is found in fish muscles (US EPA 2010; Li and Cai 2013; Lavoie et al. 2013; Finley et al. 2016; Dusek et al. 2005). Ninety-five percent of the MeHg contained in the muscles of fish is absorbed in the human intestinal tract during digestion (WHO 2007). It is redistributed to organs and tissues, including keratinized ones (Clarkson and Magos 2006). The levels of mercury in hair correlate with the concentrations of mercury in the blood (Berglund et al. 2005; Díez 2008; Horvat et al. 2012). Therefore, in recent decades, the determination of mercury in hair has been widely used to assess mercury intake in the human body (UNEP 2008). In hair, the content of methylmercury usually reaches 90% of THg (Berglund et al. 2005; Brodzka and Trzcinka-Ochocka 2009).

In different countries, regulation based on hair mercury content differs. The FAO (Food and Agriculture Organization)/WHO (World Health Organization) Expert Committee on Food Additives (JECFA) has proposed a recommended value of 2.3 µg/g of mercury in hair (WHO 2015). The permissible biological level of mercury in the hair of the population of the Russian Federation who do not have professional contact with this metal is 5 µg/g (Criteria for 1992). The US Environmental Protection Agency (US EPA) has established the recommended level of mercury in hair to be < 1 µg/g, which corresponds to the permissible intake dose (RFD) of 0.1 mcg/kg of body weight per day (NRC 2000). At the same time, the recommended reference value of 0.58 µg/g was established for women of reproductive age (Bellanger et al. 2013).

Mercury accumulation in biotic and abiotic components of biosystems has been studied in the Vologda Oblast for the last 25 years (Ivanova et al. 2020; Khabarova et al. 2018; Komov et al. 2004, 2016). Both in the Vologda region and Russia as a whole, works on the analysis of mercury in human hair are rare (Aleksina and Komov 2020; Ivanova et al. 2021; Shuvalova et al. 2018; Rumiantseva et al. 2018).

The purpose of this work is to study mercury levels in the hair of different social and demographic groups of the population of the Vologda region in Northwest Russia. This region is selected due to a heterogeneous distribution of rivers and lakes—a resource base for fishing. There is a traditionally high level of consumption of wild fish by residents. Quite often there is high mercury content in the muscles of local fish in local water bodies while the issue of mercury intake by the population is not sufficiently studied.

Materials and methods

Collection area

The study was conducted in the Vologda region (northwestern part of European Russia). The Vologda region encompasses 145,700 km^2, or 1% of the territory of Russia; the greatest distance from north to south is 385 km and from west to east 650 km (58° 27′ and 61° 36′ N; 34° 42′ and 47° 10′ E) (The environment 2007). The population in this vast region does not exceed 1.2 million and is unevenly distributed. More than half of the population lives in cities and surrounding villages (764,310 people). The most populated cities are Cherepovets and Vologda, with 300,000–320,000 people each. The rural population is significantly smaller with about 207,000 living in the eastern districts and 216,000 in the western districts (The summary 2017).

Within the Vologda region, there are many rivers and lakes suitable for fishing. The number of lakes with an area of more than 1 km^2 exceeds 4000 with most located in the western districts, where lakes occupy 4% of the territory; in the catchment areas, swamps and waterlogged forests occupy more than 20% of the area. In the eastern districts, lakes and swamps make up less than 1% of the area, but the number of rivers and streams is greater than in the western districts (Antipov 1981; The environment 1957).

Data collection

The study involved 1643 volunteers for the period from 2016 to 2017. Samples of human hair in the form of a strand of several millimeters thickness were removed from the back of the head. This procedure was conducted according to WHO recommendations, using stainless steel surgical scissors. The mercury content was determined in the hair from the root with a length of about 2 cm (UNEP 2008). The hair samples were packed in an individual paper envelope and stored in a plastic bag at room temperature (UNEP 2008). The entire sample of collected hair samples consisted of three cohorts: urban population (numbers of large cities and districts from 1 to 5), rural population of the western part of the region (numbers of districts from 6 to 15), and rural population of the eastern part of the region (16–24) (Fig. 1, SM Table S1).

The study involved 502 men and 1135 women aged from 1 to 84 years, which represents 0.14% of the population of the Vologda Oblast [urban population 0.13% ($n = 958$); rural population of the east 0.16% ($n = 327$); rural population of the west 0.17% ($n = 358$)]. Each participant completed a questionnaire to indicate their gender, age, place of residence, frequency of fish consumption, the amount of fish consumed per month (g/month), smoking status (details in the supplement Fig. S1). The age group division followed WHO recommendations (WHO 1963) with the difference that the older age group consisted of people over 45 years: Group 1: < 18 years; Group 2: 18–29 years; Group 3: 30–44 years; Group 4: ≥ 45 years. Fish consumption was classified by frequency: less than once per month, 1–2 times per month, once per week, and several times per week. The frequency of consumption was obtained from the questionnaire data. The participant indicated the approximate amount of servings of fish (one fish portion is 150–200 g) consumed per month (g/month). The participants also answered the question about the current smoking status (smoker/non-smoker).

For participants under the age of 18, parental permission was requested. This study was performed in accordance with the World Medical Association (WMA) Declaration of Helsinki: ethical principles for medical research involving human subjects (WMA 2008). The program of this study was discussed and approved by the Bioethics Commission of Cherepovets State University and the Territorial Department of Health of the Vologda Oblast (No. 2-1/55).

Material handling

The concentration of total mercury in human hair was determined by the atomic absorption method without preliminary sample preparation (Sholupov et al. 2004) using an RA-915M mercury analyzer and a PYRO-915 + pyrolysis unit (Lumex Ltd., St. Petersburg, Russia). The accuracy of the analytical procedures employed for the

Fig. 1 Map-scheme of the Vologda region with numbered districts

analysis of the Hg concentrations was checked using the certified reference materials DORM – 4 (Hg concentration is 0.412 ± 0.036 μg/g) and DOLT – 5 (Hg concentration is 0.44 ± 0.18 μg/g) from the National Research Council Canada (NRCC), obtaining recovery of 93.0 ± 2.3% and 84.0 ± 3.9%, respectively. The detection limit is 0.002 μg/g.

