UDC 613.26; 614.31
DOI: 10.21668/health.risk/2024.1.05.eng

Read online

Research article

CLUSTER APPROACH TO THE STUDY OF POPULATION HEALTH RISKS POSED BY CONTAMINATION OF FOOD PRODUCTS WITH HEAVY METALS

D.O. Gorbachev

Samara State Medical University, 89 Chapaevskaya St., Samara, 443099, Russian Federation

Food products are a source of energy and essential substances but also of anthropogenic contaminants such as heavy metals. The aim of the study was to assess population health risks posed by contamination of food products with heavy metals, taking into account peculiarities of food preferences. An epidemiological study of actual nutrition of adult population of Samara region was conducted, the sample size was 1,856 people.

At the first stage, using factor analysis, respondents' adherence to a certain model of food preferences was established; at the second stage, 5 homogeneous groups (clusters) of people with similar types of nutrition were formed using cluster analysis. The first cluster included individuals with maximum commitment to a high level of consumption of all studied foods; the second cluster was characterized by commitment to consumption of high-calorie foods such as baked goods, confectionery, sausages, potatoes, eggs, and cheese. Individuals from the cluster 3 showed a distinct preference for consumption of vegetables, fruit and dairy products. Individuals from the cluster 4 had no special preferences for any of the studied foods. The fifth cluster included people who had maximum preference for meat and meat products, smoked meats, pickles and salted fish. The content of cadmium, mercury, lead, and arsenic in food products was assessed via atomic absorption and photometric methods. The study relied on using social and hygienic monitoring data from the Samara Regional Rospotrebnadzor (Federal Service for Surveillance on Consumer Rights and Human Wellbeing) collection. Risk assessment of carcinogenic and non-carcinogenic effects was carried out in each of the five formed clusters taking into account modern methodological approaches.

It was found that in all food clusters, the hazard coefficients for intake of contaminants in median concentrations and in the 90th percentile did not exceed permissible levels. In all clusters, the endocrine system was most at risk (HI = 1.68 ÷ 1.25). For all clusters, carcinogenic risk (for median concentrations) was created by arsenic both at the individual and the population level. The risk was the highest for people whose diets were characterized by high levels of consumption of high-calorie products. Cluster approach makes it possible to identify the most vulnerable groups of population in terms of risk burden for making managerial decisions and carrying out preventive measures.

Keywords: *contamination, heavy metals, cluster analysis, public health risks, actual nutrition, food preferences, carcinogenic risk, non-carcinogenic risk.*

Nutrition has a significant impact on human health. Nutritional factor can have both positive and negative effects on the body, as, on the one hand, food is a source of essential substances, but on the other hand, foreign components such as xenobiotics found in food products can negatively affect humans. Since each individual has certain food preferences, expressed quantitatively and qualitatively in consumption of various foods, the amount of foreign components consumed with food will differ for various groups. Heavy metals are recognized as one of the most dangerous xenobiotics for humans. Contamination of food with heavy metals is a global problem for human health [1], since they are non-biodegradable pollutants that tend to accumulate and can be transferred to soil [2]. Heavy metals are found in all ecosystems; while their natural concentrations vary depending on local geology, human economic activity leads to the accumulation of heavy metals in significant concentrations in the environment [3]. A number of heavy metals, including nickel, iron, magnesium, copper and zinc, in food products in low concentrations are vital for the most important human biological functions, in particular, for metabolic processes (cytochro-

Dmitry O. Gorbachev – Doctor of Medical Sciences, Associate Professor, Head of the Common Hygiene Department (e-mail: d.o.gorbachev@samsmu.ru; tel.: +7 (846) 374-10-04 (ext. 4617); ORCID: https://orcid.org/0000-0002-8044-9806).

me and enzyme functions) [4, 5]. Other elements, including lead, cadmium, mercury, arsenic and aluminum, have a toxic effect on the body even in low concentrations, while having no significant biological value for humans, and are classified as insignificant for metabolic and biological functions [6–8].

Adverse effect of heavy metals is due to acute or chronic toxic effect on the main metabolic processes. Accumulation of heavy metals in organs and systems interferes with antioxidant protection thereby increasing risks of oxidative stress [9]. Exposure to heavy metals creates elevated risks of developing malignant neoplasms, reproductive disorders, diseases of the cardiovascular, endocrine and nervous systems [10].

According to WHO, as of 1 June, 2020, arsenic, cadmium, lead and mercury are among the 10 chemicals causing serious public health concern [11]. Although these elements are known to be toxic, their diverse technological, medical and agricultural applications still pose a huge threat to human health.

National studies assessing the risk posed by food contamination mainly use data provided by the Federal State Statistics Service on the average annual per capita consumption of the main food groups [12–14]. On the one hand, this approach simplifies risk assessment procedures and does not require special epidemiological studies of the population's nutrition. On the other hand, in this case we obtain averaged risk indicators without taking into account peculiarities of food preferences in different population groups. Nevertheless, there are studies in literature concerning risk assessment based on actual nutrition data obtained via methods of 24-hour (daily) diet reproduction and frequency assessment of a diet. They provide a more accurate risk assessment, which is necessary for managerial decisions and preventive measures [15]. In addition, calculation of exposure to contaminants in accordance with current recommendations in the Russian Federation is based on the standard body weight of 70 kg; similarly, average body weight in a surveyed group is applied in international research. In particular, based on the latest statistical data provided by the National Health Commission of the People's Republic of China in 2020, the average body weight for adult men and women was 69.6 and 59 kg respectively and this value was taken into account when calculating non-carcinogenic and carcinogenic risks. Meanwhile, using individual body weight values in calculations makes it possible to increase the accuracy of determining the level of risk [16].

Therefore, at present, it is relevant to solve a hygienic problem of assessing risks for population health posed by food contamination with heavy metals, taking into account use of epidemiological methods based on an individual assessment of diet structure. This will ultimately allow obtaining the most accurate risk assessment and making management decisions to reduce the level of risk in various population groups while taking into account individual food preferences.

The goal of the study is to assess population health risk posed by contamination of food products with heavy metals, based on a cluster analysis of actual nutrition.

