Elemental composition of mammals in natural and anthropogenic areas and their ranking using the USEtox model

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Composition élémentaire de mammifères dans les zones naturelles et anthropiques et impacts potentiels avec la méthode USEtox

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T H È S E

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COMPOSITION ELEMENTAIRE DE MAMMIFERES DANS LES ZONES NATURELLES ET ANTHROPIQUES ET IMPACTS POTENTIELS AVEC LA METHODE USETOX

Resume :

L'heterogeneite geochimique de la biosphere, due a des conditions naturelles et anthropiques differentes, est en train de changer de maniere significative du fait du developpement de l'homme et de la societe. Cependant, dans de nombreuses etudes, les donnees sur l'interaction des elements chimiques dans ces cadres de differentes conditions ecologiques locales sont absentes; peu d'attention est accordee a l'approche complexe, par exemple, l'utilisation du modele d'evaluation des impacts sur les organismes vivants. La methode de l'Analyse du Cycle de Vie (ACV) permet de mesurer l'ampleur et l'importance de l'impact sur l'environnement et l'organisme humain. Le coefficient caracteristique (CF) - est une valeur tabulaire, proposee par le modele, selon l'emplacement de la region. Dans ce document, il est propose de modifier ce coefficient en introduisant les resultats de l'analyse biogeochimique de territoires presentant des situations ecologiques differentes, afin de les classer plus precisement. Cette modification determine la pertinence de l'etude. L'Objet de la recherche est determine par Évaluation de l'etat geo-ecologique des zones locales de la Russie et du Kazakhstan avec l'aide des 'indicateurs de la composition elementaire des organes et des tissus des mammiferes et d'un classement de la toxicite des differents elements a l'aide du modele USEtox. Cette methode permet d'elargir le modele en utilisant des donnees locales sur la composition chimique du produit alimentaire - le porc - et ensuite peut etre utilisee pour evaluer les risques sanitaires pour la population des territoires etudies.

Hypotheses a confirmer dans cette these

1. Dans diverses conditions ecologiques et geochimiques environnementales, des rapports de correlation specifiques des elements chimiques avec le chrome ont ete observes dans l'organisme des mammiferes (*Sus scrofa domesticus*). Dans des echantillons de l'oblast de Pavlodar de la ville d'Ekibastuz - Cr - Eu-Cr-Yb ; dans des echantillons des villages Gazimuromsky Zavod, Taina, Kalga, Urovsky Kluchi Zabaykalsky Krai - Cr - Ca ; dans des echantillons des villages de Kizhirovo, Verkhnee Sechenovo Tomsk region Cr-Sb. La composition elementaire et les coefficients de concentration des elements chimiques changent, les rapports des elements (Th/U, Rb/Cs) changent egalement, ce qui peut servir d'indicateurs de ces conditions.

2. La composition elementaire des organes et tissus des mammiferes reflete les specificites de la technogenese de leurs habitats. Les caracteristiques de la composition se refletent dans la concentration d'un certain spectre d'elements sur les organes barrieres. Sous l'influence des usines de fusion de cuivre de l'Oural central, les embryons de petits mammiferes accumulent Sb, Cr, REE (Sm, Ce, La, Lu), Zn, Br, U. La barriere placentaire des femmes residant a proximite de l'unite industrielle du Nord s'accumule Th, Br, Zn, Sm, Hf. Dans la zone d'influence de l'unite industrielle du Nord de la region de Tomsk, la barriere hemato-encephalique est egalement perturbee par l'accumulation de Rb, Ba, Au, Fe, Cs dans les tissus du cerveau et de la moelle

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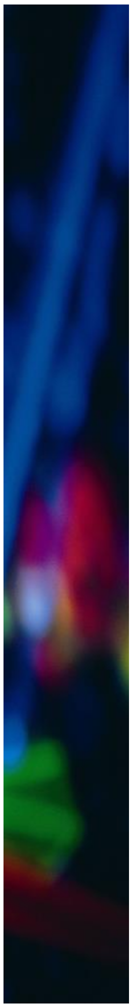
epiniere. Dans la zone de l'industrie miniere et energetique d'Ekibastuz, l'accumulation maximale d'elements est sur la barriere du gros intestin.
3. Le calcul de l'indice d'impact sur la sante humaine de la toxicite des elements en fonction de leur contenu dans le tissu musculaire d'un mammifere permet de classer les indicateurs des elements chimiques par ordre decroissant : As> Sb> Zn> Zn> Cr> Ba. L'indice de toxicite varie selon la voie d'entree des elements dans l'organisme et presente des caracteristiques specifiques selon le type de technogenese du territoire.
Les etudes que nous avons menees nous ont permis de tirer les conclusions suivantes :
1. Dans les conditions locales de territoires de la Russie et du Kazakhstan, divers elements chimiques specifiques s'accumulent et leurs correlations changent, ce qui peut etre utilise comme indicateurs de la situation geoecologique dans la region.
2. Le coefficient de toxicite modifie permet de classer les territoires locaux de la Russie et du Kazakhstan en fonction du degre de toxicite des differents elements pour la sante humaine. En general, pour le peuplement du kraï de Zabaïkalski, cet indicateur le caracterise comme la zone de charge la plus intense pour l'homme.

Mots clés :

- Bioindicateurs
- Composants chimiques
- Mammifères
- Technogenèse
- LCA indicateurs



ELEMENTAL COMPOSITION OF MAMMALS IN NATURAL AND ANTHROPOGENIC AREAS AND THEIR RANKING USING THE USETOX MODEL

ABSTRACT :

The geochemical heterogeneity of the biosphere, due to different natural and anthropogenic conditions, is changing significantly as a result of the development of man and society. Modern geo-ecological studies of different territories prove the fact of close connections of living organisms with the environment. However, little attention is paid to the complex approach, for example with the use of the model of impact assessment on living organisms. The Life Cycle Assessment (LCA) method, is allowed the magnitude and significance of the impact on the environment and the human organism to be monitored. The characteristic coefficient (CF) - is a tabular value, proposed by the model, depending on the region's location. In this thesis, however, it is proposed to modify this coefficient by introducing the results of biogeochemical analysis of territories with different ecological situations, in order to rank them more precisely. It is this modification, which determines the relevance of the study. The PhD thesis is purposed to assess the geo-ecological state of local areas of Russia and Kazakhstan with the use of indicators of the elemental compositions of organs and tissues of mammals, and a ranking of the toxicity of individual elements using the USEtox model. The modification method of the USEtox impact assessment model, using the results of the chemical analysis, can be used as a local supplement in the assessment of toxic effects on the population.

Principal propositions to be confirmed in this thesis.

1. Under various ecological and geochemical environmental conditions specific correlation ratios of chemical elements with chromium were observed in the mammalian organism (*Sus scrofa domesticus*). In samples from Pavlodar oblast of Ekibastuz city - Cr - Eu-Cr-Yb; in samples from the villages Gazimuromsky Zavod, Taina, Kalga, Urovsky Kluchi Zabaykalsky Krai - Cr - Ca; in samples from the villages of Kizhirovo, Verkhnee Sechenovo Tomsk region Cr-Sb. Elemental composition and concentration coefficients of chemical elements change, element ratios (Th/U, Rb/Cs) also change, which can serve as an indicators of these conditions.
2. The elemental composition of mammalian organs and tissues represents the specifics of the technogenesis of their natural habitat in the concentration of a certain spectrum of elements on barrier organs. Under the influence of the Central Urals copper smelting plant embryos of small mammal, accumulate Sb, Cr, REE (Sm, Ce, La, Lu), Zn, Br, U. The placental barrier of women residents living near the Northern industrial unit accumulates Th, Br, Zn, Sm, Hf. In the influence zone of the Northern industrial unit of the Tomsk region, the blood-brain barrier is also disrupted with the accumulation of Rb, Ba, Au, Fe, Cs in the tissues of the brain and spinal cord. In the Ekibastuz mining and energy industry area, the maximum accumulation of elements is on the barrier of the large intestine.
3. Calculation of the human health impact index of toxicity of elements, according to their content in the muscle tissue of a mammal, allows the chemical elements' indicators to be ranked, in diminishing order: As> Sb> Zn> Cr> Ba. The toxicity index varies depending on the route of entry of elements into the body, and has specific features depending on the type of technogenesis in the territory.

The studies we conducted allowed us to draw the following conclusions:

1. In the local conditions of the territories of Russia and Kazakhstan, various specific chemical elements accumulate, and their correlations change, these can be used as indicators of the geoecological situation in the region.
2. The modified reporting toxicity coefficient allows the local territories of Russia and Kazakhstan to be ranked according to the degree of toxicity of the individual elements for human health. In general, for the settlement of the Zabaikalsky Krai, this indicator characterizes it as the zone of the most intense load for humans.

Keywords :

- Bioindicators
- Chemical components
- Mammals
- Technogenesis
- LCA indicators

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INTRODUCTION

The geochemical heterogeneity of the biosphere, due to different natural and anthropogenic conditions, is changing significantly as a result of the development of man and society. Extraction of minerals, their processing, use and utilization, the construction and operation of industrial facilities leads to serious changes in the geo-ecological conditions of living organisms, including humans. The increased inflow of certain chemical elements into the natural environment is clearly reflected in the elemental composition of biota. Living organisms become geo-indicators of anthropogenic transformation of local territories. The main results of the study of the chemical composition of biological objects: plants or animals and humans as geoecological indicators were presented in the works of Vinogradova A.P., Vinogradova L.D., Kovalsky V.V., Dobrovolsky V.V., Perelman A.I., Kovalevsky A.L., Kista A.A., Kabaty-Pendias A. and Pendias X ., Tkalicha S.M., Saenko G.N., Avtsyna A.P., Malyugi D.P., Bowen HJM, Fortescue JAC, Kalani DK, Zhavoronkova A.A., Risha M.A., Ermakova V. V., Moiseenko T.I., Suslikova V.L., Agadzhanyan N.A., S.F. Tyutikova, V.A. Alekseenko, M.S. Panin, Malgina M.A., Ilyina V.B., Khristoforova N.K., Puzanova A.V. and many other authors.

Modern geo-ecological studies of different territories (Belan L.N., V.N. Udachin, V.S. Bezel, Panichev A.M., A.M.Syso, V.D. Strakhovenko, Yu.V. Robertus, Leonova G.A., Korobova E.M., Kuramshina N.G., Shaimardanova B.Kh., Korogod N.P. and many others) prove the fact of close connections of living organisms with the environment, which was mentioned by V.I. Vernadsky (1960). However, in many studies there is no data on the interaction of chemical elements within these frameworks of different local ecological and geochemical conditions: their wide range is rarely considered; little attention is paid to the complex approach, for example with the use of the model of impact assessment on living organisms. However, the complicated ecological situation in local areas due to the anthropogenic impact of industries needs to assess the potential negative impact on the human health.

The Life Cycle Assessment (LCA) method, one of the leading tools of environmental management in the European Union, is allowed the magnitude and significance of the impact on the environment and the human organism to be monitored. Lifecycle assessment models due to the international standards (GOST RISO) adoption (Prituzhalova, 2007) have already been rolled out in Russia (Sidorenko, Mikheev, 2017; Perminova, 2017; Yalaltdinova, 2015; Starostina, Ulanova, 2013; Mamadzhanov, Sidorenko, Latushkina 2011). The model is widely used in the works of researchers in other countries (Peña, 2018; Ortiz de García, 2017; Rosenbaum, 2011), and is recognized by the international scientific community. The negative impact indicator - the characteristic coefficient (CF) - is a tabular value, proposed by the model, for 25 inorganic and 3000 organic compounds, depending on the region's location. In this paper, however, it is proposed to modify this coefficient by introducing the results of biogeochemical analysis of territories with different ecological and geochemical situations, in order to further rank them more precisely. It is this modification which determines the relevance of the study.

Purpose of work. Assessment of the geo-ecological state of local areas of Siberia, Trans-baikalia and Kazakhstan with the use of indicators of the elemental compositions of organs and tissues of mammals, and a ranking of the toxicity of individual elements.

To resolve this problem **the following tasks** were set:

1. To take samples of biological material of mammals in local areas with different geo-ecological conditions of functioning of natural and man-made systems;
2. To establish indicators of the concentration and ratio of chemical elements in organs and tissues, as well as in biological fluid of the mammalian organism, for local territories of Russia and Kazakhstan;
3. To identify biogeochemical specificity of the formation of barrier properties of organ systems and their changes in the conditions of urbanization and human economic activity
4. To modify the method of calculating the characteristic toxicity factor of public health using the USEtox model by the introduction of the results of chemical analysis of the selected biomaterial;
5. To rank the areas according to the magnitude of the characteristic toxicity factor for public health.

Principal propositions to be confirmed in this thesis.

1. Under various ecological and geochemical environmental conditions specific correlation ratios of chemical elements with chromium were observed in the mammalian organism (*Sus scrofa domesticus*). In samples from Pavlodar region of Ekibastuz city - Cr (Eu-Cr-Yb); in samples from the villages Gazimuromsky Zavod, Taina, Kalga, Urovsky Kluchi Zabaykalsky Krai - Cr - Ca; in samples from the villages of Kizhirovo, Verkhnee Sechenovo Tomsk region Cr-Sb. Elemental composition and concentration coefficients of chemical elements change, element ratios (Th/U, Rb/Cs) also change, which can serve as an indicators of these conditions.

2. Indicator elements concentrate in the barrier organs of the domestic pig under the different environmental conditions. In the conditions of technogenesis in Seversk city, more elements accumulate in the biogeochemical barriers of the central nervous system organs, whereas under the influence of the energy and mining industries of Ekibastuz, the main accumulation of elements is in the digestive system barrier, with maximum concentrations in the large intestine.

3. Calculation of the human health impact index of toxicity of elements, according to their content in the muscle tissue of a mammal, allows the chemical elements' indicators to be ranked, in diminishing order: As> Sb> Zn> Cr> Ba. The toxicity index varies depending on the route of entry of elements into the body, and has specific features depending on the type of technogenesis in the territory.

Factual material and research methods.

The thesis is based on the results of studies conducted personally by the author, as well as with employees of the Geology department of the Engineering School of Natural Resources of the National Research Tomsk Polytechnic University. The paper also reviewed and used the material provided by fellow employees of universities and institutes in Yekaterinburg (Institute of Plant and Animal Ecology, Ural Branch of the Russian Academy of Sciences).