Statistical processing

The total sample was checked for normality using the Shapiro–Wilk test and Kolmogorov–Smirnov test for Normality. Due to the lack of normality of the distribution, non-parametric methods were used. To compare two independent samples, the Mann–Whitney *U* test was used; for three or more independent samples, the Kruskal–Wallis test was used with a significance level (p) less than 0.05. To establish the correlation dependencies, the Spearman's rank correlation coefficient was used at $p < 0.05$ (Sokal and Rolhf 1995). For the possibility of comparing the current results with the results of other studies, data were given in the form of arithmetic and geometric means, median, standard error of mean, and standard deviation.

Results

The concentrations of mercury in the hair samples varied widely from 0.002 to 7.640 μg/g, while the average value of the amount of mercury in the samples was (mean ± SE) 0.445 ± 0.018 μg/g, the median value was (Q_{25}–Q_{75}) 0.220 (0.080–0.511) (Table 1, SM Table S2).

The majority of the population had Hg levels in hair less than 1 μg/g. In 10.7% of participants, mercury concentrations exceeding 1 μg/g were noted (Fig. 2).

The frequency distributions of mercury in the hair samples of the western rural population were different from those of the urban and rural eastern populations (Fig. 2). In the west, mercury concentrations of up to 0.1 μg/g were recorded in 16% of those surveyed while in the east, it was 26% and 36% for the urban population. Mercury levels of 0.1–0.5 μg/g were recorded in the west in 36.6%, in the east in 49.9%, and 46.9% of the urban population. Mercury content in hair in the range of 0.5−1 μg/g was observed in 20.4% of those surveyed from the western part of the region, in 17.1% of the eastern population, and in 11.5% of the urban population. Values exceeding 1 μg/g of mercury in hair were recorded in 26.8% of the population of the western districts, 7.3% in the east, and 5.7% of the urban population (Fig. 2).

The minimum average value was recorded in the hair of the urban population, an intermediate average value in the rural population of the eastern districts, and the highest values were noted in the hair of the population from the western districts (Table 1, Fig. 3). There were no differences in the content of mercury in the hair between the studied men and women of the Vologda region (SM Table S2). The ratio of mercury levels in the hair of only men or only women living in the city, in the east, or west of the region, was the same as in the whole sample (Table 1, SM Table S3, S4, S5).

Table 1 Concentrations of mercury (Mean + SE) in the hair of residents of Vologda region

	Total	Urban population	Rural population of the east	Rural population of the west
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Hair mercury	0.445 ± 0.018	0.307 ± 0.014	0.367 ± 0.023	0.884 ± 0.063
Gender				
Males	0.470 ± 0.037	0.267 ± 0.026	0.384 ± 0.037	1.078 ± 0.139
Females	0.433 ± 0.019	0.321 ± 0.017	0.356 ± 0.029	0.801 ± 0.066
Age group				
< 18 y	0.270 ± 0.027	0.172 ± 0.013	0.224 ± 0.032	0.640 ± 0.122
18–29 y	0.245 ± 0.014	0.209 ± 0.015	0.258 ± 0.023	0.396 ± 0.061
30–44 y	0.665 ± 0.055	0.461 ± 0.037	0.496 ± 0.051	1.215 ± 0.177
> 44 y	0.875 ± 0.053	0.700 ± 0.066	0.653 ± 0.076	1.198 ± 0.109
Fish consumption				
< 1 meal per month	0.172 ± 0.012	0.139 ± 0.011	0.162 ± 0.021	0.299 ± 0.045
1–2 meal per month	0.409 ± 0.025	0.296 ± 0.021	0.341 ± 0.031	0.804 ± 0.090
1 meal per week	0.555 ± 0.032	0.410 ± 0.034	0.448 ± 0.040	0.965 ± 0.092
≥ 2 meal per week	0.995 ± 0.105	0.675 ± 0.083	0.599 ± 0.110	1.897 ± 0.298
Smoking status				
Non-smokers	0.426 ± 0.019	0.300 ± 0.016	0.377 ± 0.028	0.823 ± 0.069
Smokers	0.514 ± 0.045	0.328 ± 0.030	0.325 ± 0.035	1.126 ± 0.155