Materials and methods. The object of this study is adult working age population permanently residing on the territory of the Samara region (n = 1856 people), including employees of regional enterprises of fuel and energy production, automotive industry, food production, healthcare, education, agriculture and office workers. To analyze actual nutrition, questionnaires were compiled based on frequency assessment of diets, taking into account consumption of various food groups and portion sizes over the past month. Photos of food were used for clarity.

At the first stage of assessment of actual nutrition, adherence to a certain model of food preference was established by using factor analysis; nutrition models included foods with a factor value of over 0.3. At the second stage, people with similar food preferences were combined into clusters (allocation of homogeneous groups using McKean *k*-means clustering, Ward's dendrogram method, Euclidean distance, and variance analysis). Average values of adherence to nutrition models ($M \pm SD$) were obtained during the analysis of dendrograms (Ward method, clustering, and Euclidean distance). Based on variance analysis of the formed food clusters, highly significant differences in average adherence ($p < 0.001$) were obtained for each nutrition model. Negative values of adherence indicated a low level of food consumption in a particular diet model; positive values indicated a high level of food consumption. Formation of a specific cluster was based on the highest values of adherence to food consumption (nutrition models) with a factor value of over 0.3. Based on obtained data, diets with homogeneous food preferences were systematized using Nutri-prof custom software package (version 2.9). This made it possible to assess consumption of the main food groups in each of the five nutrition clusters [17]. Next, carcinogenic and non-carcinogenic risks associated with the intake of heavy metals with food were assessed for each of the five food clusters. Contamination of food products with heavy metals consumed by the population was assessed based on cadmium, mercury, lead, and arsenic levels. Food products were represented by the following groups: bread and bread products, vegetable oil and other fats, milk and dairy products, meat and meat products, eggs, fish and fish products, sugar and confectionery, fruit and berries, vegetables and gourds, potatoes. The analysis involved using social and hygienic monitoring data provided by the Samara Regional Rospotrebnadzor Office; overall, we analyzed 82,354 results of sample testing collected over 12 years. When calculating exposure, median values of contaminant concentration were taken into account; the 90th percentile was used for maximum values taking into account average body weight value calculated in each particular cluster based on the body weight data provided by the respondents. Risks of carcinogenic and non-carcinogenic effect were assessed in accordance with MU 2.3.7.2519-09 'Determining exposure and risk assessment of the effect of chemical contaminants in food products on the population'[1] and R 2.1.10.1920-04 'Human Health Risk Assessment from Environmental Chemicals'[2]. Non-carcinogenic risk (HQ) of exposure to a contaminant was calculated, taking into account exposure and the reference (safe) level of exposure, as well as the total hazard index (HI) for combined exposure to contaminants with unidirectional effect. Average daily doses of a contaminant over a lifetime and the slope factor were taken into account to calculate individual and population carcinogenic risks. Statistical analysis was carried out using SPSS 25 software.

Results and discussion. During the assessment of actual nutrition of the population, patterns were found indicating a similar nature of food preferences among surveyed individuals. At the first stage of statistical data processing, 5 nutrition models were formed by factor analysis taking into account food preferences for various foods with a factor over 0.3. Nutrition model No. 1 was characterized by a variety of products of plant and animal origin and did not have a clear focus. Nutrition model No. 2 was characterized by excessive consumption of high-calorie foods (baked goods, pasta, potatoes, confectionery, oil and butter, sausages, and cheese). Nutrition model No. 3 was characterized by high factor in terms of preference for food products of plant origin (vegetables, fruit, and nuts). The bases of nutrition model No. 4 were dairy products, fish and eggs. Nutrition model No. 5 was characterized by a meat-salt focus due to significant consumption of meat products, including sausages, smoked meats, salted fish, and pickled vegetables. Since each person adhered to the obtained nutrition model to a certain extent, a cluster method was used at the second stage, which allowed to form homogeneous groups of individuals (selection of

[1] MU 2.3.7.2519-09. Opredelenie ekspozitsii i otsenka riska vozdeistviya khimicheskikh kontaminantov pishchevykh produktov na naselenie [Determining exposure and risk assessment of the effect of chemical contaminants in food products on the population]: methodological guidelines. Moscow, Federal Center for Hygiene and Epidemiology of Rospotrebnadzor, 2010, 27 p. (in Russian).

[2] R 2.1.10.1920-04. Human Health Risk Assessment from Environmental Chemicals. Moscow, Federal Center for State Sanitary and Epidemiological Surveillance of the Ministry of Health of the Russian Federation, 2004, 143 p. (in Russian).

homogeneous groups was carried out by the McKean *k*-means method); then, a preliminary analysis of dendrograms was carried out and average values of adherence to nutrition models ($M \pm SD$) were obtained. Based on the variance analysis of the formed food clusters, highly significant differences in average adherence ($p < 0.001$) were obtained for each nutrition model.

The same maximum adherence to all five nutrition models with a high level of consumption of all studied foods was noted for individuals in the first cluster. Individuals in the second cluster were characterized by high commitment to consumption of high-calorie products such as baked goods, potatoes, confectionery, sausages, eggs, and cheese (model No. 2). For individuals from the cluster 3, there was a distinct preference for vegetables and fruit, as well as dairy products (models No. 3 and 4). Individuals from the cluster 4, unlike those from the cluster 1, adhered to all dietary patterns, but with a low level of consumption for all studied foods. The fifth cluster was made up of people with maximum preferences for the consumption of meat and meat products, smoked meats, pickled foods, and salted fish (model No. 5).

Using custom software package 'Nutri-prof' (version 2.9), data on consumption of the main food groups were obtained for each food cluster (Table 2).

For subsequent assessment of exposure and the hazard coefficient, we used data on the content of heavy metals in the main groups of food products median concentration (*Me*) and the 90th percentile concentration (Table 3).

Exposure and hazard index values with various intake methods for median values (*Me*) of contaminant concentration and the 90th percentile were calculated for all four analyzed heavy metals in each group of people with similar food preferences (Table 4).