In the framework of the study, 186 samples of organs and tissues of the domestic pig, representing all the organ systems of the animal, were examined. The main sampling territories were: settlements of Kizhirovo and Verkhniy Sechenovo of the Tomsk region and the villages of Urovskie Klyuchi, Gazimurmsky Zavod, Taina, Kalga, Trans-Baikal Territory of Russia, as well as the city of

Ekibastuz, Pavlodar Oblast of Kazakhstan. For comparative analysis, data from other regions of Russia and Kazakhstan were examined.

For the quantitative determination of bromine in the components of the environment, the following methods were used: instrumental neutron activation analysis (INAA) and inductively coupled plasma mass spectrometry (ICP-MS). All selected materials were analyzed in accredited laboratories using certified methods using standard reference samples. The reliability of the analyzes is confirmed by control determinations on different media; internal control is performed.

The reliability of the principal propositions is ensured by a statistically significant number of samples analyzed by modern highly sensitive certified analytical methods (INAA, ICP – MS) in accredited laboratories, as well as by the depth of elaboration of factual material using modern methods of statistical processing and literature on the research topic.

Scientific novelty. The calculation of the characteristic toxicity coefficient for 5 chemical elements for 4 local areas of Siberia, Zabaikalsky Krai and Kazakhstan has been modified. The ranking of local territories of Siberia, Transbaikalia and Kazakhstan, differing in geological and geoecological specificity, according to the value of the human health impact characteristic toxicity coefficient, is presented for the first time. For the first time, when studying the elemental composition of 176 samples of organs and tissues of domestic pigs (*Sus scrofa domesticus*), the INAA and ICP-MS methods established indicators of the ratio of chemical elements in the organs and tissues of mammals living under the conditions of functioning of local natural and technogenic systems in Russia and Kazakhstan. The specifics of the functioning of biogeochemical barriers within mammalian organisms (the placental barrier, the blood-brain barrier, the digestive system barrier) and their change under the conditions of technogenesis are established.

Practical significance. The features of the concentration and distribution of chemical elements in the organs and tissues of domestic pigs in territories with different geoecological conditions thus revealed make it possible to differentiate them according to the degree of environmental load, which can be a useful addition to conducting geoecological monitoring of territories.

The modification method of the USEtox impact assessment model, using the results of the chemical analysis, can be used as a local supplement in the assessment of toxic effects on the population. This method allows the model to be expanded using local data on the chemical composition of the food product - pork - and can later be used in assessing the health risks to the population of the studied territories.

The materials obtained in the course of the work were used in the preparation of practical classes for the course: "Environmental Risk Assessment" at the Geology Department of the Engineering School of Natural Resources of Tomsk Polytechnic University for the preparation of bachelors in the specialty "Ecology and Nature Management", and can also be used in "Ecology", "Geochemistry of living matter" and "Medical geology" courses for the preparation of masters in "Ecology and nature management".

Approbation of work. The main results of the dissertation were discussed at All-Russian and International symposia and conferences: International Scientific Symposium of Students and Young Scientists named after Academician M.A. Usova “Problems of geology and subsurface development” (Tomsk, 2015–2019); "Medgeo 2016" (Moscow 2016); International Conference “Radioactivity and Radioactive Elements in the Human Environment (Tomsk, 2016); International Conference "Ecobalance" (Tokyo, Japan, 2018); International Conference on Environmental Science and Technology “CEST 2019” (Greece, Rhodes, 2019).

In addition, the results of the dissertation were reported at scientific seminars in the Geology Department of TPU (Tomsk, Russia), and the I2M laboratory of the Arts et Métiers university (Bordeaux, France).

Publications. The main content and scientific results of the thesis have been published in 11 articles and abstracts, including 2 articles in peer-reviewed journals included in the Higher Attestation Commission list, of which 1 article in English in a journal indexed in the Scopus database (IF 4.9), 1 article in English in a journal indexed in the Web of Science database.

The structure and scope of work. The dissertation consists of an 8 chapters, list of references, set forth on 138 pages of typewritten text. It includes 93 Figures and 28 tables. The bibliography contains 158 sources.

In the introduction, the relevance of the research is indicated, the purpose and objectives are stated, the main results are shown, their scientific novelty and practical significance are presented, as well as the author's contribution and testing of the work. **The first chapter** discusses the functioning of the biogeochemical barriers of a living organism, and the exceptional role of the elemental composition of the organs of the domestic pig. **The second chapter** discusses methods of analyzing the ecological state of the environment, studying the natural environment using biogeochemical research methods and a life cycle assessment method. **The third chapter** provides a brief geological description of the study areas. **The fourth chapter** describes the research methodology, sampling methods, their subsequent preparation, analysis methods, methods of mathematical data processing, as well as the methodological foundations of the USEtox model. **The fifth chapter** is devoted to the statistical parameters of the accumulation of elements in the body of the domestic pig: average contents are calculated; the correlation coefficients and variations of the elements in the entire studied sample are calculated. **The sixth chapter** discusses the main indicators of technogenesis. **In the seventh chapter**, there is a comparative analysis of the content of chemical elements in samples of organs and tissues of mammals taken from the Tomsk region, Zabaikalsky Krai and Pavlodar regions. The features of the distribution and concentration of elements in the barrier systems of organs are described. **The eighth chapter** is devoted to the use of the USEtox model in assessing the toxicity of elements for public health, as well as the methodology for calculating the characteristic toxicity coefficient using local data, both at the regional level (investigated in the work of the region) and at the country level (own calculations and literature data). In **conclusion**, the main results and conclusions of the dissertation are considered.

The author's contribution is the selection and preparation of 33 samples of biological material of the Domestic Pig in the city of Ekibastuz, Pavlodar Region, for INAA, ISP-MS chemical analyzes, and the release of biological water from the body by the Dean-Stark method.

The author personally carried out statistical processing of all data, gives an interpretation of the results and formulated the protected provisions. The author calculated the characteristic toxicity coefficients for Cr, Zn, As, Ba, Sb, and also, in collaboration with the supervisors (Belyanovskaya et al., 2019), developed a methodology for calculating the characteristic toxicity coefficient in the USEtox model.

CHAPTER 1. BIOGEOCHEMICAL BARRIERS OF LIVING ORGANISMS AS INDICATOR VALUES OF CHANGES IN ENVIRONMENTAL AND GEOCHEMICAL CONDITIONS

In geological and geoecological studies the concept of "geochemical barrier" has existed for some time. It was first proposed by Perelman to determine the change in the intensity of migration of chemical elements as a result of changing environmental conditions with a sharp concentration at the boundaries of the barrier (fig. 1)

Figure 1. Physico-chemical and biogeochemical barriers in nature (According to A.I. Perelman) (Perelman, 1979)

The following types of geochemical barriers are distinguished *(*Perelman, 1979*)*: 1 - Temperature; 2 - decompression; 3 - Acid-alkaline; 4 - Redox; 5 - Adsorption; 6 - Evaporative; 7 - Mechanical; 8 - Biogeochemical.

Considering the definition of a biogeochemical barrier, it should be noted that it is characterized by the participation of living organisms, microorganisms, plants, and etc. It is significant that in the living organism itself the formation of certain barriers is associated with changes in the internal environment. Biologists identify external and internal barriers. Internal barrier systems (histo-hematic), in turn, are divided depending on the ratio of blood and barrier organ. Considering both approaches to the concept of "barrier" from the changes in the migration of chemical elements and their physiological role, the term "biogeochemical barrier" can be applied to the internal environment of a living organism.

The anthropogenic impact on the environment is predominantly negative and changes the natural communities and organisms. As a result of this effect, organisms are forced to adapt, forming protective barrier mechanisms, which we call biogeochemical barriers. Biogeochemical barriers in geology are zones of increased accumulation of chemical elements by plant and animal organisms (Baranovskaya, 2011). They are formed under the influence of environmental factors and the chemical properties of elements (Baranovskaya, 2011). Similar systems exist inside living organisms, their function is also a sharp decrease in the intensity of migration (Perelman AI, 1961 (Perelman, 1979)) of potentially hazardous substances in tissues. The ability to selectively accumulate chemical elements makes barrier organs the most indicative for geoecological territorial studies.

A living organism includes numerous barriers, some of which separate the internal environment from the external environment, while others separate the organ systems inside the body. These barriers are found, for example, in the skin, respiratory tract, brain, eyes, and blood vessels, and they support homeostasis by regulating interactions between the departments they share. Moreover, barriers such as the blood-brain barrier and the air-liquid pulmonary-air interface are highly selective and serve to protect vital organs from the effects of toxins.

Conventionally, in a living organism, we distinguish between external barriers (mucous membranes of the eye, skin, oropharynx, nasopharynx, lungs, digestive organs, excretory organs) and internal (histohematological barriers). External barrier systems protect the living organism from the penetration of toxic substances from the environment, precipitating them in the mucous tissues and on the skin, while internal barriers regulate the transport of elements with blood. The internal barrier systems include blood-brain barriers, barriers between the blood and aqueous humor of the eye, between the blood and the endolymph of the labyrinth of the ear, between the blood and genital glands, etc. Histohematological barriers determine the organ's resistance to negative external influences. Internal barriers inhibit the transfer of foreign substances from the blood into tissues, thereby fulfilling a protective function. The regulatory function of histohematological barriers is the selective accumulation of certain substances from the blood in the tissues of an organ, to create the best environment for its life. Due to the selectivity of internal barriers, the chemical composition of any given organ can significantly differ from the composition of the internal environment of an organism. Thus, it has been scientifically proven that although the content of toxic elements in muscles is usually low (Johnson, Roberts, 2012), barrier organs (liver, kidneys) can concentrate them in their tissues, and the barrier role of these organs in the concentration of Cd is confirmed experimentally (Johnson, Roberts, 2012). M.S. Johnson concludes in his study that most pollutants settle there.

Researches of Mikheeva N.A. (Mikheeva, 2018) consider the protective role and permeability of the histohematological barriers and skin of small mammals for nanoparticles and confirm their size dependence.

The main protective systems, whose function has been repeatedly confirmed experimentally, are the kidneys and liver. Their special role in the increased concentration of potentially toxic elements due to their active release from the environment is confirmed by the studies of Vreman et al. (1986) (Veen, Vreman, 1986). The leading role of the kidneys as a body barrier system for such elements as Na, Sc, Cr, Mn, Br, Sm, Rb, La, Hf, Au, Pb, and the liver in the accumulation of Zn, Se is indicated by the results of the work of E.V. Kokhonov (Kokhonov, 2005).

A significant barrier role of bone tissue in the accumulation of zinc and lead and a direct reflection of the ecological state of the territory of residence in the organs and tissues of mammals is proved in the studies of M.S. Johnson et al., 1978 (Johnson, Roberts 2012).

The gastrointestinal tract occupies a separate place among the histohematological barriers of organisms, as the zone of active absorption of elements into the blood plays an important barrier role in a living organism. The surface of the mucous membrane of the gastrointestinal tract is lined with epithelial cells, which are an effective barrier separating the internal and external environments and blocking the passage of potentially harmful substances. Intestinal cells are also responsible for the absorption of nutrients and electrolytes, so a semipermeable barrier is required that selectively passes a number of substances, preventing others from entering. For this purpose, an “intestinal barrier function” has developed in the intestine, a protective system that prevents the passage of toxins, but allows the passage of beneficial substances.

Each section of the gastrointestinal tract of the domestic pig has a specific physiological role in the digestion process. So, in the small intestine under the action of bile, intestinal and pancreatic juices, the breakdown of nutrients occurs, followed by their absorption in the blood and lymph. In the large intestine, represented by the cecum, colon and rectum, up to 90% of water and some minerals are absorbed. The mucosa of the large intestine does not have villi, but contains recesses in the intestinal glands which contain a large amount of mucus. The microbial flora of the large intestine ferments carbohydrates and destroys the residual products of protein digestion. The rectum is responsible for the formation and accumulation of feces, and their excretion from the body.

Thus, when considering the intake of chemical elements from the external environment with inhaled air, food and water, as well as through the intestines and mucous membranes, we can confidently say that their further migration will be carried out according to similar patterns that already take place in geological formations. So, the process of deceleration and sedimentation in certain parts of the body will be affected by a change in the acid-alkalinity of the medium, which is especially important for the gastrointestinal tract, in which this indicator changes depending on the acid (pH = 3) pH in the stomach to alkaline (pH = 7) in the intestines. The role of microflora in the formation of a certain spectrum of elements is also very significant. For the respiratory system, it is important to form a barrier associated with a change in the oxidizing environment to a reducing one (accumulation of carbon dioxide).

Toxic elements from the geochemical environment, whose composition is currently determined by technogenesis (Arbuzov and Ershov, 2007), which concentrate in livestock, migrate into the human body along the biogeochemical food chain (Kowalski, 1982, Kowalski, 2009), and can be dangerous for the health of the population. Research by Petersson-Grawe et al. 1997 (Petersson-Grawe, K Thierfelder et al., 1997); Lopez-Alonso et al. 2002 (Lopez-Alonso M et al, 2002) emphasize the indicator role of domestic meat in assessing environmental pollution by metals.

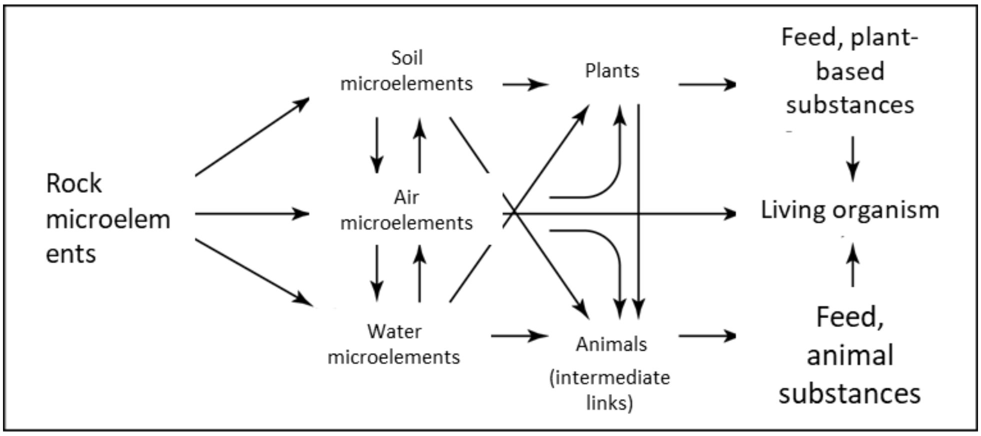

Figure 2. Migration of chemical elements and nutrients along the trophic chain (Kowalski, 1982, Kowalski, 2009)

Among biological indicators, a special category is agricultural animals (Adei, Forson-Adaboh, 2008), namely pigs, widely consumed by humans. Meat grown under anthropogenic conditions may contain elements with toxic properties (Kim et all, 2017; Santhi, 2008), such as Cd, Pb, Hg and As, which do not have significant biological functions, but are transported through the food chain (Figure 2). In addition, the lifestyle and nutrition of domestic pigs, as animals consuming both plant and animal feed produce a higher level of deposition of chemical elements (Pokarzhevsky, Van Straalen, Filimonova, 2000).