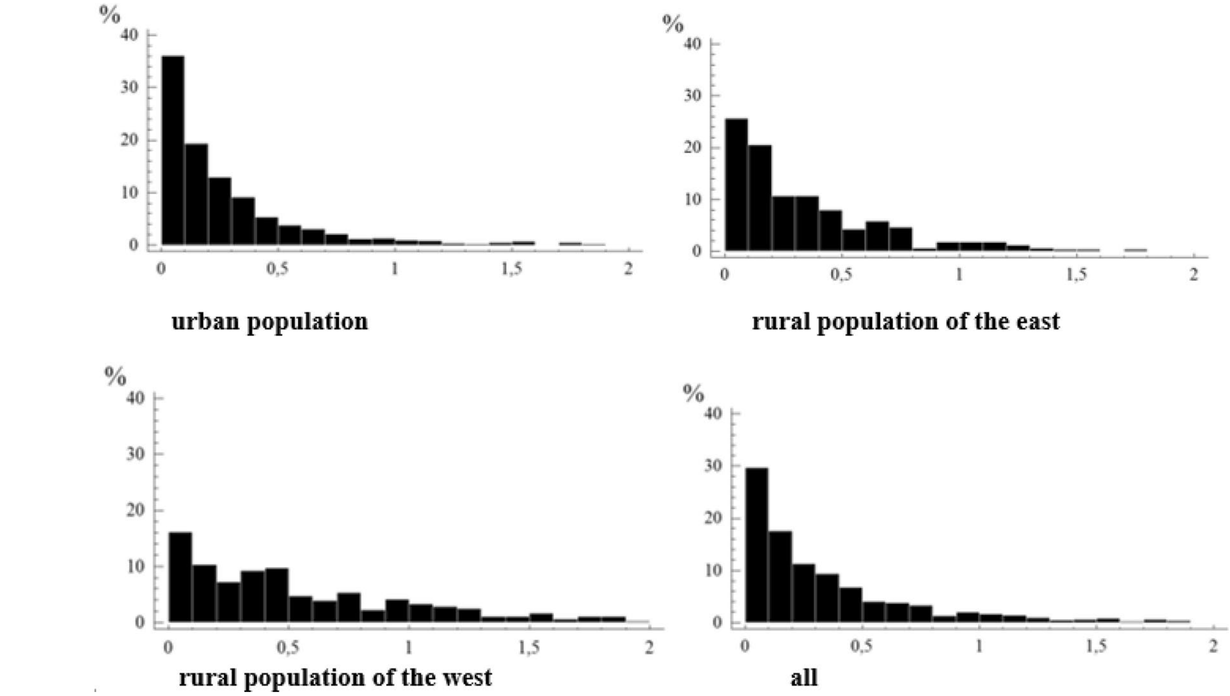

Fig. 2 Frequency distribution of total hair mercury in 1643 volunteers

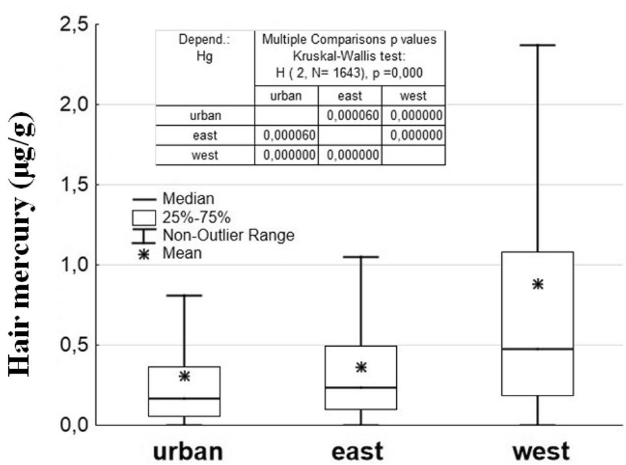

Fig. 3 Hair mercury concentration and districts of Vologda region

When comparing the mercury content in the hair of people of different age groups, statistically significant differences were found in the median test (Fig. 4, SM Table S2, S6). The minimum average value was recorded in children under the age of 18 years and in people aged 18−29 years. Intermediate values were recorded in the hair of middle-aged people aged 30−44 years and high concentrations were recorded in the hair of people older than 44 years (Fig. 4, Table 1, SM Table S2).

In the urban population, the average mercury content was: under 18 years 0.172 µg/g; 18−29 years 0.209 µg/g; 30−44 years 0.461 µg/g; and over 44 years 0.700 µg/g (Fig. 4, Table 1). In the rural population of the eastern districts, the average mercury content was: under 18 years 0.224 µg/g; 18−29 years 0.258 µg/g; 30−44 years 0.496 µg/g; and over 44 years 0.653 µg/g (Fig. 4, Table 1). The rural population of the western districts had the highest mercury values by age category (Fig. 4, Table 1). The average mercury content was: under 18 years 0.640 µg/g; 18−29 years 0.396 µg/g; 30−44 years 1.215 µg/g; and over 44 years 1.198 µg/g (Fig. 4, Table 1).

According to the mercury content in the hair of residents of the Vologda region, age correlations were established for the whole sample and in the samples of the urban, eastern, and western districts separately (Fig. 5).

Differences in the mercury content in human hair and the frequency of fish consumption were found at a significance level of $p = 0.000$ according to the median test (Fig. 6, SM Table S2, S7). The minimum value recorded in the hair of people who eat fish less than once per month was 0.172 µg/g and intermediate values observed in the hair of people who eat fish 1–2 times per month is 0.409 µg/g, and for once per week 0.555 µg/g (Table 1). High concentrations were noted in the hair of the investigated population that consumes fish several times a week (0.995 µg/g) (Fig. 6, Table 1).

Differences in the content of mercury in hair were established when comparing fish consumption in urban