Table 1

Parameters of individuals' adherence to certain nutrition models ($M \pm SD$)

Model of nutrition	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	*P*
No. 1	1.43 ± 1.73	-0.18 ± 1.21	0.86 ± 1.54	-0.28 ± 0.51	0.28 ± 1.21	<0.001
No. 2	2.19 ± 1.57	1.54 ± 0.73	-0.78 ± 0.81	-0.37 ± 0.42	-0.19 ± 0.86	<0.001
No. 3	1.72 ± 1.55	-0.08 ± 1.23	1.69 ± 1.48	-0.27 ± 0.44	-0.23 ± 0.79	<0.001
No. 4	1.62 ± 1.88	-0.25 ± 1.23	0.67 ± 1.53	-0.17 ± 0.52	0.25 ± 1.27	<0.001
No. 5	1.58 ± 2.83	-0.21 ± 0.79	-0.59 ± 0.77	-0.24 ± 0.39	1.54 ± 0.76	<0.001

Table 2

Median values of consumption of the main food groups depending on a cluster (g/day)

Food group	Cluster				
	1	2	3	4	5
Bread and bread products	243.3	253.2	173.4	137.3	231.8
Vegetable oil and other fats	47.7	50.1	34.5	28.8	51.0
Milk and dairy products	130.4	133.4	140.0	129.3	132.1
Meat and meat products	143.6	152.3	80.5	77.0	170.7
Eggs	22.7	19.7	17.5	19.7	26.0
Fish and fish products	17.5	18.9	14.2	18.6	23.8
Sugar and confectionery	50.4	63.3	39.7	43.0	42.2
Fruit and berries	114.0	105.8	149.9	126.8	101.9
Vegetables and gourds	151.0	144.9	186.8	138.1	141.6
Potatoes	76.2	85.5	92.3	72.9	81.6

Table 3

Heavy metals content (mg/kg) for food groups

Food group	Cadmium		Mercury		Lead		Arsenic	
	Me	90	*Me*	90	*Me*	90	*Me*	90
Bread and bread products	0.011	0.0258	0.0033	0.0112	0.0474	0.158	0.006	0.0087
Vegetable oil and other fats	0.0087	0.0232	0.0034	0.00776	0.0223	0.0737	0.0040	0.0068
Milk and dairy products	0.0134	0.0155	0.0017	0.0031	0.0362	0.0655	0.0074	0.0084
Meat and meat products	0.0073	0.0264	0.0052	0.01277	0.0441	0.111	0.0041	0.0048
Eggs	0.0037	0.0042	0.0034	0.00461	0.0248	0.056	0.008	0.0094
Fish and fish products	0.0122	0.0364	0.0162	0.04733	0.0749	0.2552	0.005	0.0092
Sugar and confectionery	0.0124	0.0262	0.0041	0.01769	0.0312	0.1047	0.0061	0.0069
Fruits and berries	0.0112	0.0114	0.0023	0.00561	0.0256	0.0712	0.005	0.0092
Vegetables and gourds	0.0056	0.0158	0.0022	0.00913	0.0361	0.133	0.002	0.0077
Potatoes	0.0055	0.0073	0.0018	0.0088	0.0605	0.1273	0.006	0.0081

Table 4

Exposure values (mg/kg) and hazard coefficients, taking into account food preferences and various methods of contaminant intake

Food group	Cluster									
	1		2		3		4		5	
	Exp *Me*	Exp 90	Exp *Me*	Exp 90	Exp *Me*	Exp 90	Exp *Me*	Exp 90	Exp *Me*	Exp 90
Cadmium										
Bread and bread products	3.08E-05	7.21E-05	3.20E-05	7.51E-05	2.20E-05	5.15E-05	1.74E-05	4.07E-05	2.93E-05	6.87E-05
Vegetable oil and other fats	4.77E-06	1.27E-05	5.01E-06	1.34E-05	3.45E-06	9.21E-06	2.90E-06	7.74E-06	5.07E-06	1.35E-05
Milk and dairy products	2.01E-05	2.32E-05	2.06E-05	2.38E-05	2.16E-05	2.49E-05	1.99E-05	2.30E-05	2.03E-05	2.35E-05
Meat and meat products	1.20E-05	4.36E-05	1.27E-05	4.61E-05	6.76E-06	2.44E-05	6.76E-06	2.44E-05	1.43E-05	5.18E-05
Eggs	9.67E-07	1.10E-06	8.39E-07	9.52E-07	7.46E-07	8.46E-07	8.39E-07	9.52E-07	1.11E-06	1.26E-06
Fish and fish products	2.46E-06	7.34E-06	2.65E-06	7.91E-06	2.00E-06	5.96E-06	2.61E-06	7.79E-06	3.34E-06	9.97E-06
Sugar and confectionery	7.19E-06	1.52E-05	9.02E-06	1.91E-05	5.70E-06	1.20E-05	6.13E-06	1.30E-05	6.01E-06	1.27E-05
Fruit and berries	1.47E-05	1.49E-05	1.36E-05	1.39E-05	1.93E-05	1.96E-05	1.63E-05	1.66E-05	1.31E-05	1.34E-05
Vegetables and gourds	9.72E-06	2.74E-05	9.33E-06	2.63E-05	1.20E-05	3.39E-05	8.89E-06	2.51E-05	9.12E-06	2.57E-05
Potatoes	4.81E-06	6.39E-06	5.40E-06	7.17E-06	5.84E-06	7.75E-06	4.61E-06	6.11E-06	5.16E-06	6.85E-06
HQ	0.22	0.45	0.22	0.46	0.19	0.38	0.17	0.33	0.21	0.45
Mercury										
Bread and bread products	1.04E-05	3.54E-05	1.08E-05	3.68E-05	7.44E-06	2.53E-05	5.88E-06	2.00E-05	9.93E-06	3.37E-05
Vegetable oil and other fats	2.10E-06	4.80E-06	2.21E-06	5.05E-06	1.52E-06	3.48E-06	1.28E-06	2.93E-06	2.24E-06	5.11E-06
Milk and dairy products	2.88E-06	5.25E-06	2.95E-06	5.37E-06	3.09E-06	5.64E-06	2.86E-06	5.21E-06	2.92E-06	5.32E-06
Meat and meat products	9.70E-06	2.38E-05	1.03E-05	2.52E-05	5.44E-06	1.34E-05	5.44E-06	1.34E-05	1.15E-05	2.83E-05