Most commonly, scientists pay particular attention to the content of elements in the muscles, liver, and kidneys of domestic pigs, but the elemental composition of the whole organism is also of scientific interest, as a model of the human body, reflecting in its composition the environmental impact. We call all internal barriers biogeochemical because they initially belong to a biological object. However, in the future they should be differentiated in more detail. The main issue in the application of data on the formation of such barriers in mammals remains their geo-indicator role, which is important for assessing the geo-ecological situation prevailing in regions that differ in geochemical conditions due to natural and technogenic environmental influences.

The elemental composition of the organs and tissues of the domestic pig indicates its geographical origin (Franke et al., 2005; Kim et all, 2017; Park et al., 2018) and the level of environmental impact (Larionov, 2005). Studies conducted by M. López-Alonso et al., 2007 (Lopez-Alonso et all, 2007) reveal the difference in the content of heavy metals in the liver, kidneys, and muscles of pigs grown in different countries of the European Union. The results of these studies were used later to compare the samples of biological material of pork grown in different countries (Kim et all, 2017) and note specific features of the elemental composition characterizing the geographical features of the region (Figure 3).

Elements	Domestic	Imported				
	Korea	USA	Germany	Austria	Netherlands	Belgium
Macro elements (ICP-OES)						
Al	$5.96^{d} \pm 0.345$	$4.27^{c} \pm 1.51$	$10.1^{e} \pm 2.81$	$1.27^{a} \pm 0.46$	Not detected	$2.86^{b} \pm 2.86$
B	$7.83^{c} \pm 0.077$	$5.68^{a,b} \pm 0.102$	$5.68^{a,b} \pm 0.126$	$6.21^{b} \pm 0.125$	$5.55^{a} \pm 0.10$	$5.58^{a} \pm 0.13$
Ca	$55.0^{b} \pm 5.00$	$65.2^{c} \pm 11.6$	$56.4^{b} \pm 17.8$	$309.5^{e} \pm 209.6$	$91.5^{d} \pm 10.8$	$10.6^{a} \pm 2.02$
Fe	$13.5^{d} \pm 3.32$	$8.05^{c} \pm 0.949$	$4.2^{a} \pm 0.183$	$6.61^{b} \pm 1.02$	$7.91^{c} \pm 0.708$	$7.76^{c} \pm 1.87$
K	$512.7^{a} \pm 49.6$	$1167.6^{e} \pm 105.8$	$871.0^{c} \pm 157.8$	$1272.5^{f} \pm 185.6$	$667.6^{b} \pm 70.0$	$941.9^{d} \pm 357.3$
Mg	$29.9^{a} \pm 2.69$	$78.6^{d} \pm 8.61$	$57.6^{c} \pm 11.5$	$85.4^{d,e} \pm 16.1$	$48.2^{b} \pm 2.18$	$56.5^{c} \pm 22.8$
Na	$362.0^{c,d} \pm 25.6$	$344.7^{b,c} \pm 31.3$	$318.3^{a,b} \pm 65.8$	$482.3^{a,b} \pm 106.2$	$750.8^{c} \pm 60.2$	$293.4^{a} \pm 31.9$
P	$335.0^{a} \pm 27.1$	$755.7^{d} \pm 61.7$	$588.5^{c} \pm 94.9$	$885.1^{e} \pm 178.6$	$407.6^{b} \pm 31.9$	$569.4^{c} \pm 217.8$
S	$70.0^{a} \pm 4.58$	$131.4^{c,d} \pm 14.7$	$97.6^{b} \pm 19.5$	$149.3^{d} \pm 26.0$	$114.7^{c} \pm 11.7$	$93.3^{b} \pm 33.0$
Zn	$3.75^{a} \pm 0.336$	$8.25^{d} \pm 0.958$	$6.07^{c} \pm 1.04$	$8.50^{d} \pm 2.03$	$5.49^{b,c} \pm 0.421$	$4.92^{a,b} \pm 1.38$
Trace elements (ICP-MS)						
As	$0.013^{b} \pm 0.003$	$0.215^{d} \pm 0.017$	$0.141^{c} \pm 0.004$	$0.006^{a} \pm 0.001$	$0.008^{a} \pm 0.001$	$0.006^{a} \pm 0.001$
Ba	$0.068^{a} \pm 0.008$	$0.198^{d} \pm 0.044$	$0.175^{c} \pm 0.035$	$0.061^{a} \pm 0.011$	$0.125^{b} \pm 0.017$	$0.121^{b} \pm 0.024$
Be	0.0005 ± 0.000	$0.0002^{a,b} \pm 0.000$	Not detected	$0.00004^{a,b} \pm 0.0000$	$0.00004^{a,b} \pm 0.0000$	Not detected
Bi	$0.0001^{b} \pm 0.000$	$0.0001^{b} \pm 0.000$	$0.0002^{b} \pm 0.000$	$0.00003^{a} \pm 0.0000$	$0.0001^{b} \pm 0.000$	$0.0001^{b} \pm 0.000$
Cd	$0.0006^{a} \pm 0.000$	$0.002^{b,c} \pm 0.001$	$0.003^{b,c} \pm 0.001$	$0.001^{b} \pm 0.000$	$0.004^{c} \pm 0.001$	$0.004^{b,c} \pm 0.001$
Co	$0.007^{c} \pm 0.001$	$0.011^{d} \pm 0.003$	$0.002^{b} \pm 0.001$	$0.001^{b} \pm 0.000$	$0.0001^{a} \pm 0.000$	Not detected
Cr	$0.003^{c} \pm 0.000$	$0.0009^{a} \pm 0.000$	$0.0006^{b} \pm 0.000$	$0.00007^{a} \pm 0.0000$	$0.0005^{b} \pm 0.000$	$0.0005^{b} \pm 0.0000$
Cs	$0.010^{a} \pm 0.001$	$0.010^{a} \pm 0.001$	$0.013^{a,b} \pm 0.004$	$0.012^{a,b} \pm 0.002$	$0.010^{a} \pm 0.002$	$0.025^{c} \pm 0.012$
Cu	$0.0007^{a} \pm 0.000$	$0.0008^{a} \pm 0.000$	$0.002^{b} \pm 0.001$	$0.002^{b} \pm 0.001$	$0.0007^{a} \pm 0.0000$	$0.0008^{a} \pm 0.000$
Ga	$0.009^{b} \pm 0.001$	$0.020^{b,c} \pm 0.005$	$0.017^{b,c} \pm 0.003$	$0.005^{a} \pm 0.001$	$0.012^{b} \pm 0.002$	$0.012^{b} \pm 0.002$
Li	$0.007^{c} \pm 0.000$	$0.002^{a} \pm 0.000$	$0.002^{a} \pm 0.001$	$0.0005^{a} \pm 0.000$	$0.003^{a} \pm 0.001$	$0.001^{a} \pm 0.000$
Mn	$0.145^{c} \pm 0.020$	$0.346^{d} \pm 0.036$	$0.149^{c} \pm 0.011$	$0.038^{a} \pm 0.015$	$0.074^{a,b} \pm 0.004$	$0.053^{a} \pm 0.009$
Ni	$0.45^{d} \pm 0.078$	$0.23^{c} \pm 0.071$	$0.043^{a} \pm 0.027$	$0.983^{b} \pm 0.137$	Not detected	Not detected
Pb	$0.05^{c} \pm 0.004$	$0.029^{a} \pm 0.005$	$0.134^{e} \pm 0.033$	$0.078^{d} \pm 0.035$	$0.047^{b} \pm 0.003$	$0.057^{c} \pm 0.013$
Rb	$0.001^{a} \pm 0.000$	$0.002^{b} \pm 0.000$	$0.002^{b} \pm 0.000$	$0.002^{b} \pm 0.000$	$0.002^{b} \pm 0.000$	$0.003^{c} \pm 0.001$
Se	$0.126^{a} \pm 0.006$	$0.376^{d} \pm 0.041$	$0.238^{b} \pm 0.025$	$0.22^{b} \pm 0.025$	$0.309^{c} \pm 0.025$	$0.231^{b} \pm 0.053$
Sr	$0.363^{b} \pm 0.019$	$3.87^{a} \pm 1.62$	$1.24^{a} \pm 1.13$	$0.314^{b} \pm 0.1$	$0.123^{a} \pm 0.081$	$0.140^{a} \pm 0.030$
U	$0.0007^{b} \pm 0.000$	$0.00005^{a} \pm 0.000$	Not detected	Not detected	Not detected	Not detected
V	$0.016^{e} \pm 0.001$	$0.012^{e} \pm 0.002$	$0.002^{a} \pm 0.001$	$0.004^{b} \pm 0.002$	$0.008^{d} \pm 0.001$	$0.006^{c} \pm 0.001$

Superscript letters (a–f) within the rows represent significant differences ($p < 0.05$) in the concentration levels of the corresponding analyzed elements.

Figure 3. The content of chemical elements in the meat of *Sus scrofa domesticus* according to the results of ICP-OES, ICP-MS (Kim et all, 2017), mg/g

The migration of heavy metals in the soil-plant-animal system is presented in the work of G.A. Larionov (Larionov, 2005), who established that the maximum permissible heavy metal content in meat of pigs and cows grazed in areas with high levels of natural pollution was exceeded. The author analyzed the content of heavy metals in pork grown in areas with varying degrees of technogenic impact (Figure 4).

Region	Heavy metal, mg/kg				
	Cd	Pb	Cu	Zn	Hg
Kahspapsky	-	0,4	-	-	-
Komsomolsky	0,00	0,4	-	-	0,000
Kozlovsky	-	0,02	0,45	7,84	0,002
Urmarsky	0,00	0,00	0,22	3,48	-
Cheboksarsky meat factory	0,00	0,00	-	-	0,002
Cheboksarsky meat factory	0,00	0,24	0,94	20,70	0,000
Cheboksarsky «Bacon»	0,01	0,02	0,78	3,42	0,003
Yantikovsky	-	0,01	-	-	0,003
Average	0,02±0,02	0,46±0,028	0,598±0,162	8,860±4,080	0,0017±0,0006
MPC	0,05	0,5	5,0	70,0	0,03

Figure 4.The content of heavy metals in the meat of *Sus scrofa domesticus* (Larionov, 2005)

There are other factors that influence the elemental composition of a living organism, for example, the amount of atmospheric emissions and airborne pollution, the content of HM in snow cover, water and diet feeds (Penkova et al., 2008). Thus, according to the data of Nikolik et al. (Nikolic et al., 2017), different types of pig breeding, namely free grazing, have an effect on the formation of the elemental composition of their meat. The highest concentrations of Fe were found in the meat of grazed animals, and most likely enter the body along with particles of swallowed soil. Studies by Haldimann, Dufossé, Mompart, and Zimmerli (1999) (Haldimann et all, 1999) confirm the dependence of the concentration of Se in the meat of farm animals on the concentration of this element in soils in the region of habitat. M. López-Alonso et al., 2007 (Lopez-Alonso et al., 2002) noted a positive correlation between As content in the soils of the studied region and pig liver and kidney. The intake of substances into the body from the soil is confirmed by the studies of Baranovskaya, 2011 (Baranovskaya, Rikhvanov, 2011)). It is assumed that the specific behavior of the animal, namely loosening the soil, leads to increased concentration in the digestive system of the greatest number of chemical elements.

Thus, the study of the concentrations of chemical elements in the pig's body is a useful means of evaluating the anthropogenic impact or studying natural anomalies in the region.

CHAPTER 2. METHODS OF ANALYSIS OF THE ECOLOGICAL STATE OF THE ENVIRONMENT

2.1 The study of the natural environment biogeochemical research methods

According to V.I. Vernadsky, living organisms are concentrators of dispersed rare substances and various chemical elements (Krivolutsky, Stepanov, Tikhomirov, 1988). Although biological systems are dependent on many biotic and abiotic factors, their changes can often be caused by the influence of human activity. In this regard, the definition of "bioindication" can be formulated as follows: "Bioindication is the detection and determination of biologically and environmentally significant anthropogenic pressures based on the reactions of living organisms and their communities" (Turovtsev and Krasnov, 2004). The concentration of chemicals in the environment correlates to their concentration in indicators (Markert et al., 2009). This affects and transforms the elemental composition of organisms due to accumulation of certain metals and pollutants (Lamborg et al., 2014).

Classical objects of bioindication are organs and tissues of living organisms. Vertebrate animals are much less frequently used as bioindicators than invertebrate animals or plants. Meanwhile, the sustainable functioning of natural ecosystems is determined by the integrity of the entire trophic system, since it is the highest trophic levels that act as significant factors in the stabilization and intensification of biogeochemical cycles.

Such biological objects as fish (Popov et al., 2012), small mammals (Johnson and Roberts, 2012; Sanchez-Chardi A and Lopez-Fuster MJ, 2009; Bezel, 1987; Kokhonov, 2005; Guardian, 2004; Snegin et al. 2014), large wild mammals (Budis et al., 2013), and farm animals (Huang et al., 2017; Kim et al., 2017; Santhi, 2008) are widely used as biological indicators. The relevance of using the latter has become apparent due to the fact that, as a result of the migration of chemical elements into natural ecosystems, maximum toxic effects are experienced precisely by the highest trophic levels (Hamers et al., 2006; Bezel and Mukhacheva, 2012; Nesterkova, 2014). Thus, the specificity of industrial production is reflected in their elemental composition and the level of deposition of chemical elements.

According to E.V. Kokhonov (Kokhonov, 2005), in the Tomsk region and on the territory of the Northern Industrial Hub, there is high variability in the accumulation of elements in the body of small mammals compared with Altay Mountains. According to S.A. Khoreva et al. (Horeva et al., 1958), changes in the chemical composition of the gastrointestinal tract are noted for animals living on the territory of the Tomsk Region, in particular in areas with radiation pollution. The works of Moskvitina N.S., Kuranova V.N., Babenko A.S. and other researchers in the Tomsk region show the possibility of using living organisms and their elemental composition as indicators of the state of the environment.

2.2 Study of the impact on human health by Life Cycle Assessment

Pollution from heavy metals and other chemicals is one of the types of environmentally negative effects on the environment and particularly living organisms. Complicated environmental tension dictates the need to develop measures aimed at minimizing the negative impact on the environment. However, to make effective decisions, it is necessary to have a clear idea of the currently existing methods, approaches, concepts and models for assessing the environmental state of the environment used worldwide, due to the lack of a uniform gradation and structure of these methods.