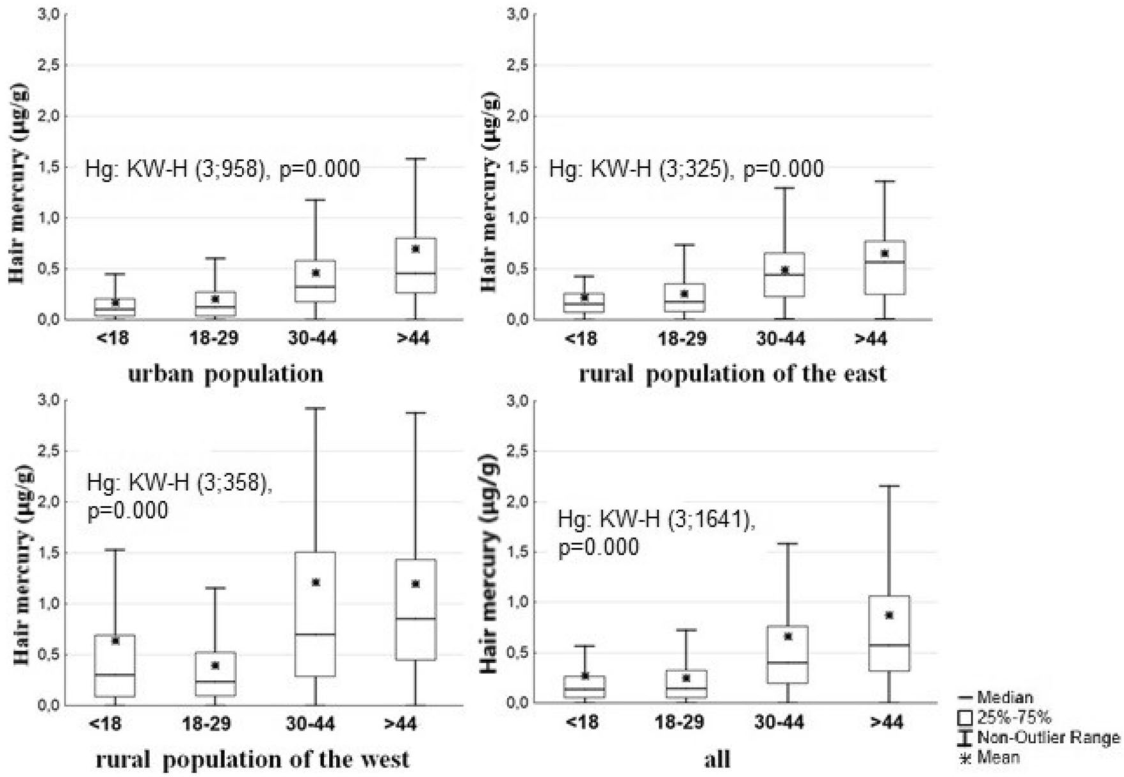

Fig. 4 Hair mercury concentration and age groups

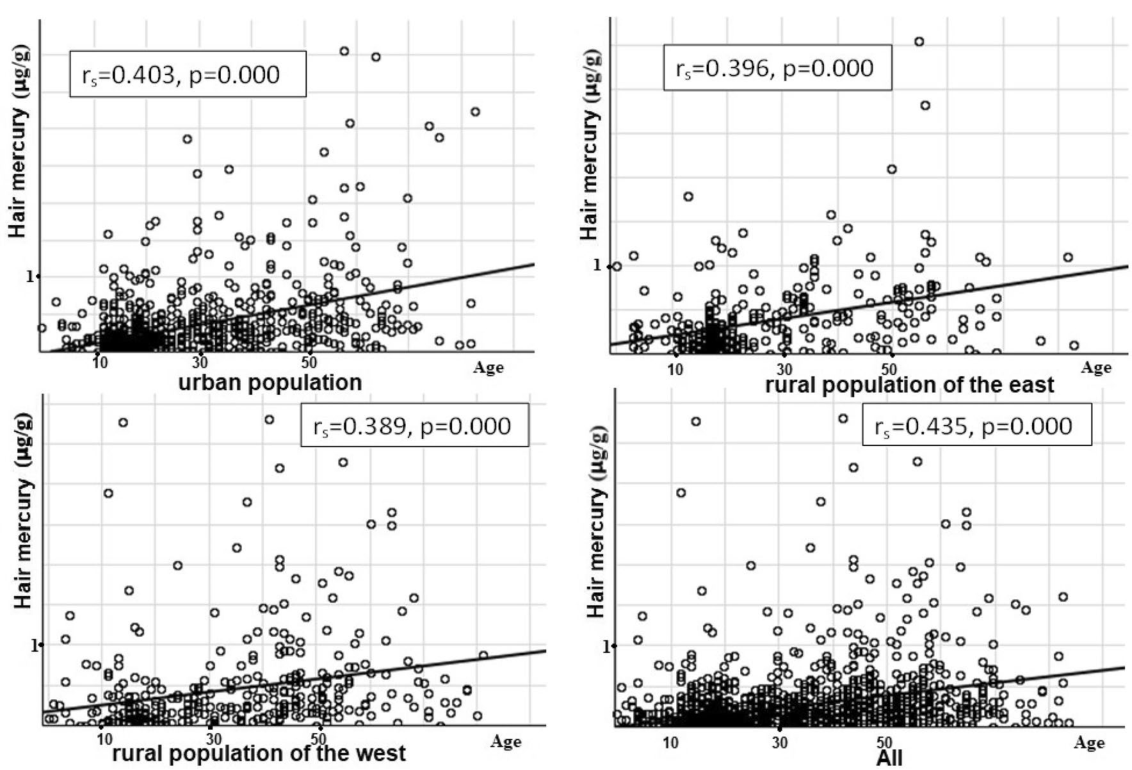

Fig. 5 Hair mercury content with respect to age for the studied populations

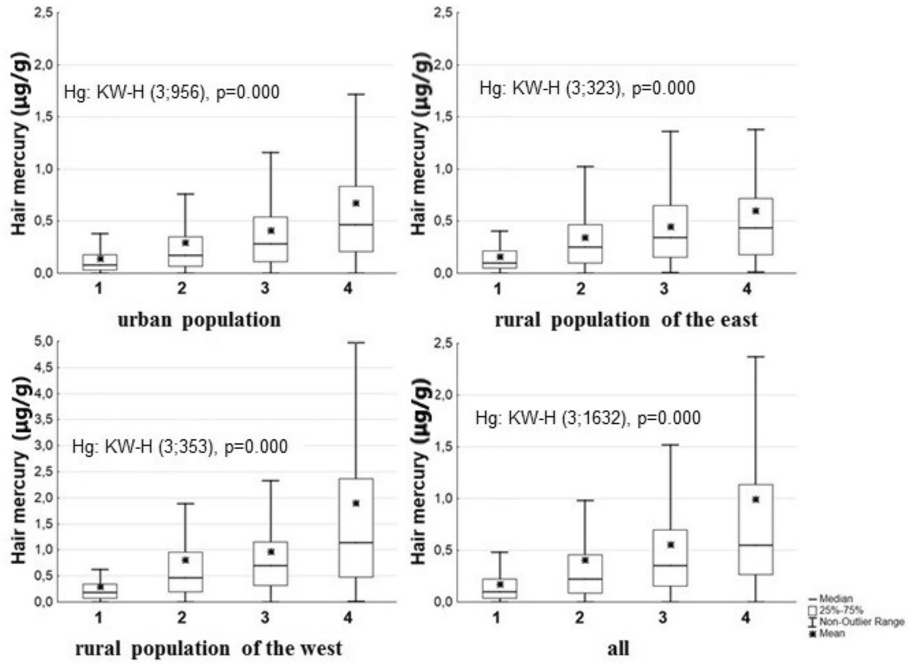

Fig. 6 Hair mercury concentration and fish consumption: (1) < 1 fish meal per month; (2) 1–2 fish meals per month; (3) 1 fish meal per week; (4) ≥ 2 fish meals per week)

and rural populations of western and eastern regions (Fig. 6, SM Table S3, S4, S5, S7). In urban populations, the average content of mercury in the hair of people who consume fish less than once a month was 0.139 µg/g; for fish consumption 1–2 times a month 0.296 µg/g; once a week consumption 0.410 µg/g; and several times a week 0.675 µg/g (Fig. 6, Table 1). In the rural population of the eastern districts, the average mercury content in the hair of people who consume fish less than once a month was 0.162 µg/g; for fish consumption 1–2 times a month 0.341 µg/g; once a week 0.448 µg/g; and several times a week 0.599 µg/g (Fig. 6, Table 1). In the rural population of the western districts, average mercury content in the hair of people who consume fish less than once per month was 0.299 µg/g; for fish consumption 1–2 times a month 0.804 µg/g; once a week 0.965 µg/g; and several times a week 1.897 µg/g (Fig. 6, Table 1).