End of the Table 4

Food group	Cluster									
	1		2		3		4		5	
	Exp *Me*	Exp 90	Exp *Me*	Exp 90	Exp *Me*	Exp 90	Exp *Me*	Exp 90	Exp *Me*	Exp 90
Eggs	1.00E-06	1.36E-06	8.71E-07	1.18E-06	7.74E-07	1.05E-06	8.71E-07	1.18E-06	1.15E-06	1.56E-06
Fish and fish products	3.69E-06	1.08E-05	3.98E-06	1.16E-05	3.00E-06	8.76E-06	3.92E-06	1.15E-05	5.01E-06	1.47E-05
Sugar and confectionery	2.68E-06	1.16E-05	3.37E-06	1.45E-05	2.13E-06	9.19E-06	2.29E-06	9.88E-06	2.25E-06	9.69E-06
Fruit and berries	3.40E-06	8.30E-06	3.16E-06	7.70E-06	4.48E-06	1.09E-05	3.79E-06	9.24E-06	3.04E-06	7.43E-06
Vegetables and gourds	4.31E-06	1.79E-05	4.14E-06	1.72E-05	5.34E-06	2.22E-05	3.95E-06	1.64E-05	4.05E-06	1.68E-05
Potatoes	1.78E-06	8.70E-06	2.00E-06	9.77E-06	2.16E-06	1.06E-05	1.70E-06	8.33E-06	1.91E-06	9.33E-06
HQ	0.14	0.42	0.14	0.44	0.11	0.36	0.1	0.32	0.14	0.44
Lead										
Bread and bread products	1.04E-05	3.54E-05	1.08E-05	3.68E-05	7.44E-06	2.53E-05	5.88E-06	2.00E-05	9.93E-06	3.37E-05
Vegetable oil and other fats	2.10E-06	4.80E-06	2.21E-06	5.05E-06	1.52E-06	3.48E-06	1.28E-06	2.93E-06	2.24E-06	5.11E-06
Milk and dairy products	2.88E-06	5.25E-06	2.95E-06	5.37E-06	3.09E-06	5.64E-06	2.86E-06	5.21E-06	2.92E-06	5.32E-06
Meat and meat products	9.70E-06	2.38E-05	1.03E-05	2.52E-05	5.44E-06	1.34E-05	5.44E-06	1.34E-05	1.15E-05	2.83E-05
Eggs	1.00E-06	1.36E-06	8.71E-07	1.18E-06	7.74E-07	1.05E-06	8.71E-07	1.18E-06	1.15E-06	1.56E-06
Fish and fish products	3.69E-06	1.08E-05	3.98E-06	1.16E-05	3.00E-06	8.76E-06	3.92E-06	1.15E-05	5.01E-06	1.47E-05
Sugar and confectionery	2.68E-06	1.16E-05	3.37E-06	1.45E-05	2.13E-06	9.19E-06	2.29E-06	9.88E-06	2.25E-06	9.69E-06
Fruit and berries	3.40E-06	8.30E-06	3.16E-06	7.70E-06	4.48E-06	1.09E-05	3.79E-06	9.24E-06	3.04E-06	7.43E-06
Vegetables and gourds	4.31E-06	1.79E-05	4.14E-06	1.72E-05	5.34E-06	2.22E-05	3.95E-06	1.64E-05	4.05E-06	1.68E-05
Potatoes	1.78E-06	8.70E-06	2.00E-06	9.77E-06	2.16E-06	1.06E-05	1.70E-06	8.33E-06	1.91E-06	9.33E-06
HQ	0.15	0.42	0.15	0.44	0.13	0.38	0.11	0.33	0.15	0.43
Arsenic										
Bread and bread products	1.90E-05	2.75E-05	1.97E-05	2.86E-05	1.35E-05	1.96E-05	1.07E-05	1.55E-05	1.81E-05	2.62E-05
Vegetable oil and other fats	2.48E-06	4.21E-06	2.60E-06	4.43E-06	1.79E-06	3.05E-06	1.51E-06	2.56E-06	2.63E-06	4.48E-06
Milk and dairy products	1.25E-05	1.42E-05	1.28E-05	1.46E-05	1.35E-05	1.53E-05	1.24E-05	1.41E-05	1.27E-05	1.44E-05
Meat and meat products	7.64E-06	8.20E-06	8.08E-06	8.67E-06	4.29E-06	4.60E-06	4.29E-06	4.60E-06	9.09E-06	9.75E-06
Eggs	2.36E-06	2.66E-06	2.05E-06	2.31E-06	1.82E-06	2.05E-06	2.05E-06	2.31E-06	2.70E-06	3.04E-06
Fish and fish products	1.14E-06	2.05E-06	1.23E-06	2.21E-06	9.25E-07	1.67E-06	1.21E-06	2.18E-06	1.55E-06	2.79E-06
Sugar and confectionery	4.19E-06	4.52E-06	5.26E-06	5.67E-06	3.32E-06	3.58E-06	3.58E-06	3.85E-06	3.51E-06	3.78E-06
Fruit and berries	7.40E-06	1.33E-05	6.87E-06	1.24E-05	9.73E-06	1.75E-05	8.24E-06	1.48E-05	6.62E-06	1.19E-05
Vegetables and gourds	3.92E-06	1.51E-05	3.76E-06	1.45E-05	4.85E-06	1.87E-05	3.59E-06	1.38E-05	3.68E-06	1.42E-05
Potatoes	5.93E-06	7.91E-06	6.66E-06	8.88E-06	7.19E-06	9.59E-06	5.68E-06	7.57E-06	6.36E-06	8.48E-06
HQ	0.22	0.33	0.23	0.34	0.2	0.32	0.18	0.27	0.22	0.33

It was found that the hazard coefficients for intake of contaminants in the median concentration and in the 90th percentile did not exceed the permissible level in all food clusters.