Currently the Life Cycle Assessment, LCA (Russian) or Life-Cycle Assessment, LCA (English) method is one of the leading environmental management tools in the European Union. It is based on a series of ISO-standards and designed to assess the environmental, economic, social aspects and environmental impacts on production and waste management systems. The LCA method, one-of-a-kind, is used in almost all industries, in particular, in mechanical engineering, construction, electronics, traditional and alternative energy, the production of polymers, food products, product design, and waste disposal (Starostina, 2011). In the Russian Federation, this method is also increasingly becoming part of the practice of assessing risks for the population and ecosystems

(Sidorenko, Mikheev, 2017; Starostina, Ulanova, 2013; Mamadzhanov, Sidorenko, Latushkina 2011).

Life cycle assessment takes place in four stages:

I. Definition of goals, objectives and scope;

II. Inventory analysis: determination of input (water, raw materials, energy) and output (emissions into the environment, waste) flows;

III. Environmental impact assessment carried out at the intermediate (Midpoint) and final (Endpoint) stages, each of which includes certain categories of impact (Figure 5);

IV. Evaluation (interpretation) of the results.

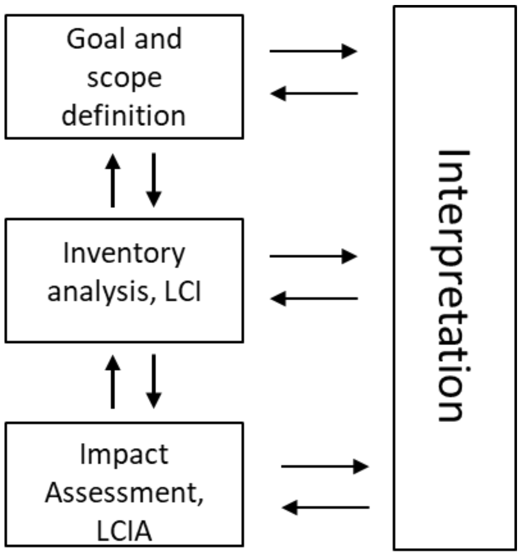

Figure 5. Life Cycle Assessment framework, (European Commission, 2010)

Life cycle impact assessment is a vital phase of any LCA. Assessment of the impact of the life cycle is aimed at understanding and quantifying the magnitude and significance of the potential environmental impacts of a product or service throughout the entire life cycle (Standards, 1991; Starostina, 2011). Understanding of these effects is the first step in preventive, recovery measures (European Commission, 2010). When assessing the life cycle, emissions and consumed resources that can be attributed to a specific product are organized and documented in a life cycle inventory. Then an impact assessment is carried out considering the impact on public health, the environment and issues related to the use of natural resources. The impacts considered in include climate change, depletion of the ozone layer, eutrophication, acidification, human toxicity (carcinogenic and non-carcinogenic), inorganic respiratory substances, ionizing radiation, ecotoxicity, the photochemical formation of ozone, land use and depletion of resources. Emissions and resources belong to each of these impact categories. Then they are converted into indicators using impact assessment models (table 1.) (Bare, Young, Hopton, 2018).

Table 1. LCIA models (Bare et al., 2018)

Model	**Authors**	**Description**
1	**2**	**3**
CML 2001	CML 2001 is developed by the Institute of Environmental Sciences, Leiden University, The Netherlands	CML 2001 is an impact assessment method which restricts quantitative modelling to early stages in the cause-effect chain to limit uncertainties.
EDIP 2003	The "Environmental Development of Industrial Products (EDIP)" is developed by the Institute for Product Development (IPU) at the Technical University of Denmark. EDIP 2003 is the update of the EDIP 1997 LCIA method methodology.	EDIP 2003 considers the characteristics of the receiving environment to increase the relevance of the calculated impacts.
Impact 2002+	IMPACT 2002+ is a methodology that is originally developed at the Swiss Federal. Institute of Technology Lausanne (EPFL), Switzerland.	New concepts and methods have been developed within IMPACT 2002+ for the comparative assessment of human toxicity and eco-toxicity. Human Damage Factors are calculated for carcinogens and non-carcinogens, employing intake fractions, best estimates of dose-response slope factors, as well as severities.
TRACI	The U.S. Environmental Protection Agency developed an Impact Assessment methodology called TRACI, short for "Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts".	Within the TRACI methodology the impact categories were characterized at the midpoint level, including a higher level of societal agreement concerning the certainties of modelling at this point in the cause-effect chain.
UBP 2013	Swiss national policy targets or international targets supported by Switzerland	The Ecological Scarcity Method permits impact assessment of life cycle inventories according to the ‘distance to target’ principle.

Continuation of table 1		
1	2	3
USEtox	USEtox is developed under the United Nations Environment Program (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative	The model provides both recommended and interim characterization factors for human health and freshwater ecotoxicity impacts.

Life cycle assessment models allow us to calculate substance-specific characteristic coefficients (CC), which represent the likelihood of a substance contributing to a specific type of impact. Models such as CML 1992, Eco-Indicator 95, IMPACT 2002+, TRACI, USEtox, etc. provide a calculation of the negative impact of metals on HC, but many uncertainties are still associated with this (Monteiro, Freire, 2012; Pizzol et al., 2011). These differences in the results of life cycle impact assessments are mainly related to differences in characterization models, such as spatial coverage (Dreyer, Niemann, Hauschild, 2003).

There are several types of spatial differentiation among impact assessment models, most of which can only provide information on environmental impacts at the continental level (table 2), so the regional aspect of the impact assessment system still needs to be developed.

Table 2. Types of spatial differentiation (Hauschild, Potting, 2000)

Levels of spatial differentiation	**Description**	**Models**
Site-generic	All sources are considered to contribute to the same generic receiving environment	EDIP 97 (Potting, Hauschild, 2006), CML2001 baseline (European Commission, 2010), EcoIndicator 99 (Pizzol et al., 2011)
Site-dependent	Source categories are typically defined at the level of countries or regions within countries (scale 50–500 km).	TRACI (Bare, 2012), EDIP2003 (Potting, Hauschild, 2006)
Site-specific	Models allow large accuracy in modelling of the impact very close to the source.	USEtox (Fantke et al., 2017), Recipe (Huijbregts et al.., 2016)

Most impact assessment models can only provide information on environmental impacts at the global level. However, the industrial impact often affects not only the areas where the products are manufactured but also border areas that are subject to wind or cross-border transport. Thus, it becomes necessary to assess impacts at a more local level.

Amongst all LCIA methods, the USEtox recommended by the European Commission is the only LCIA model that has a geographic separation parameter. The model includes 8 continental and 17 subcontinental zones, each of which is characterized by different climatic, hydrological, geographic, economic and other parameters Fantke et al. 2017; Rosenbaum, Margni, Jolliet, 2007). USEtox is currently little known in Russia, and is not used in environmental studies, nevertheless, the model is applied in the works of Yalatdinova A. R. (Yalaltdinova, 2015) and Perminova T.A. (Perminova, 2017) performed under dual postgraduate studies. The model is widely used in the works of researchers worldwide (Ortiz de García et al., 2017b; Peña et al., 2018; Rosenbaum et al., 2011, 2008), and most importantly, it is recognized and recommended by the world scientific community: United Nations Environment Program (UNEP), Society of Environmental Toxicology and Chemistry (SETAC), European Commission, Institute of the Environment and Sustainable Development, United States Environmental Protection Agency (EPA), etc., as the best scientific model for assessing the toxic effects of chemicals on ecosystems and human health. Despite all the advantages of using the USEtox model in assessing the impact of the life cycle, this model does not include a high level of spatial resolution, nor coverage of the metal database (Fantke et al., 2017).

In this paper, we propose a way to eliminate these limitations using one of the methods of environmental monitoring - biogeochemical studies. This method is based on the analysis of biological substrates, such as animal and human tissues, plants or microorganisms. The biogeochemical research method provides information on the direct reaction of organisms, communities or ecosystems to natural or anthropogenic changes (Durkalec et all, 2018), since biota reacts even to minor changes in external conditions and can also predict its geographical origin (Denisova, 2008; Franke et all, 2005; Gauthier-Lafaye et all, 2008; Huang et all, 2017; Ilyinskikh et all, 1998; Sheppard, 2011). Thus, bioindication results expressed by the concentration of metals in biological material can be extrapolated to the USEtox life cycle assessment model to expand its spatial differentiation.

CHAPTER 3. CHARACTERISTICS OF NATURAL-TECHNOGENIC SYSTEMS IN RUSSIA AND KAZAKHSTAN

The studied areas have various geological, geotectonic lithological and metallogenic features (Figure 6). They are located within different geological formations formed by rocks of diverse composition and age (Tectonics. USSR, 1964). Each studied region is located in the zone of various minerals deposits. The selected zones are also heterogeneous within one state. The territory of Pavlodar region in Kazakhstan is located in the junction zone of the Kazakh folded country and the West Siberian platform. The lithological composition of the region has a variety of igneous, metamorphic and sedimentary rocks. The Ekibastuz coal basin is located within the region; there are deposits of Cu, Mo, Au. The East Kazakhstan region has a complex structure and is located at the junction of the folded complex of Central Kazakhstan, the Zaysan folded system, the Genghis-Tarbagatai meganticlinorium, and the West Siberian platform structure. The formations are composed of igneous, sedimentary, metamorphic formations with a predominance of volcanic-sedimentary rocks (sandstones, siltstones, limestones, acidic effusive, etc.). Due to the variety of rocks in the region, more than 100 mineral deposits are exploited: polymetallic, rare-metal ores, coal, oil, brown coal, oil shale, etc. Tomsk region (Russia) is mainly located in the southeastern part of the West Siberian platform. In the southeast of the region, there are manifestations of volcanic rocks associated with the Tom-Kolyvan folded zone. On the territory are concentrated deposits of brown coal, gas, oil, ore minerals, etc. The territory of the Trans-Baikal Territory is localized on the border of the Siberian Platform and the Sayano-Baikal Mountain Region. Structural complexes are predominantly composed of sedimentary and acidic, less often the main igneous and metamorphic rocks. In the studied settlements of the Transbaikal Territory, such minerals as Au, coal, polymetallic ores, etc. are noted. The Republic of Tyva is located within the Altai-Sayan folded region, which contains magmatic (ophiolites, granites, etc.), sedimentary (carbonate, terrigenous and other) rocks. On the territory of the studied region, there are manifestations of Au, Fe, Ag, Cu, REE, Ni, etc. The geological characteristics of the local territories determine their geoecological features, and such specifics of the economic development of these regions as mining and processing of minerals form features of technogenic impact.

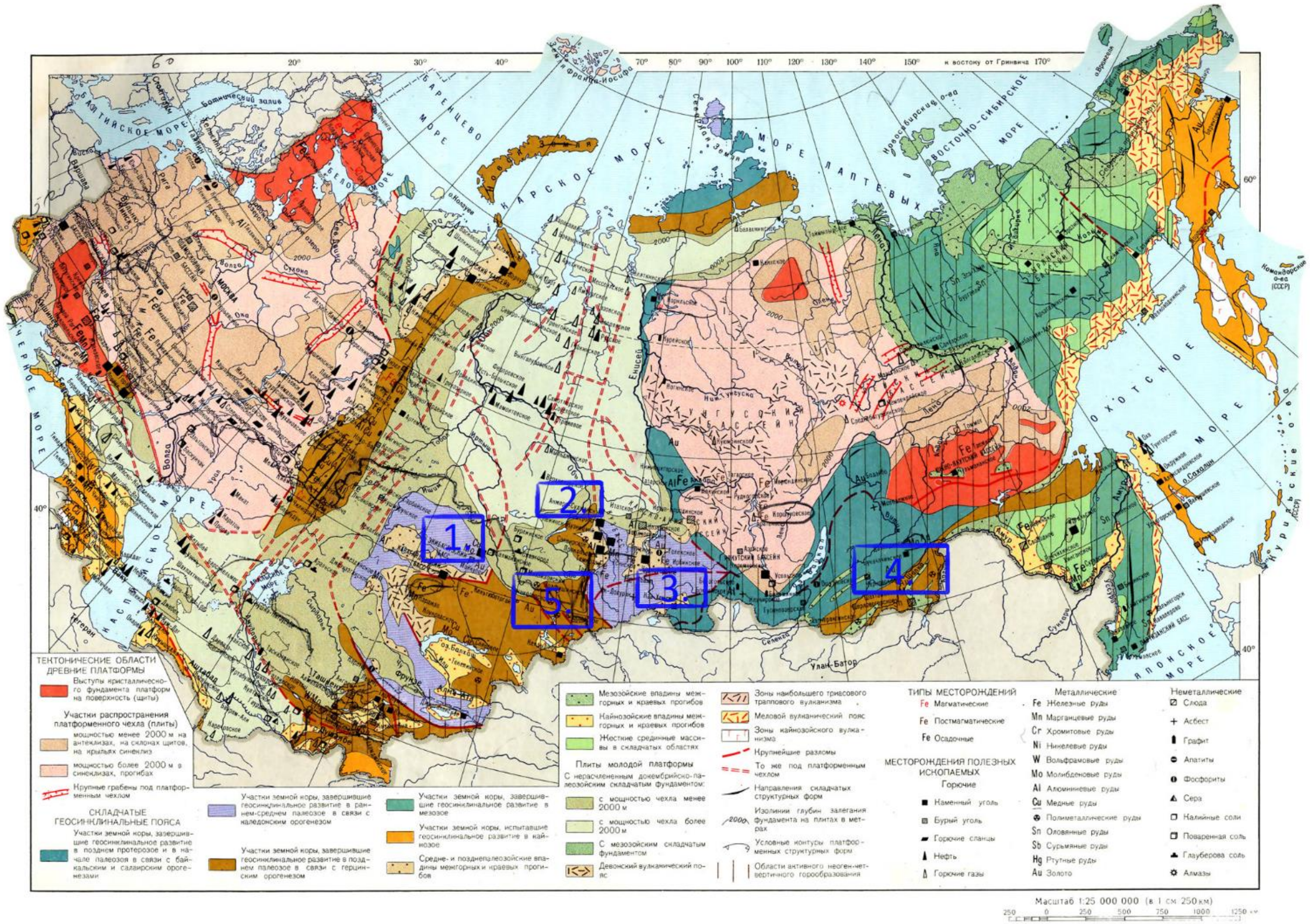

Figure 6.Tectonic map of the USSR (Tectonics. USSR, 1964) with additions by the author

Note: Republic of Kazakhstan: 1 - Pavlodar region, 5 - East Kazakhstan region; Russian Federation: 2 - Tomsk Region, 3 - Republic of Tuva, 4 - Trans-Baikal Territory

Kazakhstan. Ekibastuz city, Pavlodar region. The city of Ekibastuz is an example of a zone of intense anthropogenic impact of industrial enterprises on the environment. Pavlodar region is one of the largest industrial centers of the Republic of Kazakhstan.