The correlation between hair mercury content and the amount of fish consumed was established both for the entire sample and separately in the city and in the eastern and western districts of the Vologda region (Fig. 7).

Differences were found in the mercury content in the hair of smokers and non-smokers, both across the entire sample and among urban and western populations according to the median test (SM Table S2, S3, S5). At the same time, there are no differences in the amount of mercury between smokers and non-smokers in the eastern rural population (Fig. 8, SM Table S4).

Discussion

The average mercury content in the hair of residents of the Vologda Region was 0.445 µg/g, which is comparable to the results of studies in coastal areas, e.g., Calcutta, India (0.49 µg/g) (Gibb et al. 2016); Naples, Italy (0.638 µg/g) (Diez et al. 2008); and Western Canadian Arctic communities (0.6 µg/g) (Walker et al. 2020). At the same time, mercury in the hair of residents of the Vologda region was several times higher than the average content of mercury in the hair of residents of central Poland (0.174 µg/g) (Marcinek-Jacel et al. 2017), Germany (0.109 µg/g) (Schwedler et al. 2017), Canada (Health 2019) and Northern India (Masih et al. 2016). The levels of mercury in the hair of people who live in gold mining areas, e.g., Bolivar, Colombia, 1.56 µg/g (Olivero-Verbel et al. 2011) and Kadoma, Zimbabwe, 1.47 µg/g (Bose-O'Reilly et al. 2020) are several times higher than in the current study. Also, high levels of mercury (1.97 µg/g) in hair were observed in people who engaged in the extraction of mercury from mines (Sakamoto et al. 2007). The average mercury content in hair samples used for this study is significantly lower than in other studies in coastal areas, e.g., Coast of Persian Gulf, Iran (Bandar Abbas, 1.56 µg/g, Bushehr, 1.97 µg/g, and Mahshahr, 5.12 µg/g) (Okati and Esmaili-sari 2018); Columbian Amazon, 17.29 µg/g (Olivero-Verbel et al. 2016); Sundarban, India, 0.80 µg/g (Gibb et al.

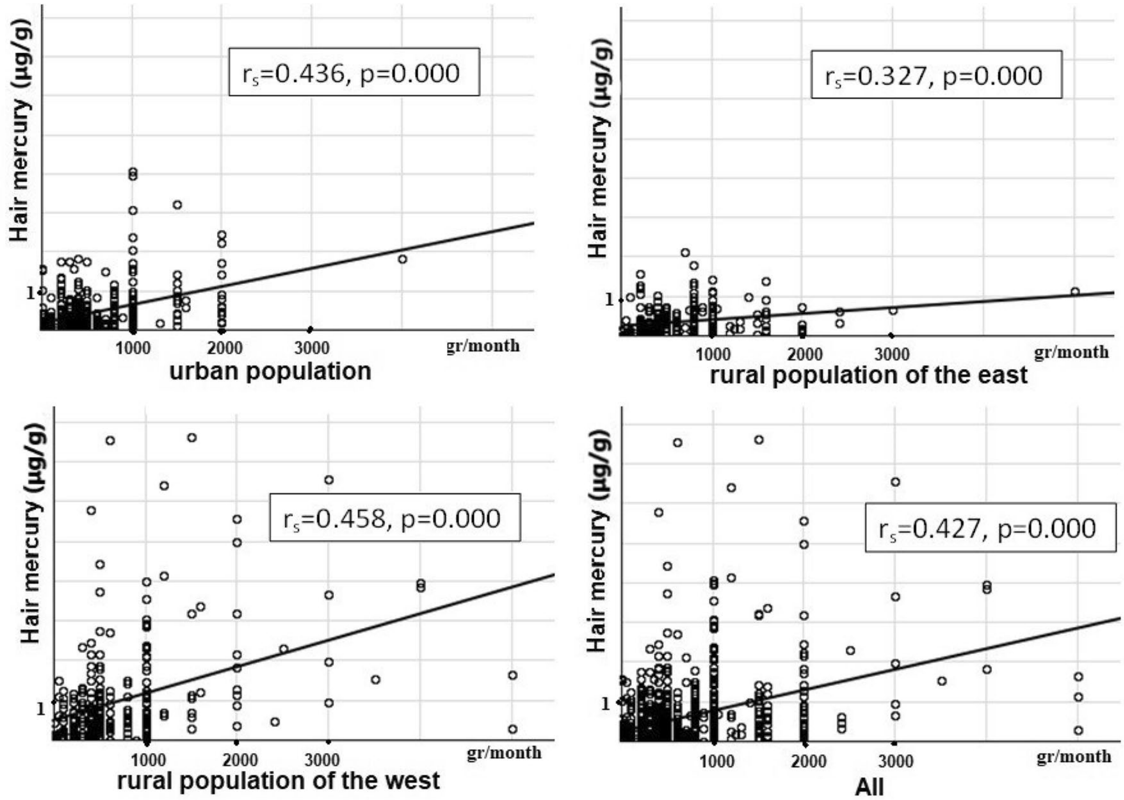

Fig. 7 Dependence of the mercury content in hair on the amount of fish consumed (g/month) in the population of the Vologda region and by district

2016); Japan, 1.82 µg/g (Yasutake et al. 2004); China, 0.83 µg/g (Liu et al. 2008); Malaysia, 11.45 µg/g (Hajeb et al. 2008); Iran (Nur, 4.20 µg/g, Nowshahr, 3.30 µg/g, Sari, 3.27 µg/g) (Okati et al. 2012); Camito, Colombia, 4.91 µg/g (Olivero et al. 2002).