Based on the results of assessment of hazard coefficients, the greatest non–carcinogenic risk for various methods of contaminant intake is due to lead in the clusters 1, 2, 5 and cadmium in the clusters 1, 2 and 5. The greatest non–carcinogenic risk due to intake of mercury from food is characteristic of the clusters 1, 2 and 5; risks associated with intake of arsenic are highest for the 2nd cluster. V.M. Boev et al. found that HQ was at the permissible level for intake of individual contaminants, as well as HI for combined intake of lead, cadmium, arsenic and mercury with food in median concentrations and in the 90th percentile [18]. Research conducted by A.G. Setko et al. assessed non-carcinogenic risk and demonstrated that the level of risk was at an acceptable level (HQ ≤ 1) for main contaminants (nitrates, mercury, arsenic, cadmium) between 2007 and 2015 [19].

The study of contribution of specific food products groups that pose maximum risk according to the hazard index demonstrated that bread and bread products play a major role in formation of risks both when all the studied contaminants are in median concentrations and in the 90th percentile concentrations in the first and second nutrition clusters, with the greatest contribution made by intake of lead and cadmium in maximum concentrations with this type of food products (Table 5).

Contribution of milk and dairy products to formation of the cadmium hazard coefficient in median concentrations was noted at maximum values in the clusters 3 and 4 (21.7–23.1 %). The share of meat products in formation of the hazard coefficient, taking into account intake of mercury in median concentrations, ranges from 17 to 26.2 %; the largest contribution is typical for the clusters 1, 2 and 5. When considering contribution of sugar and confectionery products to formation of the hazard coefficient in the 90th percentile, maximum values of 10.8 % and 10.1 % were found in the 4th nutrition cluster due to intake of mercury. Plant-based diet of the cluster 3 indicates maximum contribution of vegetables and gourds to formation of the hazard coefficient for lead. The contribution of eggs, potatoes, fish and fish products on average does not exceed 10 % of non-carcinogenic risk for analyzed contaminants with various intake methods, which is also determined by the nature of individual consumption.

Analysis of literature on food contamination with heavy metals has shown that studies of risk are often based on data from the Federal State Statistics Service on average annual per capita consumption of the main groups of food products, which indicate regional peculiarities of risk formation. Thus, results of assessment of exposure to heavy metals in the Orenburg region on the basis of average per capita food consumption showed that milk and dairy products ranked first in terms of contributions to total exposure to lead, cadmium and arsenic; vegetables and gourds ranked second and third in terms of contributions to total exposure to lead, cadmium and arsenic; bread products, vegetables and gourds ranked first in terms of contributions to total mercury exposure, bread products ranked second, milk and dairy products ranked third [18]. Assessment of non–carcinogenic risks to health of the population of 16 districts of the Republic of Bashkortostan from contamination with lead, cadmium, chromium, nickel, copper, and zinc revealed 3 districts with high risk values (HI = 1.01–1.34) due to consumption of vegetable crops by the population of these districts [20]. In the Saratov region, bread and dairy products made the greatest contribution to formation of non-carcinogenic risks posed by food contaminated with heavy metals [21]. In our study, we used a methodological approach that takes into account peculiarities of food preferences in the surveyed population, which allowed us to more accurately assess the risk burden caused by contamination, identify the most vulnerable groups of the population in terms of high risks in order to take managerial decisions and organize preventive measures.

Table 5

Contribution of food products (%) to the formation of hazard coefficient in various food clusters, taking into account oral intake of contaminants

Food group	Cluster of nutrition	Cadmium		Mercury		Lead		Arsenic	
		Me	90	*Me*	90	*Me*	90	*Me*	90
Bread and bread products	1	28.6	32.2	24.8	27.7	28.8	33.3	28.6	27.2
	2	28.8	32.1	24.8	27.4	28.8	33.5	28.7	27.6
	3	22.1	27.1	21.0	22.9	22.5	26.3	22.3	20.3
	4	20.1	24.6	18.4	20.4	20.8	24.6	20.1	18.8
	5	27.4	30.2	22.6	25.6	26.9	31.5	27.0	26.5
Vegetable oil and other fats	1	4.4	5.7	5.0	3.8	2.7	3.0	3.7	4.2
	2	4.5	5.7	5.1	3.8	2.7	3.1	3.8	4.3
	3	3.5	4.8	4.3	3.2	2.1	2.4	3.0	3.2
	4	3.4	4.7	4.0	3.0	2.1	2.4	2.8	3.1
	5	4.7	5.9	5.1	3.9	2.8	3.2	3.9	4.5
Milk and dairy products	1	18.7	10.4	6.9	4.1	11.8	7.4	18.9	14.1
	2	18.5	10.2	6.7	4.0	11.6	7.3	18.6	14.1
	3	21.7	13.1	8.7	5.1	13.9	8.8	22.1	15.8
	4	23.1	13.9	8.9	5.3	15.0	9.6	23.4	17.1
	5	19.0	10.3	6.6	4.0	11.7	7.4	19.0	14.6
Meat and meat products	1	11.2	19.4	23.1	18.6	15.8	13.8	11.5	8.9
	2	11.5	19.7	23.4	18.7	16.1	14.1	11.7	9.1
	3	6.8	12.8	15.4	12.1	9.7	8.6	7.1	5.2
	4	7.8	14.8	17.0	13.6	11.4	10.1	8.1	6.1
	5	13.4	22.8	26.2	21.5	18.4	16.3	13.6	9.9
Eggs	1	0.9	0.5	2.4	1.1	1.4	1.1	3.6	2.7
	2	0.8	0.4	2.0	0.9	1.2	0.9	3.0	2.3
	3	0.8	0.4	2.2	1.0	1.2	0.9	3.0	2.2
	4	1.0	0.6	2.7	1.2	1.6	1.3	3.9	2.9
	5	1.0	0.6	2.6	1.2	1.6	1.3	4.0	3.1
Fish and fish products	1	2.3	3.3	8.8	8.4	3.3	3.9	1.7	2.1
	2	2.4	3.4	9.1	8.6	3.4	4.0	1.8	2.2
	3	2.0	3.1	8.5	7.9	2.9	3.5	1.5	1.8
	4	3.0	4.7	12.3	11.7	4.5	5.4	2.3	2.7
	5	3.1	4.4	11.4	11.1	4.4	5.2	2.3	2.8
Sugar and confectionery	1	6.7	6.8	6.4	9.1	3.9	4.6	6.0	4.5
	2	8.1	8.2	7.7	10.8	4.7	5.5	7.3	5.5
	3	5.7	6.3	6.0	8.3	3.4	4.0	5.2	3.7
	4	7.1	7.8	7.2	10.1	4.3	5.1	6.4	4.7
	5	5.6	5.6	5.1	7.3	3.2	3.8	5.2	3.8
Fruit and berries	1	13.7	6.7	8.1	6.5	7.3	7.0	11.2	13.5
	2	12.2	5.9	7.2	5.7	6.5	6.3	10.0	12.2
	3	19.4	10.3	12.7	9.9	10.5	10.2	16.0	18.5
	4	18.9	10.0	11.8	9,4	10.4	10.2	15.5	18.4
	5	12.3	5.9	6.9	5.6	6.4	6.2	9.9	12.0
Vegetables and gourds	1	9.0	12.2	10.3	14.0	13.6	17.4	5.9	14.9
	2	8.4	11.3	9.5	12.8	12.6	16.1	5.5	14.0
	3	12.1	17.8	15.1	20.1	18.5	23.9	8.0	19.3
	4	10.3	15.2	12.3	16.7	15.9	20.8	6.8	16.8
	5	8.5	11.3	9.2	12.7	12.5	16.2	5.5	14.3
Potatoes	1	4.5	2.9	4.2	6.8	11.5	8.4	8.9	7.9
	2	4.9	3.1	4.6	7.3	12.4	9.1	9.7	8.7
	3	5.9	4.1	6.1	9.6	15.3	11.3	11.8	10.0
	4	5.3	3.7	5.3	8.5	14.1	10.5	10.7	9.3
	5	4.8	3.0	4.3	7.1	12.1	8.9	9.5	8.6