The city of Ekibastuz is located southwest of the administrative center - the city of Pavlodar (Figure 6). To the north-west the region borders on Akmola, to the south-west Karaganda region, Aktogai to the north, Bayanaul to the south - and north-east the Aksu districts of Pavlodar region. By land area, the city of Ekibastuz is 2nd in the region. It accounts for 15% of the total area, or 1,887,602 hectares, including agricultural land 1,768,200 hectares; arable land 35,000 hectares, hayfields 25,800 hectares. The region includes only 26 settlements in the rural zone, including 2 villages - Solnechny, Shiderty, 8 rural districts, 3 villages. The administrative center is the city of Ekibastuz, the distance from the regional center is 132 km. The Karaganda-Pavlodar motorway passes in the immediate vicinity of the city of Ekibastuz,

The constant water flow is the Irtysh-Karaganda Canal. The channel connects separate small lakes along its length, which are reservoirs of water. The underwater canal flows from the river to the Irtysh, and a small extent due to precipitation and groundwater. Groundwater flow is provided by the terrain in the lower reliefs.

The climate in the region is sharply continental. The territory of Ekibastuz is very far from the ocean and prevailing winds are from the west and north. Thus, the various air masses, including industrial emissions, contribute to a significant contrast in conditions. The region is characterized by frosty, moderately severe winters and warm summers.

According to the report on the state of the environment of the Republic of Kazakhstan, the city of Ekibastuz accounts for 48% of atmospheric emissions (Ministry of Energy of the Republic of Kazakhstan, 2017).

Engineering, metalworking, chemical, light industry enterprises and the production of building materials are concentrated in the Pavlodar region. The region has three large urban areas - Pavlodar, Ekibastuz, and Aksu. Ekibastuz is characterized by a dangerous environmental situation, due to a widespread mining industry (coal mining) near the urban zone. The Ekibastuz coal deposit is the largest in the world. Bogatyr Access Komir LLP is an open-pit coal mining enterprise. The production capacity of the mine is 42 million tons of coal per year. Industrial coal reserves - 1.3 billion tons, cut depth - 175 m. (Rusina E.Yu., 2018; Sembaev, 2014).

The environmental condition of Ekibastuz is complicated by the presence in the adjacent territories of many unorganized sources of pollution (quarries, dumps, etc.), which are significant sources of atmospheric, soil and water pollution (Ministry of Energy of the Republic of Kazakhstan, 2017).

According to the Committee of Statistics, total atmospheric emissions have been steadily increasing since 2017. The main reason is an increase in production of the industrial enterprises of the region, including those located in the studied region of Ekibastuz State District Power Station-1 (aka Bulat Nurzhanov), Ekibastuz Station GRES-2 . The main sources of air pollution in the city of Ekibastuz are thermal power plants and coal mining (Сембаев, 2014). As a result of coal mining, ecosystems are polluted by technogenic substances such as coal, ash, dust. In the territory of Ekibastuz, there are large CHP plants that operate on Ekibastuz (local), Karaganda and Kuznetsk (imported) coal and fuel oil. High-ash coals, and insufficient cleaning by ash collectors at the local regional hydroelectric power station (TPP) and the Central Thermal Power Station (CHP), lead to significant emissions of harmful substances into the atmosphere - 45.8% of all emissions in the region, of which 94% belong to two power plants. According to the national report on the state of the environment of Kazakhstan in 2017, the substances polluting the air are, in order of priority, carbon monoxide, particulate matter, nitrogen dioxide, and sulfur dioxide.

Another of the city's urgent problems is water supply. Wastewater treatment is not effective, which causes secondary pollution of water by toxic elements and heavy metals, which increases the risk of water use dangerous to health. The permissible exposure limit is exceeded for all controlled substances, including ammonium and petroleum products.

According to research results, the city's soils are contaminated with cadmium, arsenic, and mercury (Sembaev, 2014).

According to the RSE "Kazhydromet", the average values of the background gamma radiation of the surface layer and background gamma radiation are within acceptable limits. The average daily density of radioactive fallout and the average value of their fallout density do not exceed the maximum permissible level.

Thus, the landscape-geochemical features of the region and its high degree of economic development result in increasingly harmful emissions into the natural environments, and this has negative consequences for the health of the population living in this territory. Without a doubt, such a critical environmental situation requires special study and assessment.

The village of Putnitsevo of the East Kazakhstan region. East Kazakhstan region, due to historical development associated with the predominance of non-ferrous metallurgy and mining, is one of the most disadvantaged regions in the Republic. The main mining and metallurgical enterprises are located in the zone of the densest river network. Due to technical necessity, the largest heat power enterprises are also located here. Such an arrangement means that all gaseous, liquid and solid waste pollutants from industrial enterprises inevitably fall into the river network and soil, causing environmental damage both to the territory (biocenoses) and the region's population (Toguzova, 2006; Mambetkaziev, Danilova, Mabetkaziev, 2011). The Republic's reserves are concentrated in the region: 27% of its lead, 47.7% of zinc, 47.9% of copper. The share of forecasted lead resources is 24.8%, zinc - 56.7%, copper - 29.3% of the total resources of the republic (City Information Site).

The village of Putintsevo is located in the Zyryanovsky district of the East Kazakhstan region of Kazakhstan. It is part of the Maleevsky rural district. It is located about 15 km north of the regional center, the city of Altai (Zyryanovsk) (Figure 7).

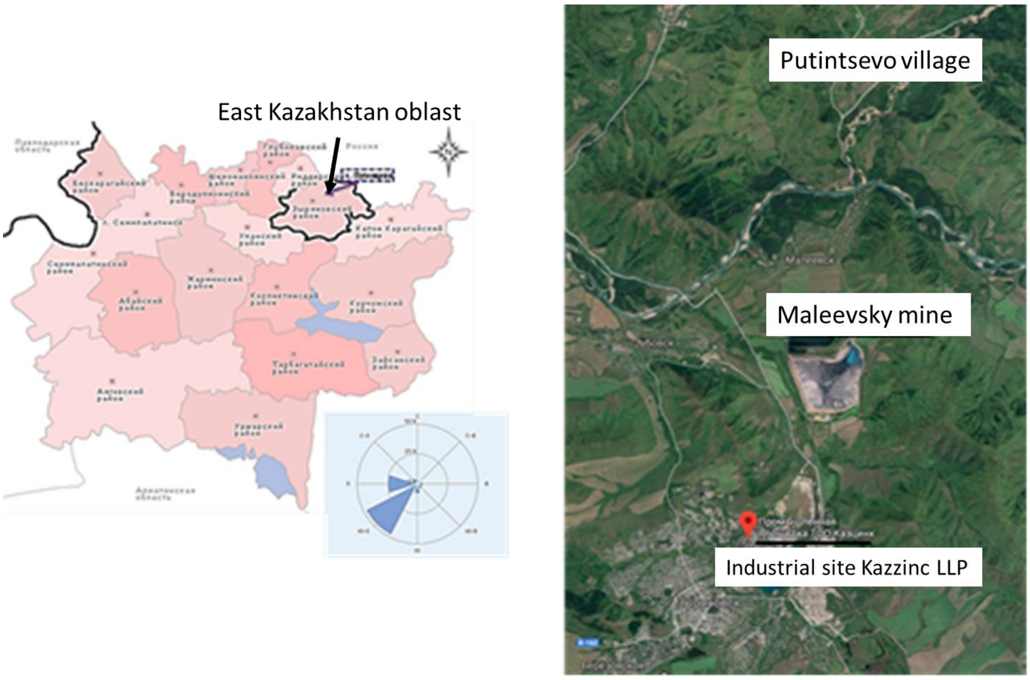

Figure 7. The village of Putintsevo on a map of the East Kazakhstan region (Kazakhstan. National Encyclopedia, 2005), made on the basis of the maps.google.com map with the author's additions

The village of Putintsevo is located in the immediate vicinity and on the leeward side of the Altai mining and processing complex, which includes the Kazzinc LLP's largest underground mine - the Maleevsky mine and the Altai processing plant. The average metal content in the ore of the Maleevsky mine is Zn - 7.5%, Cu - 2.3%, Pb - 1.3%, Au - 0.75 g / t, Ag - 7.5 g / t. A large proportion of Kazzinc's total production of zinc and copper concentrates is obtained from this mine. The mine supplies all the raw materials to the Ust-Kamenogorsk Zinc Plant (Kazakhstan. National Encyclopedia, 2005).

The Zyryanovsk coal-preparation plant "Altai", located on the eastern outskirts of Zyryanovsk, mainly processes the ores of the Maleevsky deposit of the polymetallic and copper-zinc type, as well as the ore of the Aleksandrovsky deposit of the Grekhov ore zone. The main sources of environmental impact are the crushing and ore beneficiation of site in heavy suspension, the grinding and flotation site, thickening and filtering, the reagent site with a lime plant, tailings, the experimental site, and the site for the production of copper sulfate (Maleevsky mine (Kazzinc), 2019).

Industrial waste produced across this region repeat the composition of the extracted and processed raw materials and determine the nature of the pollution of the territory.

Russia. Tomsk district of the Tomsk Oblast. Tomsk Oblast is a region of the Russian Federation with a total area of 316.9 thousand km^2, located in the southeastern part of the Western Plain on both sides of the Ob River (Figure 8). The work carried out by scientists, geologists, ecologists, and geochemists showed that the territory of the Tomsk Oblast is characterized by significant geochemical heterogeneity due to both natural and technogenic factors (Rikhvanov et al., 2006). This heterogeneity creates conditions for the accumulation of chemical elements by living organisms living in this territory.

The Tomsk Oblast in the north borders the Tyumen Oblast, in the west - Omsk, in the south - Novosibirsk and Kemerovo, in the east - the Krasnoyarsk Territory. It consists of 16 municipal districts. The administrative center is Tomsk.

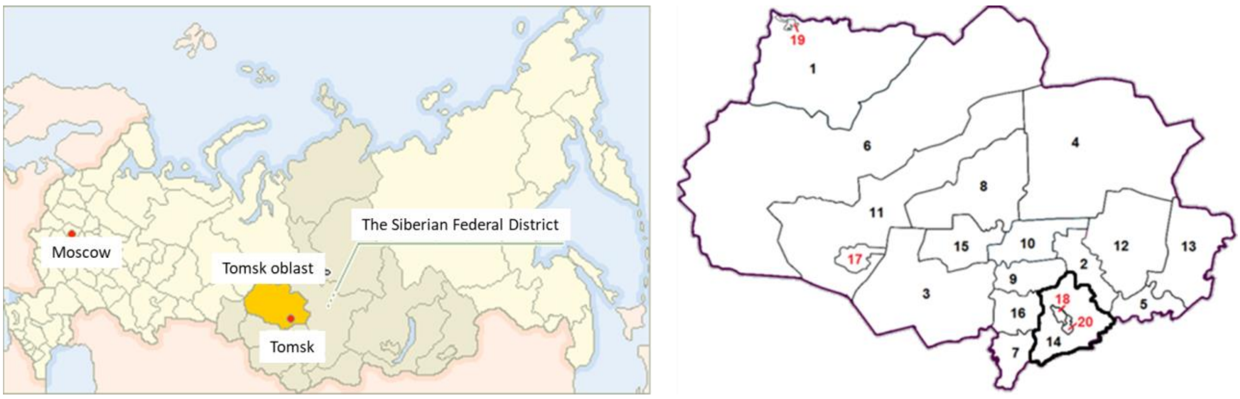

Figure 8. Tomsk Oblast on a map of Russia, map of Tomsk Oblast, (Rikhvanov et al., 2006)

Note: 1. Aleksandrovsky district, 2. Asinovsky district. 3. Bakcharsky district, 4. Verkhneketsky district 5. Zyryansky district, 6. Kargasoksky district, 7. Kozhevnikovsky district, 8. Kolpashevsky district, 9. Krivosheinsky district, 10. Molchanovsky district, 11. Parabelsky district, 12. Pervomaisky district, 13 Teguldetsky district, 14. Tomsky district, 15. Chainsky district, 16. Shegarsky district, 17. Kedrovy city, 18. Seversk city, 19. Strezhevoy city, 20. Tomsk city

The climate of the Tomsk region is transitional: from temperate to sharply continental. Annual average precipitation ranges from 400 to 570 mm, with the highest rainfall occurring in the west, as well as in the east and northeast when approaching the Central Siberian plateau (Evseeva, 2001).

Regarding the influence of natural factors on the formation of the elemental composition of animals, one can distinguish a wide range of minerals, primarily fossil fuels, located in the region. There are manifestations of brown coal deposits, more than 100 hydrocarbon deposits, about 18% of Russian peat reserves (Арбузов and Ершов, 2007). The main oil and gas regions of the region are Aleksandrovsky, Kargasok, and Parabelsk. There are also mineral ore deposits in the region: iron ore Bakcharsky deposit (Nikolaeva, 2011), zircon-ilmenite deposits (Rikvanov, 2001), bauxite, zinc, gold and many more (Evseeva, 2001).

Another factor influencing the potential contribution of the elements is cross-border transport carried by a dense river network located in the region. Water masses move from south to north, transit flow from the Kemerovo (Tom, Yaya, Kiya) region and the Krasnoyarsk Territory (Chulym, the upper Keti, Cheti and Tyma) make up 50% of the water flow.

In the territory of the Tomsk region, one can observe manifestations of elements such as gold, antimony, uranium, scandium in the peat and coal of the region (Arbuzov, 2007; Bernatonis, 1989; Smolyaninov et all, 1990). Moreover, the research results of A.M. Mezhibor (Mezhibor, 2009) showed that the accumulation of elements in peat is influenced not only by natural factors but also by the impact of technogenic factors (Baranovskaya, 2011). Potential anthropogenic sources of elements entering the environment spread across the region and are associated with the main industries. The economy of the region is concentrated, mainly, in sectors such as oil and gas, chemical and petrochemical, mechanical engineering, nuclear, electric power, the timber and food industries.

Amongst all the districts of the Tomsk region, the Tomsk district is of particular interest (Figure 9), as a spesific industrial center of the region, where the bulk of the population lives.