The results in the current study exceed recommended values of 2.3 µg/g (FAO/WHO 2006) for 2.7% of the sample population of the Vologda Region, with 7 people (0.4%) exceeding 5 µg/g (RF). 10.7% of all people studied had exceedances of 1 µg/g (US Environmental Protection Agency). According to a study conducted in Spain, a link was established between the concentration of mercury in the hair and cognitive development delay in preschool children (Freire et al. 2010). In a study in Wanshan China, it was found that an increase in the concentration of mercury in the hair by 1 µg/g leads to a decrease of 1 IQ (intelligence quotient) point in children (Feng et al. 2020). A group of children with high concentrations of mercury (mercury level above 4.03 µg/g) in their hair in Brazil had neuropsychological indicators worse than a group of children with low levels of mercury (mercury level 0.05–0.91 µg/g) in their hair (Santos-Lima et al. 2020). Negative effects of mercury on neuropsychological functions were also noted in other studies of the Amazon region (Grandjean et al. 1999) and the territory of the Faroe Islands (Grandjean et al. 1997; Debes et al. 2006, 2016).

The maximum percentage excess of 1 µg/g was in residents of the west of the region (26.8%). Exceeding these regulatory standards was observed in the coastal areas of the Persian Gulf, Iran (63%) of the studied (Okati and Esmaili-sari 2018), exceeded the recommendations of 40% of children from Japan (Kusanagi et al. 2018), 42.5%—in the coastal cities of China (Liu et al. 2008). In Naples, Italy, 6% of the sampled population had hair mercury levels exceeding 1 µg/g (Diez et al. 2008). In the current study, the bulk of the sample of the eastern rural population and the urban population in all areas had mercury levels below 0.5 µg/g; however, at the same time, the average mercury values in the hair were 0.367 µg/g and 0.307 µg/g, respectively. In a Florida study, the bulk of the sample had mercury levels less than 0.5 µg/g, with an arithmetic mean of 0.666 µg/g (Nair et al. 2014). The main part of the sample (94% of the population) in Naples, Italy, had mercury levels below 1 µg/g, 4.6% had mercury levels in hair at 1–2 µg/g, and 1.3% had more than 2 µg/g (Diez et al. 2008).

The average mercury content in the hair of people living in the western districts of the Vologda region is several times higher than the levels of mercury in the hair of people in the