Assessment of the hazard index for the combined effects of heavy metals on critical organs and systems was carried out in various clusters based on the pessimistic scenario of food contaminant consumption in the 90th percentile concentrations. Based on the obtained results, the highest total hazard index under simultaneous exposure to cadmium, mercury, lead and arsenic was noted in the second cluster for the endocrine system (HI = 1.68); the lowest risk level for this system was noted in the fourth cluster (HI = 1.25). Under combined exposure to mercury, arsenic and lead in maximum concentrations as regards the nervous system, the highest value of the total hazard index was also characteristic of the second cluster (HI = 1.22), and the minimum value was found in the fourth nutrition cluster (HI = 0.92). Risk of adverse effects on kidneys due to intake of cadmium and mercury was found to be acceptable. Risk levels were also found to be acceptable for effects of combined intake of mercury and lead on the reproductive system, intake of arsenic on the cardiovascular system, skin and gastrointestinal tract, and intake of lead on the hematopoietic system.

Assessment of hazard index for the combined effects of heavy metals on the body in similar studies, which did not consider peculiarities of food preferences in various population groups, found the highest risks for the endocrine system, central nervous system, and reproductive system [18]. Chemical contamination of food also has a negative impact on children as the most vulnerable category of the population with imperfect protection systems against xenobiotics. Correlation analysis between chemical contamination of food on young children and indicators of primary morbidity of children in the Russian Federation between 2012–2017 helped establish the relationship between contamination of food consumed by the analyzed heavy metals and primary incidence of endocrine pathology in both children of the first year of life and children from 0 to 14 years of various nosologies: obesity, insulin-dependent and insulin-independent diabetes mellitus [22, 23]. Analysis of these risks is necessary to predict development of adverse effects on a number of target organs under contaminant intake scenarios in different age groups [24–26].

Assessment of carcinogenic risk, taking into account intake of cadmium, arsenic and lead, demonstrated that when arsenic was ingested in median concentrations by the clusters 1, 2 and 5, the risk level corresponded to the third range (individual lifetime risk of more than $1 \cdot 10^{-4}$, but less than $1 \cdot 10^{-3}$), which is unacceptable, while the maximum level of carcinogenic risk was characteristic of the second cluster (Table 6). Carcinogenic risk caused by intake of cadmium and lead in median concentrations in all clusters was at the maximum permissible level.

Analysis of risk for the population of the Samara region from combined intake of the analyzed contaminants in the median concentration demonstrated that the largest number of new cases, 1.76 per 10,000 population, was found in the second cluster, due to intake of arsenic in the median concentration only, the number of new cases was also maximum in the second cluster, 1.03 per 10,000 population over 70 years.

Table 6

Level of carcinogenic risk in various nutrition clusters based on concentrations of heavy metals, taking into account various intake scenarios

Nutrition cluster	Arsenic		Cadmium		Lead	
	Me	90	*Me*	90	*Me*	90
1	1.01E-04	1.51E-04	4.61E-05	9.62E-05	2.43E-05	7.05E-05
2	1.03E-04	1.6E-04	4.77E-05	1.01E-04	2.53E-05	7.31E-05
3	9.11E-05	1.45E-04	4.26E-05	8.16E-05	2.21E-05	6.37E-05
4	7.93E-05	1.23E-04	3.69E-05	7.05E-05	1.89E-05	5.38E-05
5	1.01E-04	1.51E-04	4.59E-05	9.77E-05	2.48E-05	7.12E-05

When studying carcinogenic risks, taking into account intake of heavy metals in maximum concentrations (the 90th percentile), it was found that the level of this risk also corresponded to the third range (individual lifetime risk of more than $1 \cdot 10^{-4}$, but less than $1 \cdot 10^{-3}$), which is unacceptable, due to intake of arsenic in all clusters and intake of cadmium in the second cluster.

Due to combined intake of all three analyzed contaminants in maximum concentrations, the level of carcinogenic risk corresponded to the third range in all five clusters. The highest value of carcinogenic risk was noted in the second cluster.

Levels of risk for the population of the Samara region demonstrated that the second cluster had the highest probability of developing cancer equaling 1.6 new cases per 10,000 people over 70 years due to intake of arsenic in the 90th percentile concentration (pessimistic scenario); the maximum probability due to intake of cadmium was noted in the first cluster, 1.01 new cases per 10,000 people; the highest probability due to intake of lead was detected in the second cluster, 0.73 new cases per 10,000 people over 70 years. The highest number of new cases – 3.33 per 10,000 people, was also found in the second cluster due to combined intake of the analyzed contaminants in the 90th percentile concentrations.