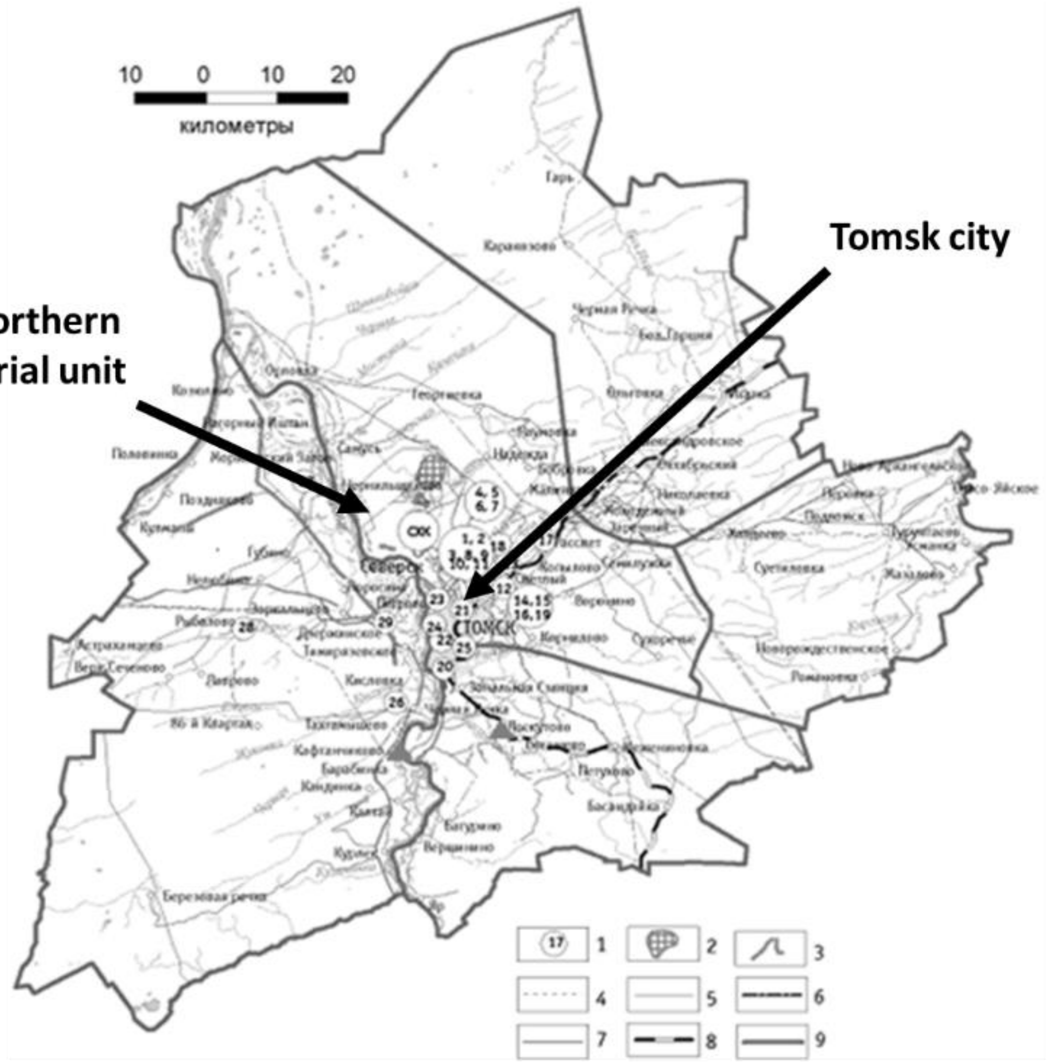

Figure 9. Layout of the main industrial facilities in the Tomsk region (based on materials from the State Unitary Enterprise Shopping Center Tomskgeomonitoring and the Geology Department of TPU) (Rikhvanov et al., 2006)

Note:1 - industrial enterprises: 1 - Tomsk Petrochemical Plant (TPP); 2 - CHP-3; 3 - greenhouse plant; 4 - treatment facilities of TPP; 5 - ash dump of TPP-3; 6 - industrial waste landfill; 8 - livestock farm, state farm; 9 - base Su-13 management "Himstroy"; 10 - gas recovery base of the main gas pipeline; 11 – "Agropromstroy" base; 12- Mezheninovskaya poultry farm; 13 - state farm "Tomsk"; 14 - litterhouse Mezhininovskaya p / f; 15 - city dump; 16 - pig storage pond; 17 - Tugan poultry farm; 18 - coal warehouse; 19 - field irrigation pig farm; 20 - CJSC "TIZ"; 21 - OJSC "Rolt"; 22 - Sibkabel CJSC; 23 - Shpalozavod OJSC; 24 - ZAO Drozhzhzavod; 25 - GRES-2; 26 - ABZ (Ashot) (production of building materials); 27 - Ship repair plant; 28 - Sausage shop "Rybolovsky"; 29 - ABZ.

2 - platforms LRAO; 3 - production wells of water intakes; 4 - communication lines; 5 - pipeline; 6 - power lines; 7 - automobile roads; 8 - railway; 9 - borders of medical districts.

The industrial structure of the Tomsk region is formed by more than 200 large and medium-sized industrial enterprises. The main sources of large-scale pollution in the Tomsk region are: the Tomsk Petrochemical Plant (TNKhK) the largest in the Russian Federation, the Siberian Chemical Plant (SKHK), agro-industrial complexes (Mezheninovskaya, Tuganskaya, Tomsk pig farms), as well as industrial landfills and household waste (Ecological monitoring, 2011), ash dumps, quarries, treatment facilities in Tomsk, etc.

The Tomsk region has been studied for many years (Perminova, 2017; Baranovskaya, 2011; Mezhibor, 2009; Rikhvanov, 2001; Rikhvanov et all, 2006), in connection with the location of enterprises of the Northern Industrial Hub. More than thirty industrial complexes are located on the territory of the Northern Industrial Block, including the world's largest nuclear fuel cycle enterprise - the Siberian Chemical Combine (SCC) and Russia's largest oil and gas refinery - Sibur (formerly Tomsk Petrochemical Plant). SCC is potentially the most dangerous site, primarily because of its proximity to settlements (10-15 km from residential areas of the city of Tomsk), and a large number of accidents (Rikhvanov et all, 2006).

Increased content of rare earth elements is recorded in Tomsk region soils, which also indicates the presence of a powerful source of constant pollution (Zhornyak, 2009; Rikhvanov, 2006; Talovskaya, 2008). The transfer of rare-earth elements can occur due to the long-range transfer of emissions from SCC (Rikhvanov, 2000), or may be a consequence of the emission of chimneys at Tomsk State District Power Station-2 (Arbuzov, Ershov, 2007). The soils near of the northern industrial unit are enriched with Ba, Sr, V, Th, and Ag, compared with other soils of the Tomsk region (Ecological monitoring , 2012). The influence of the industrial complex is also recorded in the study of atmospheric air, manifesting itself in the concentration of uranium and thorium in solid snow sediment in the direction of wind transport (Rikhvanov, 2000).

The main geochemical signs of the impact of the enterprises of the northern industrial unit on living organisms are the high content of uranium and lanthanides

(Rikhvanov et all, 2006). The increased content of these microelements is recorded both in barrier organs and in individual organisms of various species, small mammals, amphibians, birds, etc. (Ilinskih et al., 1998; Kuranova, 1999), in river fish (Ilinskih et al., 2001; Berzina et all, 1993), large wild animals, and in individual human biosubstrates (Ilinskih et al., 2001).

Thus, the negative impact of industrial enterprises located in the Tomsk region has a complex effect on the elemental composition of natural environments and living organisms. Anthropogenic activity leads to active concentration of radioactive, rare earth elements, lanthanides by living organisms, which necessitates their detailed study from a geoecological point of view.

2.2. Zabaykalsky Krai (aka Transbaikalia/Zabaikalie). The Zabaikalye Territory is in the southeast of Siberia, with an area of 431.5 thousand km^2. It occupies 4% of the territory of Russia. During the study, biological material of the domestic pig is selected in the territory of three regions of the Transbaikal Territory: Nerchinsk-Zavodsky District (village of Uvelskie Klyuchi), Kalgan District (village of Kalga), Gaimursky-Zavodsky District (village of Gazimursky Plant, village of Taina).

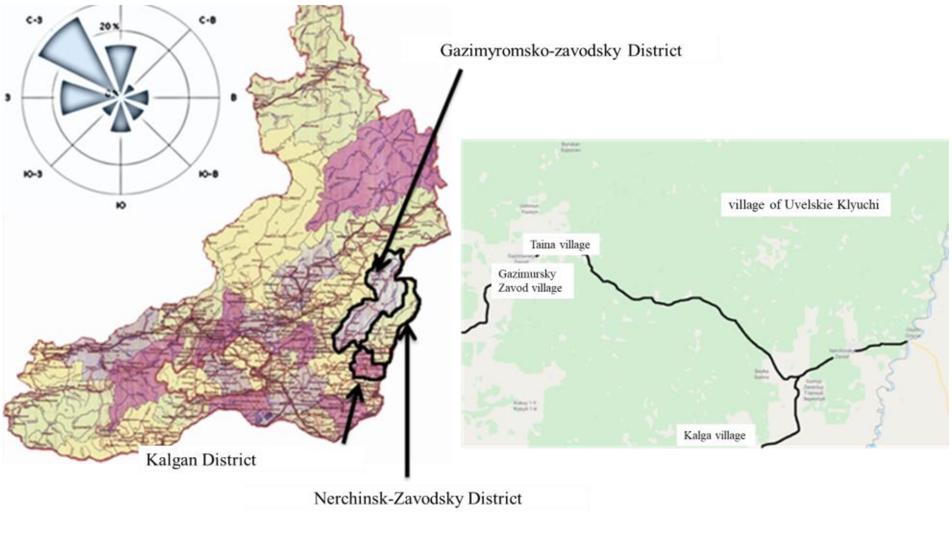

Figure 10. Sampling points in the Trans-Baikal Territory, (The Government of the Trans-Baikal Territory and the Ministry of Natural Resources of the Trans-Baikal Territory, 2017), sampling points in the Trans-Baikal Territory made on the basis of the maps.google.com map with the author’s additions

The main industries of Transbaikalia are mining, fuel and energy, transport. In terms of resources, it is the oldest and richest mineral resource region of the country. In the bowels of the region contain 87% of the proven reserves of uranium, 42% of fluorspar, 36% of zirconium, 30% of molybdenum, 25% of copper, 23% of titanium, 16% of tungsten, 13% of silver, 9% of gold and other minerals. 331 sites are registered with the Office for all types of control, including 143 mining enterprises. As a result of their activities, 119.1 million tons of waste are generated in the region, of which mining waste makes up 116.76 million tons (98% of the total), 243.9 thousand tons of municipal solid waste are transferred for disposal (The Government of the Trans-Baikal Territory and the Ministry of Natural Resources of the Trans-Baikal Territory, 2017).

The critical ecological situation of the region leads to significant environmental pollution. According to a comprehensive assessment of the quality of surface waters by hydro chemical indicators in 2017, out of 31 water bodies of the Trans-Baikal Territory, 20 water bodies (or 65%) have polluted or very polluted waters (quality class 3); dirty (quality class 4) - 10 (or 32%), slightly polluted - 1 (or 3%). In water reservoirs of the Territory, excesses of the maximum permissible concentrations for COD and BOD5, copper, manganese and oil products were most often recorded there is an increase with the content of zinc, phosphates and oil products. According to the assessment of the quality of drinking water, the Nerchinsky Zavodsky District and the Gazimuro-Zavodsky District have the largest share of drinking water samples that do not meet hygienic standards. The level of air pollution in the Trans-Baikal Territory is characterized as high and elevated. Climatic conditions and geographical features of the area, as well as the features of the heating season, cause an increase in air pollution in the autumn-winter period. About 122 thousand tons of pollutants are released into the atmosphere annually: solid substances - 43 thousand tons; liquid and gaseous –79 thousand tons. The problem of disposal, storage and disposal of waste also remains relevant. The formation of the bulk of the waste is determined by the industrial profile of the region, and the bulk of waste of hazard classes 4 and 5 comes from mining enterprises. Technogenic accumulations (about 2.9 billion tons) are formed by dumps of poor and substandard ores, tailings of flotation and gravity concentration, products of chemical processing of non-ferrous metal ores (The Government of the

Trans-Baikal Territory and the Ministry of Natural Resources of the Trans-Baikal Territory, 2017).

The ecological problems of the region extend to the studied territories (Figure 11). The village of Urovskie Klyuchs is located close to the Savkinsky gold ore deposit, which was launched in 2008. The balance reserves of the deposit amount to 5.9 tons of gold, forecast resources - 18 tons of gold (Business Directory NEDRADV Savkinskoye deposits, 2017). In the Kalgan district, near the territory of the village of Kalga, is Kadainsky mine (exploitation period 1954-1993) for the beneficiation and mining of polymetallic ores. The mine includes the Kadainsky polymetallic deposit, the Mikhailovsky polymetallic deposit by underground mining and Novopokrovskoye opencast. In the Gaimursky-Zavodsky district, there is a large mine for the extraction of bulk gold - Novo-Shirokinsky mine. The Solnechny and Kultuminsky gold mines previously operated in the region (Business Directory NEDRADV Savkinskoye deposits, 2017).

Figure 11. Location of sampling points and environmental impact sources, made on the basis of the maps.google.com map with the author’s additions

Thus, the geoecological situation of the studied territories is characterized as critical primarily due to the proximity of mining facilities in each sampling area.

2.3 Tyva Republic. The Republic of Tuva is located in the geographical center of Asia in the south of Eastern Siberia, in the upper Yenisei. The maximum length of the territory from north to south is 420 km, from west to east - 630 km, the maximum and minimum lengths are 720 km and 120 km, respectively. The total area of the republic is 168.6 thousand km². Mineral resources of the Republic of Tyva are characterized by a wide variety of types of minerals (State Report, 2012; Grechishchev, 2012). Deposits of coking and steam coal, ferrous, non-ferrous, rare and noble metals, non-metallic materials, fresh and mineral underground waters, and mineral building materials have been explored here. On this basis, large mining complexes can develop. Mining is the main industry of the republic.