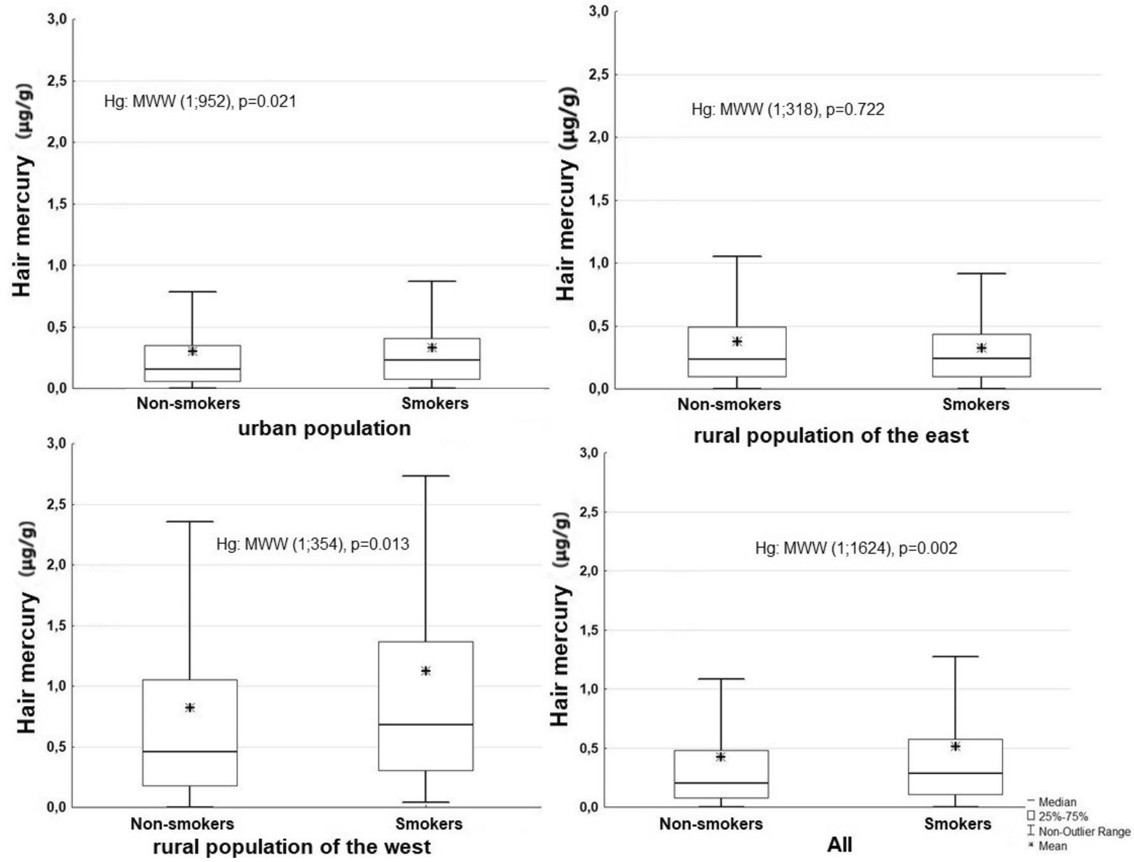

Fig. 8 Hair mercury concentration and groups by smoking status

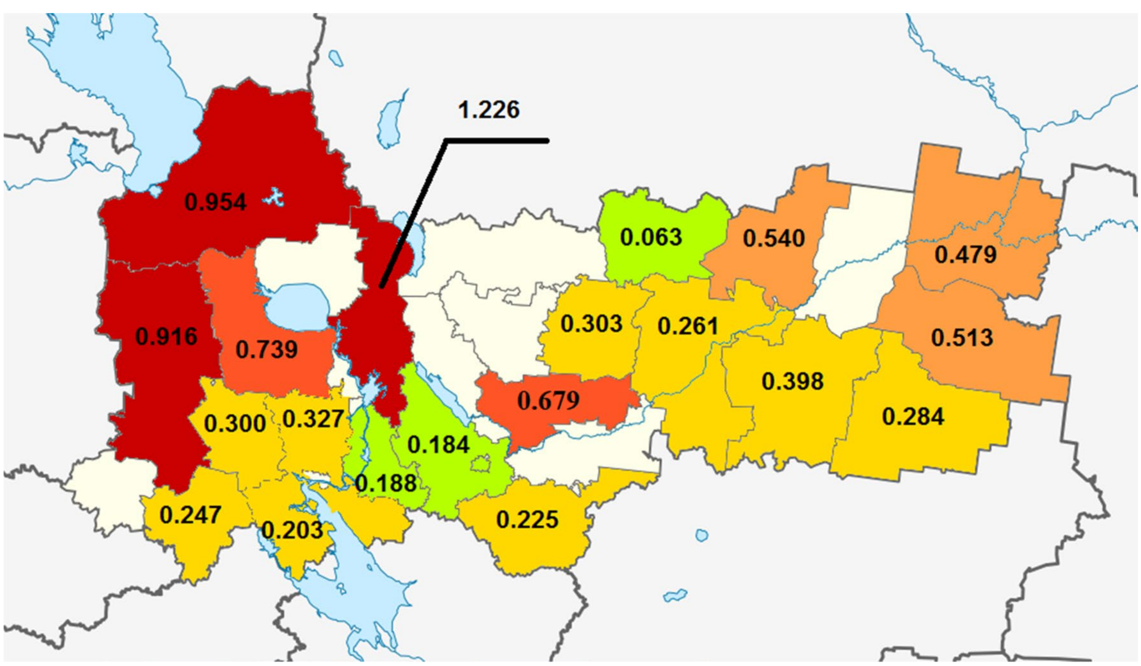

Fig. 9 Map of the distribution of mercury (μg/g) in the hair of residents of various districts of the Vologda region

urban population and the population of the eastern regions (Fig. 9, Table 1). In the western districts, a high number of lakes and a high degree of waterlogging of catchment basins prevail, in contrast to other districts of the region (Abramova 1965; Antipov 1981; The environment 1957, 2007). The main commercial sources of fish products are the reservoirs of the western part of the Vologda region: Beloe Lake (808.3 tons); Rybinskoe reservoir (376.9 tons); Kubenskoe Lake (183.7 tons); Onezhskoe Lake (267.0 tons); Sheksninskoe reservoir (95.3 tons); and Lake Vozhe (64.0 tons). At the same time, the catch on rivers and small lakes amounts to 14.6 tons (Comprehensive territorial 2017).

According to the results of this study, the concentration of mercury in hair does not differ significantly between men and women. This replicates the findings in Ningbo, People's Republic of China (Liu et al. 2008) and in other studies (Kosatsky et al. 2000; Mortada et al. 2002; Olivero et al. 2002; Health 2019). Mercury content was measured in the hair of residents of coastal cities in China (men, 0.94 µg/g; women, 0.72 µg/g) (Liu et al. 2008), as well as in students of Chinese universities (Wu et al. 2020). No differences were found in the study on the territory of Upper Maroni, French Guiana (men, 9.4 µg/g; women, 9.9 µg/g) (Fujimura et al. 2012) or on the territory of the Amazon region of Brazil (Santos-Lima et al. 2020).

A difference in mercury content between men (2440 µg/g) and women (1940 µg/g) was noted in the Zhoushan district, China (Liu et al. 2008) as well as in other studies: Florida (men 2.02 µg/g, women 0.96 µg/g) (Schaefer et al. 2014); Naples, Italy (men 0.709 µg/g, women 0.563 µg/g) (Diez et al. 2008), in coastal communities in Malaysia (where the content was higher for women) (Hajeb et al. 2008), and in the hair of the adult population of the Karakuwacho Peninsula, Japan (Yan et al. 2014) where the geometric means were women 1.43 µg/g and men 2.55 µg/g (Yasutake et al. 2003). Differences in gender may be related to social aspects such as particular traditions, which are more prevalent in the rural population and less so in the cities.

Higher mercury levels were found in the hair of older individuals. Studies in Pakistan (Shah et al. 2016), in Canada (Health 2019) also found age differences. In previous studies of coastal cities in China, an increase in mercury concentrations in hair with age was noted (Liu et al. 2008). In studies of northern India (Masih et al. 2016), there were increases in the level of mercury depending on age, from 0.04 to 0.11 µg/g, but the concentration of mercury in the hair was significantly less than in the current study. Also, in the French Riviera territory (where high average concentrations of mercury were observed in the hair of the population over 40 years of age (0.91 µg/g), low levels of mercury were observed in the hair of children (0.36 µg/g) (Petrova et al. 2020). In a study in Wanshan, China, the average mercury content in children's hair was 1.53 µg/g, which is five times higher than in the current study (0.27 µg/g) (Feng et al. 2020). A correlation between the accumulation of mercury in hair and age was recorded in the study responses in Kuwait (Bou-Olayan and Al-Yakoob 1994). Studies in Canada have also found a link between an increase in mercury in hair and age (Ripley et al. 2018; Ratelle et al. 2020). However, in contrast to this study, the study in Yanonam showed a low significant correlation between mercury concentration and age where the level of correlation is four times higher (Vega et al. 2018). A low significant correlation between mercury concentration and age was noted in men from Terengganu, Malaysia (Hajeb et al. 2008). In a study in Naples, Italy, a negative correlation was found ($rs = -0.345$ ($p = 0.000$) (Diez et al. 2008).