Development of malignant neoplasms of the gastrointestinal tract due to intake of carcinogens with food has been confirmed by epidemiological studies conducted by various authors. Thus, cadmium, lead and arsenic are recognized as primary carcinogens for colon cancer; cadmium in food is recognized as primary carcinogen for cancer of recto-sigmoid junction and rectum [27, 28].

Thus, assessment of levels of population health risks posed by food contamination with heavy metals was conducted in this study. It involved clustering of the surveyed population based on the nature of food preferences, as well as taking into account the actual body weight in each cluster. This allows for the most accurate assessment of these risks and prediction of adverse effects in various population groups; the study results can be used for managerial decisions as well as for planning activities related to social and hygienic monitoring. In addition, the proposed cluster approach can be used to assess multi-thread effects of chemical compounds on various population groups.

Conclusions. In this study, five population groups with similar food preferences were formed based on the cluster analysis of actual nutrition and data on the nature of consumption of the main food groups were obtained for each cluster. In all clusters, the hazard coefficients for intake of contaminants in median concentrations and in the 90th percentile concentration did not exceed permissible level, while the greatest non-carcinogenic risk due to intake of lead, cadmium, and mercury was detected among people with a high level of consumption of all analyzed products (the first cluster). The highest carcinogenic risks were also identified for people whose diets were based on high consumption of high-calorie products such as bread, potatoes, confectionery, processed meat and dairy products (the second cluster) as well as among individuals whose diet was based on high consumption of meat products, processed meat and fish (the fifth cluster).

Formation of risk level, taking into account contributions of the main food groups, is influenced by the regional aspects of consumption of locally produced products and those imported from other regions. Under various intake scenarios in all food clusters, endocrine system is most at risk: the maximum level (HI = 1.68) was detected in the "high–calorie" second cluster; the minimum level (HI = 1.25), in the cluster with minimal preference for all studied foods.

In all clusters, levels of individual carcinogenic risk, mainly due to arsenic entering in median concentrations, corresponded to the third range, which is unacceptable, and was the highest in the ‘high-calorie’ second cluster. The level of carcinogenic risk due to arsenic intake in maximum concentrations (‘pessimistic scenario’) also corresponded to the third range and was the highest in the second cluster. The level of carcinogenic risk due to combined intake of all three analyzed contaminants in maximum concentrations corresponded to the third range in all five clusters. The maximum risk due to arsenic intake in median concentrations was found in the second cluster, 1.03 per 10,000 people over 70 years; for the 90th percentile, 1.6 new cases per 10,000 people over 70 years, which is several times higher than the risk due to cadmium and lead intake.

Funding. The research was not granted any sponsor support.

Competing interests. The author declares no competing interests.

References

1. Balali-Mood M., Naseri K., Tahergorabi Z., Khazdair M.R., Sadeghi M. Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. *Front. Pharmacol.*, 2021, vol. 12, pp. 643972. DOI: 10.3389/fphar.2021.643972

2. Mahmood A., Malik R.N. Human Health Risk Assessment of Heavy Metals via Consumption of Contaminated Vegetables Collected from Different Irrigation Sources in Lahore, Pakistan. *Arab. J. Chem.*, 2014, vol. 7, pp. 91–99. DOI: 10.1016/j.arabjc.2013.07.002

3. Khan A., Khan S., Khan M.A., Qamar Z., Waqas M. The Uptake and Bioaccumulation of Heavy Metals by Food Plants, Their Effects on Plants Nutrients, and Associated Health Risk: A Review. *Environ. Sci. Pollut. Res. Int.*, 2015, vol. 22, no. 18, pp. 13772–13799. DOI: 10.1007/s11356-015-4881-0

4. Nkansah M.A., Agorsor P.-I., Opoku F. Heavy Metal Contamination and Health Risk Assessment of Mechanically Milled Delicacy Called Fufu. *Int. J. Food Contam.*, 2021, vol. 8, pp. 6. DOI: 10.1186/s40550-021-00085-y

5. Tchounwou P.B., Yedjou C.G., Patlolla A.K., Sutton D.J. Heavy Metal Toxicity and the Environment. *Exp. Suppl.*, 2012, vol. 101, pp. 133–164. DOI: 10.1007/978-3-7643-8340-4_6

6. Pratush A., Kumar A., Hu Z. Adverse effect of heavy metals (As, Pb, Hg, and Cr) on health and their bioremediation strategies: a review. *Int. Microbiol.*, 2018, vol. 21, no. 3, pp. 97–106. DOI: 10.1007/s10123-018-0012-3

7. Li G., Xiong C., Xu W., Mei R., Cheng T., Yu X. Factors Affecting the Aluminum, Arsenic, Cadmium and Lead Concentrations in the Knee Joint Structures. *Front. Public Health*, 2021, vol. 9, pp. 758074. DOI: 10.3389/fpubh.2021.758074

8. Igbokwe I.O., Igwenagu E., Igbokwe N.A. Aluminium Toxicosis: A Review of Toxic Actions and Effects. *Interdiscip. Toxicol.*, 2019, vol. 12, no. 2, pp. 45–70. DOI: 10.2478/intox-2019-0007

9. Fu Z., Xi S. The Effects of Heavy Metals on Human Metabolism. *Toxicol. Mech. Methods*, 2020, vol. 30, no. 3, pp. 167–176. DOI: 10.1080/15376516.2019.1701594

10. Kim H.S., Kim Y.J., Seo Y.R. An overview of carcinogenic heavy metal: Molecular toxicity mechanism and prevention. *J. Cancer Prev.*, 2015, vol. 20, no. 4, pp. 232–240. DOI: 10.15430/JCP.2015.20.4.232

11. Witkowska D., Słowik J., Chilicka K. Heavy Metals and Human Health: Possible Exposure Pathways and the Competition for Protein Binding Sites. *Molecules*, 2021, vol. 26, no. 19, pp. 6060. DOI: 10.3390/molecules26196060

12. Frolova O.A., Bocharov E.P., Akhtyamova L.A. Risk assessment from exposure to chemical contaminants in food. *Gigiena i sanitariya*, 2016, vol. 95, no. 8, pp. 743–748. DOI: 10.18821/0016-9900-2016-95-8-743-748 (in Russian).