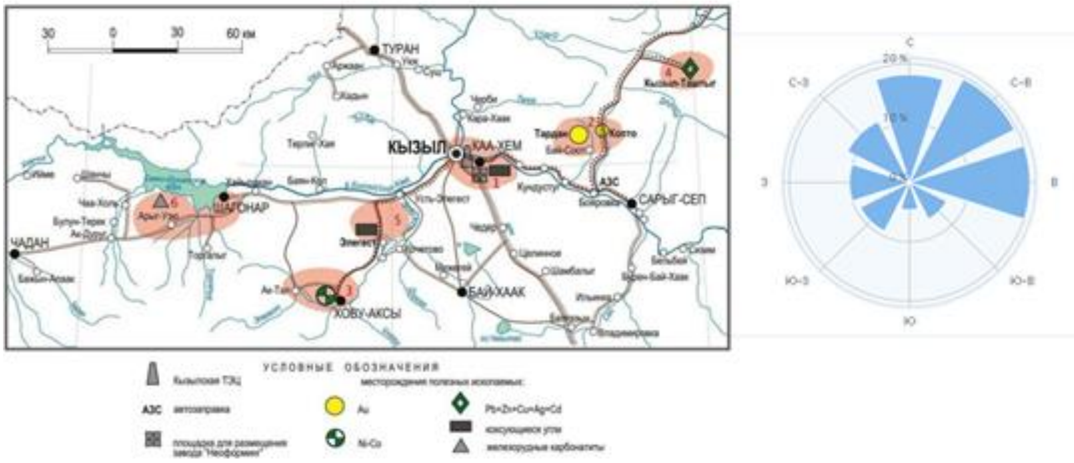

Figure 12. Mineral deposits in the region of the sampling region (Andreychik, 2012) and wind direction in the Republic of Tuva (Weather archive in Kyzyl, 2019)

Biological material samples were obtained in the village of Hovu-Aksy, located on the Elegest River, and the center in Chedi-Kholsky kozhuun. The ecological situation of the settlement is complicated because in the region from 1970 to 1990, the enterprise "Tuvacobalt" functioned, producing copper-nickel-cobalt concentrate (State Report, 2012).

The ore base of the enterprise is the Khovu-Aksinskoye deposit, the main components of the ores are Co, Cu, Ni. Although the enterprise closed in 1990, the dumps of the deposit contain large amounts of pollutants, such as arsenic, sodium cyanide, etc. (Zabelin, 2016).

Thus, mixed environmental and geochemical conditions determined by both natural (location of minerals, wind direction) and anthropogenic (waste from mining and processing industries) factors determine the need for biological monitoring of the region according to the elemental composition of living matter.

CHAPTER 4. METHODS OF SAMPLING AND SAMPLE PREPARATION OF BIOLOGICAL MATERIAL

4.1 Source material and sampling procedure

Domestic pig (lat. *Sus scrofa domesticus*) is a large artiodactyl, a subspecies of the wild boar, domesticated by humans and raised mainly for meat production. Pigs are omnivores with a single-chamber stomach and intestinal type of digestion. This allows them to adapt quite well to different types of feeding from herbivorous to carnivorous. Pork is the most consumed type of meat in the world - 43% of the total volume (chicken - 29.5%, beef - 23.5%, other types - 4%) (Komlatsky et al., 2017).

The organs and tissues of domestic pigs are examined as an indicator of their geographical origin (Kim et al., 2017; Park et al., 2018; Wang et al., 2014) and the level of environmental load (Huang et al., 2017), in addition, the elemental composition of the whole organism is also of scientific interest, as a model of the human body, because its composition reflects the environmental impact.

In the course of the study in 2013, 2017, 2019, the INAA-146 method and the ICP-MS method analyzed 40 samples of organs and tissues of the Domestic Pig, selected by employees of the Geology Department of the School of Engineering of Natural Resources with the participation of the author (table 3).

Table 3. Samples of biological material taken as a result of the study

Territory		Type of biomaterial	N of samples	Sampling location	Type of analysis
1		2	3	4	5
Russia	Tomsk district	Duodenal ulcer; bronchi; internal fat of the eyes; brain; larynx; diaphragm; gall bladder; fat; teeth; leather; bone; blood; lungs; uterus; breast; ureter; muscle (meat); adrenal; nose; liver; esophagus; pleura; pancreas; bud; rectum; spleen; a heart; spinal cord; colon; small intestine; trachea; an ear; tail; stubble; thyroid; tongue; ovaries	78	Kizhirovo village Verkhnee Sechenovo village	INAA
		Heart, kidney, liver, lung	4	Mezheninovka village	
	The Republic of Tuva	Muscle, spleen, stomach, gastrointestinal tract	4	Hovy-Aksy village	
	Zabaikalsky Krai	Muscle; hoof; bone marrow	3	Urovskie kluchi village	
		Tibia; hoof; muscle; skin; bone marrow	5	Kalga village	
		Tibia; bone marrow; leather; muscle; hoof	5	Gazimursky zavod village	
		Tibia; bone marrow; hoof; skin	4	Taina village	
		Lungs; spine; tubular bone; bud; brain; spinal cord; spleen; liver; a heart; lungs; spine; tubular bone; bud; brain; spinal cord; spleen; liver; ovary	18	Kizhirovo village Verkhnee Sechenovo village	ICP-MS
		Vertebra (2); spinal cord (1); blood (3)	6	Asino city	
		Vertebra (2); spinal cord (2)	4	village Kornilovo, village Semeluzhki	
		Vertebra	1	Urtash village	
Kazakhstan	Pavlodar region	Larynx; stomach; small intestine (8); large intestine (4); rectum (5); a heart; blood; spleen; bone; skeletal muscle; ureter; uterus; kidney	31	Ekibastuz city	INAA
	East Kazakhstan region	Brain, spine, spinal cord, heart, spleen, kidney, liver, lung	8	Putincevo village	
	Pavlodar region	Vertebra; spinal cord	2	Ekibastuz city	ICP-MS

In the analysis, organs and tissues of a female domestic pig about 6 months old were used, organs and tissues combining each of the organ systems for internal comparison with each other are presented in table 4.

Table 4. Samples of biological material taken as a result of the study

Organ system	Organs
Digestive system	Tongue, larynx, stomach, 12 duodena, esophagus, rectum, large intestine, small intestine, oropharynx
Circulatory system	Blood, spleen, heart
Genitourinary System	Uterus, ureter, ovaries
Integumentary system	Grease, leather, bristles
Musculoskeletal system	Bone (tubular, spine), cartilage, skeletal muscle
Central nervous system	Brain, spinal cord
Endocrine system	Adrenal glands, mammary gland, liver
Respiratory system	Lungs, trachea

For a detailed study of the gastrointestinal tract, we selected the organs of each part of the intestinal tract from the beginning to the end of the organ: 8 samples of the small intestine, 4 samples of the colon, 6 samples of the rectum, samples of the stomach and pharynx were also taken (20 samples analyzed in total). The pharynx is included in the study of the gastrointestinal tract, due to the anatomical composition lining its mucous tissue, forming both the gastrointestinal tract and the nasopharynx, and is also studied as a zone of entry not only of water and food masses, but also air.

Samples were taken in private courtyards in the territory of the East Kazakhstan and Pavlodar regions of the Republic of Kazakhstan, the Tomsk agglomeration, the Republic of Tyva, and the Trans-Baikal Territory of Russia, in order to establish their elemental chemical composition.

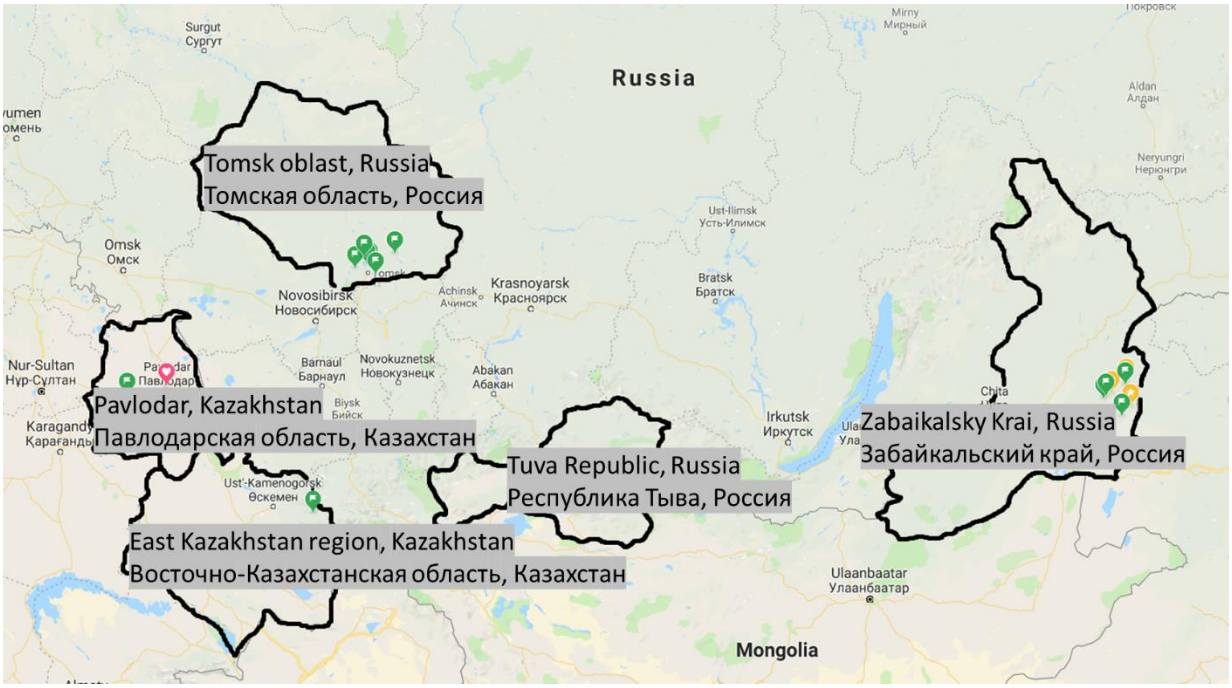

Figure 13. The location of the cities of Russia and Kazakhstan, on the territory where studies of the elemental composition of domestic pig ash were carried out (based on the maps.google.com map with the author's additions)

The study used samples of biological material - the placenta and the embryo of small mammals of the bank vole (Myodes glareolus) species provided by colleagues from the Institute of Plant and Animal Ecology of the Ural Branch of the Russian Academy of Sciences, Yekaterinburg city. Animals were captured in the amount of 152 samples in the zone of impact of the Sredneuralsk Copper Smelter, Revda city. For the study, we also used samples of biological material from women residents of the city of Tomsk, sampled by candidate of medical science Stankevich S.S., head of the Center for Support of Breastfeeding and Rational Feeding in Tomsk, 10 samples in total. Samples of small mammals and placental tissue of women were analyzed by INAA with standard sample preparation.

4.2 Sample preparation of biological material

The essence of the biomaterial sample preparation technique consists in drying and subsequent grinding of samples, followed by ashing. The general scheme of processing and analysis of biomaterial samples is shown in Figure 5:

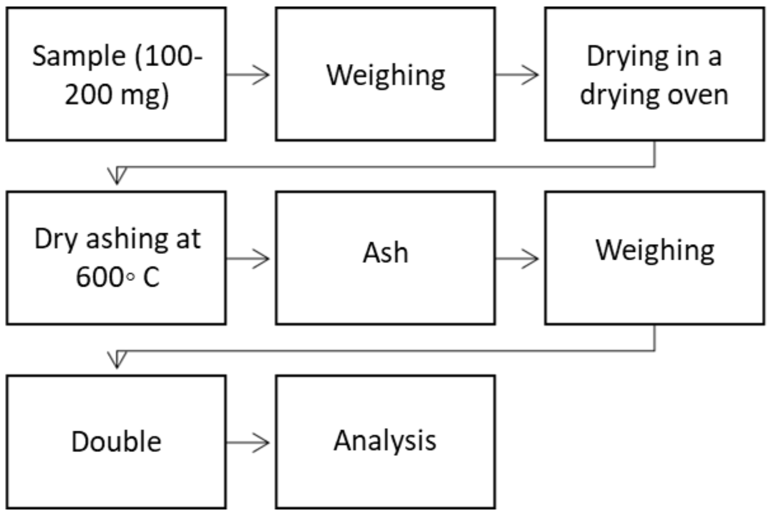

Figure 14.The scheme of processing and analysis of samples by the INAA method

Ashing of samples is carried out in laboratory conditions in special muffle furnaces at a temperature of 600°C. The muffle furnaces allow them to withstand a certain temperature regime, which dramatically increases the productivity of work, while improving quality. Ashing can be carried out in porcelain and metal crucibles, having previously established that these crucibles do not contaminate samples. An indicator of complete ashing is the appearance of a uniform color of ash (from white to ash gray and brown) and the absence of black specks.

In addition to the ash component of the body tissues, biological water is isolated from organs and tissues as a liquid component of the body. For the extraction of fluid from organs, the Dean and Stark method is used, which is a standard method used for the quantitative determination of water in various substances (Chemical Encyclopedia in Five Volumes, 1988). The essence of the method consists in heating the sample with a water-insoluble solvent, to form an azeotropic mixture, the composition of which does not change upon boiling. This is achieved using the Dean and Sark apparatus (Рихванов et al., 2019). Heating stops once the volume of water in the receiver trap ceases to increase, which indicates the complete extraction of fluid from the sample. Measuring the volume of condensed water makes it possible to calculate its amount in a certain structure (organ), as well as to study its chemical composition further. The method allows one to obtain intercellular and intracellular space fluid, since thermal destruction of the walls of the animal cell occurs.

Analytical methods of laboratory research. To determine the elemental composition of the samples, we used instrumental neutron activation analysis (INAA) and inductively coupled plasma mass spectrometry (ICP-MS). All the selected materials were analyzed in accredited laboratories using certified methods with standard reference samples. The reliability of the analyzes is confirmed by control determinations on different media. Internal control is performed.

1. Instrumental neutron activation analysis. 147 samples of the biological material of the domestic pig were analyzed by the method of instrumental neutron activation analysis. The analysis of the samples is carried out at the IRT-T research nuclear reactor in the nuclear geochemical laboratory (YLL) of the Department of Geology of the National Research Tomsk Polytechnic University (accreditation certificate RA.RU.21AB27 of 04/08/2015). Analysis was carried out by A.F. Sudyko and L.F. Bogutskaya according to the instructions of NSAM VIMS No. 410-YAF. The thermal neutron flux density in the irradiation channel is 21013 neutrons/(cm^{2}s), the duration of sample irradiation is 20 hours. The measurements were carried out on a gamma spectrometer with a germanium-lithium detector DGDK-63A. The studies were carried out using a standard reference sample - standard EC-1 "Canadian Elodea".