Fish consumption is one of the main sources of mercury in the human body (EFSA 2012; Mozaffarian and Rimm 2006; Sheehan et al. 2014; USEPA 1997; Hightower and Moore 2003; Horvat et al. 2012; Rose et al. 2015; Tong et al. 2017; Yasutake et al. 2003; Batista et al. 1996; Holsbeek et al. 1996; Harada et al. 1998; Al-Majed and Preston 2000; Olivero et al. 2002). According to the results of the survey, residents of the Vologda region consume an average of 606.9 g of fish per month, which is comparable to the consumption of fish in European countries (Czech Republic, 741.6 g/month; Slovakia, 758.3 g/month) (FAO 2019, 2020). The urban population consumes less fish (498.7 g/month) than the eastern population (669.3 g/month) and the western population (723.9 g/month) of the region. In Malaysia, the same pattern of fish consumption is observed: the urban population consumes fish in much smaller quantities than the rural population, where high levels of mercury in the hair are noted (Hajeb et al. 2008). Most likely, this is due to the difference in diet, lifestyle, and environmental factors (Hajeb et al. 2008). In this work, differences were obtained depending on the frequency of fish consumption and these results are comparable with previous studies. The same differences in nutrition are observed in the hair of residents of European countries. In central Poland, the minimum average concentrations were observed in the hair of people who do not eat fish (0.121 µg/g) while the maximum in the hair of people who eat fish several times a week was 0.464 µg/g (Marcinek-Jacel et al. 2017). According to the DEMOCOPHES project, differences were also found depending on the frequency of fish consumption in the hair of women and children from Germany (Schwedler et al. 2017). Residents of the French Riviera who consumed fish very often had an average concentration of mercury in their hair of 1.32 µg/g, whereas the average concentration of mercury in the hair of people who consumed fish almost never is 0.42 µg/g (Petrova et al. 2020). In studies in northern India, differences were found from the frequency of fish consumption (rarely consumed, 0.02 µg/g; often consumed, 0.16 µg/g) (Masih et al. 2016). In Japan, in the area of the

Karakuwacho Peninsula where fish is the main food source, there are also differences in the frequency of fish consumption in adults and in children (Yan et al. 2014). In studies in Canada, those eating fish less than once per month had mercury levels of 0.44 µg/g while those eating fish more than once per month had 2.01 µg/g (Ripley et al. 2018). In the western Canadian Arctic, people who eat fish less than once a week (0.42 µg/g) had mercury concentrations half as low as people who eat fish more than five times a month (0.84 µg/g) (Walker et al. 2020). An Iranian study examined the accumulation of mercury in women's hair (less than once a month, 0.50 µg/g; several times a week, 3.55 µg/g) (Okati et al. 2012). Differences in nutrition were found both on the coast of the Persian Gulf, Iran (fish consumption less than once a month, 0.83 µg/g; several times a week, 4.19 µg/g) (Okati and Esmaili-sari 2018), and in studies in Naples, Italy (fish consumption, 0.761 µg/g; do not eat fish, 0.464 µg/g) (Diez et al. 2008). However, in the studies conducted in gold mining regions, no differences were found depending on the frequency of fish consumed (Olivero-Verbel et al. 2011). Most likely, this is due to different sources of mercury intake in the human body. The correlation between the mercury content and the amount of fish consumed is the same in all parts of the Vologda region. Also, a positive correlation was found between the Hg content in hair and fish consumption (grams/month) in the Malaysian population (Hajeb et al. 2008). A correlation was also established in Upper Malone, French Guiana (Fujimura et al. 2012) and in Naples, Italy ($rs = 0.536$, $p < 0.05$) (Diez et al. 2008). A South China study found that the more local fish consumed the higher the risk of negative health effects of mercury (Chen et al. 2018).

The current study found differences in the amount of mercury in the hair of smokers and non-smokers. Also, differences were noted in the study at Chinese universities. It was found that the average concentration of total mercury in the hair of smokers (0.45 µg/g) was significantly higher than in the hair of non-smokers (0.29 µg/g) at $p < 0.05$ (Wu et al. 2020). The researchers noted that the established differences are possible due to the accumulated mercury in tobacco, which could enter the human body as a result of smoking. Smoking was considered an important source (accounting for 11–18%) for the estimated daily intake of THg (Shao et al. 2013).

Conclusion

The average mercury content in the hair of sampled residents of the Vologda region was 0.445 ± 0.018 µg/g. Of these, 10.7% of the studied samples had mercury concentrations above 1 µg/g. Significantly higher concentrations of mercury were observed in the hair of participants from the western part of the region (0.884 ± 0.063 µg/g), where reservoirs are the main commercial sources of fish products. Intermediate values were observed in the rural population of the eastern districts (0.367 ± 0.023 µg/g) and minimum concentrations were observed in the hair of the urban population (0.307 ± 0.014 µg/g). There were no differences in the content of mercury in the hair between the studied men (0.470 ± 0.037 µg/g) and women (0.433 ± 0.019 µg/g) living in the Vologda region. A positive correlation between the amount of mercury in the body of people and their age was established. Statistically significant higher levels of mercury were recorded in the hair of people over 45 years of age. Mercury levels in the hair are positively correlated with the amount of fish consumed. There were statistically significant higher levels of Hg in the hair of people who consume fish several times a week compared with people who consume fish less than once a week. The mercury content in the hair of non-smokers (0.426 ± 0.019 µg/g) was statistically significantly lower than that of smokers (0.514 ± 0.045 µg/g).

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Author contributions VTK, OYR and ESI conceived the idea of this study, OYR and ESI collected the samples, OYR performed laboratory analyses, OYR, VTK and ESI discussed the results, OYR, VTK and ESI analyzed the data, OYR, ESI, VTK wrote the manuscript. All authors reviewed the manuscript before the submission.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose. The authors declare no competing interests.

Consent to participate Each participant provided written informed consent to be included in the study. For participants under the age of 18, parental permission was requested. This study was performed in accordance with the World Medical Association (WMA) Declaration of Helsinki: ethical principles for medical research involving human subjects (WMA 2008). The program of this study was discussed and approved by the Bioethics Commission of Cherepovets State University and the Territorial Department of Health of the Vologda Oblast (No. 2-1/55).

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