13. Tarmaeva I.Yu., Efimova N.V., Baglushkina S.Yu., Belykch A.I. Contamination of food raw materials and foodstuffs in Irkutsk region. *ZNiSO*, 2017, no. 10 (295), pp. 43–45. DOI: 10.35627/2219-5238/2017-295-10-43-45 (in Russian).

14. Bogdanova O.G., Efimova N.V., Bagaeva E.E., Tarmaeva N.A. Risk assessment for public health associated with nitrate content in crop products. *Voprosy pitaniya*, 2021, vol. 90, no. 3 (535), pp. 40–49. DOI: 10.33029/0042-8833-2021-90-3-40-49 (in Russian).

15. Eliseev Yu.Yu., Chekhomov S.Yu., Eliseeva Yu.V. Comparative Assessment of Nitrate Concentrations in Vegetables Grown on Commercial and Subsistence Farms in the Saratov Region. *ZNiSO*, 2021, no. 3, pp. 52–56. DOI: 10.35627/2219-5238/2021-336-3-52-56 (in Russian).

16. Zuo T.-T., Jin H.-Y., Chen A.-Z., Zhang L., Kang S., Li A.-P., Gao F., Wei F. [et al.]. Novel Integrated Tiered Cumulative Risk Assessment of Heavy Metals in Food Homologous Traditional Chinese Medicine Based on a Real-Life-Exposure Scenario. *Front. Pharmacol.*, 2022, vol. 13, pp. 908986. DOI: 10.3389/fphar.2022.908986

17. Gorbachev D.O. The use of software complex "Nutri-prof" in the assessment of actual nutrition and nutritional status of the population. *Journal of New Medical Technologies, eEdition*, 2019, no. 5, pp. 100–104. DOI: 10.24411/2075-4094-2019-16482 (in Russian).

18. Boev V.M., Kryazheva E.A., Begun D.N., Borshchuk E.L., Kryazhev D.A. Hygienic assessment of population health risks caused by combined oral introduction of heavy metals. *Health Risk Analysis*, 2019, no. 2, pp. 35–43. DOI: 10.21668/health.risk/2019.2.04.eng

19. Setko A.G., Mryasova J.K., Turin A.V. Risk of health disorders in children casued by consumption of contaminated food products. *Health Risk Analysis*, 2018, no. 4, pp. 89–95. DOI: 10.21668/health.risk/2018.4.10.eng

20. Bakirov A.B., Daukaev R.A., Larionova T.K., Fazlieva A.S., Kurilov M.V., Allayarova G.R., Afonkina S.R., Zelenkovskaya E.E. The results of research work on the assessment of food safety in the diet of residents of an industrially developed region. *Meditsina truda i ekologiya cheloveka*, 2021, no. 4 (28), pp. 7–14. DOI: 10.24412/2411-3794-2021-10401 (in Russian).

21. Chekhomov S.Yu., Eliseeva Yu.V., Pichugina N.N., Eliseev Yu.Yu. Potential risk for health of rural population related to consumption of local food products containing residual amounts of heavy metals. *Saratovskii nauchno-meditsinskii zhurnal*, 2020, vol. 16, no. 4, pp. 934–939 (in Russian).

22. Tikhonova Yu.L. Comparative analysis of chemical contamination of baby foods and primary pediatric morbidity. *Rossiiskii vestnik gigieny*, 2021, no. 3, pp. 28–32. DOI: 10.24075/rbh.2021.021 (in Russian).

23. Tikhonova Yu.L., Milushkina O.Yu., Bokareva N.A., Kozyreva F.U. Hygienic aspects of food safety for infant nutrition. *Voprosy detskoi dietologii*, 2022, vol. 20, no. 4, pp. 51–60. DOI: 10.20953/1727-5784-2022-4-51-6 (in Russian).

24. Bogdanova O.G., Efimova N.V., Molchanova O.A. Analysis of health risks associated with food safety. *Gigiena i sanitariya*, 2021, vol. 100, no. 12, pp. 1481–1486. DOI: 10.47470/0016-9900-2021-100-12-1481-1486 (in Russian).

25. Di Bella C., Traina A., Giosuè C., Carpintieri D., Lo Dico G.M., Bellante A., Del Core M., Falco F. [et al.]. Heavy Metals and PAHs in Meat, Milk, and Seafood from Augusta Area (Southern Italy): Contamination Levels, Dietary Intake, and Human Exposure Assessment. *Front. Public Health*, 2020, vol. 8, pp. 273. DOI: 10.3389/fpubh.2020.00273

26. Pajević S., Arsenov D., Nikolić N., Borišev M., Orčić D., Župunski M., Mimica-Dukić N. Heavy metal accumulation in vegetable species and health risk assessment in Serbia. *Environ. Monit. Assess.*, 2018, vol. 190, no. 8, pp. 459. DOI: 10.1007/s10661-018-6743-y

27. Boev V.M., Borshchuk E.L., Kryazhev D.A., Savina E.K. Malignant tumors of the rectum, rectosigmoid connections and colon and hygienic evaluation of carcinogenic chemicals entering the oral route. *ZNiSO*, 2017, no. 6 (291), pp. 13–17. DOI: 10.35627/2219-5238/2017-291-6-13-17 (in Russian).

28. Loud J.T., Murphy J. Cancer Screening and Early Detection in the 21st Century. *Semin. Oncol. Nurs.*, 2017, vol. 33, no. 2, pp. 121–128. DOI: 10.1016/j.soncn.2017.02.002

Gorbachev D.O. Cluster approach to the study of population health risks posed by contamination of food products with heavy metals. Health Risk Analysis, 2024, no. 1, pp. 47–58. DOI: 10.21668/health.risk/2024.1.05.eng

Received: 30.11.2023
Approved: 25.01.2024
Accepted for publication: 05.03.2024