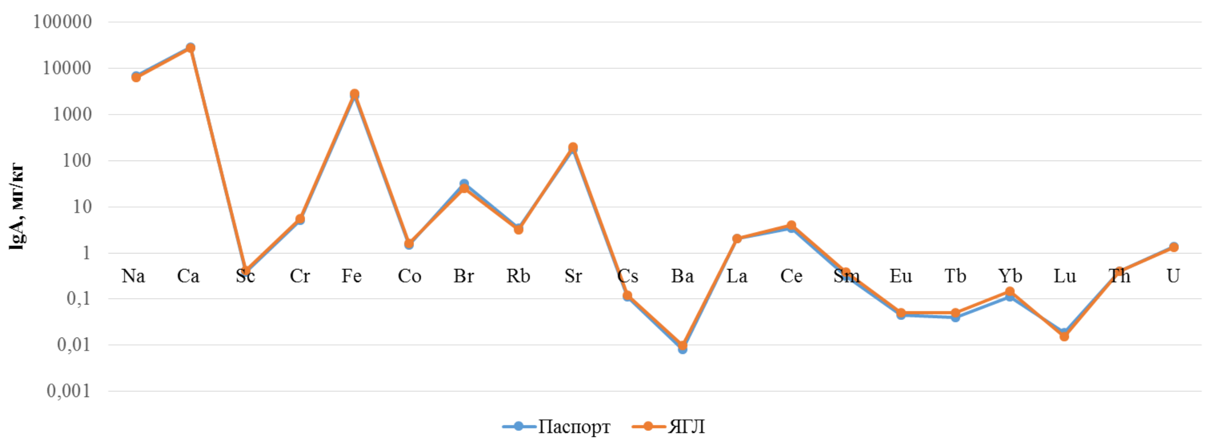

Figure 15. Comparison of INAA results (IAEA passport-standard "Birch Leaves" (паспорт); YAGL(ЯГЛ) - nuclear-geochemical laboratory of the Geology Department of TPU)

The detection limit of elements depending on their activation properties and the composition of the matrix of the analyzed sample mainly ranges from n * 1 to n * 10^{-6}%.

Sample preparation for INAA takes place in several stages: a package of aluminum foil (size 3 cm x 3 cm) is taken, pre-treated with alcohol, a bag is formed with tweezers, then the weight of the foil (mg) is determined on an electronic balance, the sample code is affixed to the bag, the sample is poured into bags on electronic scales to determine the weight of the sample (ideally 100 mg) and the total weight.

2. Inductively coupled plasma mass spectrometry. ICP – MS is a modern method for the determination of elements in small (μg/kg) and ultralow (ng / kg and less) concentrations. It is based on the use of inductively coupled plasma as a source of ions and a mass spectrometer for their separation and detection and allows almost all chemical elements in one sample to be determined in a minimum period of time (about 1 min.).

The analysis of samples of organs and tissues of the domestic pig is carried out in the analytical center of the Plasma Chemical and Analytical Center LLC (Tomsk, RA.RU.516895 accreditation certificate 03.24.2016).

Biological water is analyzed in the accredited scientific and educational center "Water" (Accreditation certificate No. POCC RU.0001. 511901 valid until 09.09.2018) of the National Research Tomsk Polytechnic University (head of the center Kopylova Yu.G.), where the method of inductively coupled plasma is used by by certified technique HCAM 480X on a NexION 300D spectrometer.

Data processing technique. Processing and generalization of the obtained analytical material are carried out on a personal computer using the office suite Microsoft Office (Excel, Word 2013) and the program "Statistica 7". To build the graphic material, the software "Surfer 10" and "Inkscape 0.91" are used. Samples were organized for the Tomsk agglomeration, individual settlements, as well as for the degree of remoteness from the alleged sources of pollution.

Statistical processing of information (with a reliability level of 95%) is carried out according to the following parameters: checking that the maximum values belonged to the sample population; assessing the numerical characteristics of the chemical element contents in the biological material of the domestic pig in each study area; comparing the correspondence of the distribution of chemical elements with the hypothesis of the normal distribution law according to the Kolmogorov-Smirnov test results; assessment of the nature and strength of the relationship between chemical elements in the study area according to the Pearson and factor analysis method of the main components of the geochemical dispersion spectrum. When calculating the average contents of elements from the total sample, "hurricane samples" were removed, but they are shown in the scatter of values. When some elements were present in concentrations below the detection limit of the analysis, half the threshold value is used in the calculation (Mikhalchuk et Yazikov, 2014). Regardless of the nature of the distribution of elements, we took the arithmetic mean values of the sample as average levels of content, which, with both normal and asymmetric distribution, gives the most consistent estimate of the concentration values (Tkachev, 1975). The detected values below the detection limit were replaced by half the limit, abnormally high concentrations were replaced by values equal to the average content plus three standard errors calculated considering these abnormal concentrations. Anomalous values were established for each element studied, which were not considered when calculating the arithmetic mean and concentration coefficient.

The significance of the differences in the sample sets is estimated using the Kolmogorov-Smirnov statistical non-parametric analysis method, the differences were considered significant at a p-level $p < 0.001$.

In the analysis, the following indicators were calculated:

1. Absolute content of elements in samples, analyzed by chemical analysis methods INAA, ICP-MS (mg/kg).

2. The concentration coefficient, which is an indicator of the level of anomalous content of elements and is calculated as the ratio of the element content in the environment (C) to its arithmetic mean content in the sample (Cc)

$$K_k C \div C_c$$

Formula 1. The concentration coefficient

Based on the calculated values of the concentration coefficient (for $K_к > 1$), geochemical series were compiled in descending order of values.

The interpretation and synthesis of the results were carried out using published and stock information on the subject.

2. An additive indicator, which is the sum of concentration coefficients in excess of one.

3. Coefficient of variation equal to the ratio of the sample standard deviation to mean value.

4.2.1 Methodology for assessing the toxicity of elements using the USEtox model

The basics of the USEtox model developed on the Microsoft Excel platform and related calculations are fully described in the user manual available on the website (USEtox, 2017). This study examined the principles used to calculate the characteristic toxicity coefficient (CF), as well as calculating the exposure factor modified during the study. All formulae used are shown in English according to the representation in the model, and their decoding is maximally adapted to Russian.

In accordance with the user manual (Fantke et al., 2017) the USEtox model is currently used to calculate the characteristic toxicity coefficient (CF), which estimates the impact on human health and freshwater ecosystems from emissions of pollutants into indoor air, as well as into urban air, rural areas, freshwater bodies and agricultural soils. Human health effects include carcinogenic effects, non-carcinogenic effects and general effects (carcinogenic and non-carcinogenic).

The characteristic toxicity coefficient (CF), which is required to assess human health or environmental impacts, is usually defined as a combination of these three factors (formula 2):

$$CF = EF \times FF \times XF$$

Formula 2. Calculation of the characteristic coefficient of toxicity, [Dali/kg]

This formula covers two main aspects related to the behavior of chemicals in the environment and their accumulation and transmission at trophic levels (FF and XF) and related to human or environmental exposure (EF).

• FF - fate factor or "fate" factor, [kg of substance r in the environment/kg of substance released in the environment/day.] It reflects the resistance of the chemical in the environment (for example, in days), as well as its relative distribution in ecosystems.

• XF - exposure factor, [kg of substance/day per kg in the environmental component] describes the effective human consumption of a certain environmental component - air, water, soil - by inhalation and if swallowed.

• EF - effect factor [kg of intake/day] reflects the effects on human health and the state of ecosystems as a result of the entry of a chemical element/substance into a living organism in various ways (through the air, water, soil or food).

The assessment of the impact on humans of a chemical released into the environment (indoors or outdoors) is based on a causal chain (integrated over time) linking the chemical mass in the environmental components (estimated in the model of the "fate" of the chemical) with/and consumption of substance by the population through various routes of entry. Human exposure factors XF corresponding to specific pathways (XP) can be distinguished both directly (through drinking water or breathing air) and indirectly (through food such as meat, dairy products, vegetables, and fish).

The characteristic toxicity factor (CF) is calculated by USEtox documentation. The calculations use the default values set by the model for the Central Asia zone for the Fate Factor (FF) and the Effect Factor (EF). To calculate the exposure factor (XF), data modified according to the results of chemical analysis are taken. To do this, the results of the study of pork are used in calculating the exposure factor, which reflects the effective intake of elements via soil or air into the human body when eating meat products.

The indirect exposure factor can be indirectly interpreted as the equivalent rate of consumption of the contaminated component i (pork) through the food substrate, corresponding to the exposure route XP (air, soil). Each exposure factor represents an increase in human exposure through the XP path due to an increase in concentration in component i (Usetox, 2013).

When calculating the exposure factor, BAF is taken into account - the factor of biological accumulation of a substance in the environment (meat, milk) - which expresses the accumulation of an element by a component (meat, milk) from the natural environment (air, soil).

The equation for calculating the human exposure factor for the indirect path has the form (equation 2):

$$XF_{xp,i}^{\text{indirect}} = \frac{BAF_{xp,i} \times IR_{xp} \times P}{p_i \times V_i}$$

Formula 3. Calculation of the indirect exposure factor for humans, [kg intake/day per kg in compartment]

Note: ρ_i is the bulk density of medium i [kg_i/m_i^3], and Vi [m_i^3] is the volume of medium i linked to the exposure pathway xp. IR_{xp} [kg/day] is the individual ingestion rate of a food substrate corresponding to exposure pathway xp, P is the population head count, and is the bioaccumulation factor.

The bulk density of the medium i and the individual consumption rate are tabular values and are taken from the model for calculation. The volume of medium i (V [m^3]) is calculated by the following formula:

$$V_{\mathrm{i}} = h_{i\,[m]} \times S_{i\,[m^2]}$$

Formula 4. The volume of medium i calculattion

Note: h_i [m] is the height of medium i (continental and global air, or soil), the table value presented in the model, and $S_{i\ [m2]}$ is the area of medium i (continental and global air, or soil), depending on the geographical features of the studied region.

According to the model documentation, the biological accumulation factor is calculated as follows:

$$\mathrm{BAF_{xp,i}} = \frac{\mathrm{C_{xp}}}{\mathrm{C_i}}$$

Formula 5. The calculation of the bioaccumulation coefficient, [kg_{xp} / kg_i]

Note: C_{xp} is the concentration of an element in the food substrate corresponding to the xp exposure pathway, for example, in meat or milk, and Ci is the concentration in the environment (soil, air) (Fantke et al., 2017; Usetox, 2013).

In the USEtox model, BAF, defined by the model, does not express the influence of environmental conditions on the accumulation of elements in meat or milk (Fantke et al., 2017). However, in order to take into account the geoecological features of the region, BAF is replaced by the ratio of the concentration of Cr (C_{Cr}) [mg/kg_{xp}] in pork meat (according to the results of chemical analysis) and the Clarke concentration of substances in the biosphere (according to Glazovsky) [mg/kg] (Glazovsky, 1982).

Clarke concentration is chosen to calculate the concentration coefficient of elements since this value expresses their average concentration in the biosphere.

CHAPTER 5. GENERAL STATISTICAL PARAMETERS OF THE ACCUMULATION OF CHEMICAL ELEMENTS IN THE BODY OF A MAMMAL (SUS SCROFUS DOMESTICUS)

The statistical parameters of the accumulation and distribution of chemical elements reflect the general laws of their behavior in the organs and tissues of the object of study *Sus scrofa domesticus*. Statistical data on the absolute contents of elements, calculated for the entire data array, are used as normalization of values when calculating the concentration coefficient. An analysis of the results of studying the elemental composition of the ash of the biomaterial of domestic pigs showed heterogeneity of the sample.

The absolute content of elements in the animal's body (table 5), clearly demonstrating the main statistical parameters of the studied material, are presented in the table below.

Table 5. Elemental composition of the organism Pig domestic (*Sus scrofa domesticus*) according to the INAA

Element	X	λ	Me	Mo	Min	Max
1	2	3	4	5	6	7
Na	51608	5131	27600	23400	400	328228
Ca	38606	5783	7436,32	500	50	233591
Sc	0,27	0,07	0,033513	0,0045	0,001	7
Cr	24	6,68	5,29	0,25	0,04	821
Fe	3208	612	1067,819	45	20	60400
Co	1,63	0,17	1,229718	0,05	0,004	12
Zn	652	55	375	2,5	2,50	4043
As	1,39	0,11	1	1	0,20	8
Br	167	17	97,6372	-	0,25	1204
Rb	72	6	68,27553	0,5	0,50	276
Sr	64	10	10	10	10	679
Ag	0,67	0,21	0,05	0,05	0,01	24
Sb	0,24	0,07	0,037	0,0045	0,003	9
Cs	0,24	0,03	0,11	0,05	0,004	3
Ba	32	6	5	5	2,62	386
La	0,82	0,18	0,05	0,05	0,01	13
Ce	2,49	0,42	0,05	0,05	0,01	24
Nd	1,28	0,24	0,25	0,25	0,03	19
Sm	0,36	0,06	0,045	0,045	0,005	4
Eu	0,04	0,01	0,012	0,0025	0,001	1
Tb	0,04	0,01	0,01	0,01	0,001	0,4
Yb	0,11	0,02	0,1	0,1	0,002	1
Lu	0,03	0,00	0,01	0,005	0,001	0,1

Continuation of table 5

1	2	3	4	5	6	7
Hf	0,19	0,06	0,026764	0,0045	0,002	7
Ta	0,03	0,005	0,01	0,01	0,001	0,3
Au	0,24	0,08	0,016368	0,001	0,001	8
Th	0,23	0,05	0,02	0,02	0,01	3
U	0,35	0,09	0,05	0,05	0,02	11

Note: X is the arithmetic mean of the sample, mg/kg, λ is the standard error, min is the minimum, max is the maximum, Me is the median, and Mo is the mode.

The variability of the contents of the studied elements is considered in more detail when calculating the levels of their accumulation in the biomaterial.

Coefficients of variation ranged from 90% to 250%. According to the gradation of the coefficients of variation, indicators lying in the range of over 60% attribute the sample to highly variable (Tkachev, 1975). This variability is due to the high specificity of living material and the work of barrier systems. A high scatter of values indicates a multifactorial intake of elements into the body and the impossibility of using parametric criteria for statistical data analysis.

Analyzing the values of the variation coefficients within groups of elements with approximately the same average content in the body, one can note their heterogeneity, for example in the essential elements Na, Ca, Fe, Zn, Rb, Fe, Ca. The elements most often found in the studied organism, namely Na, Zn, Rb, exhibit a relatively low coefficient of variation for this sample (59-88%), confirming the physiological nature of their accumulation. Other vital elements Ca, Fe vary more significantly (V <200%), which suggests changes in their content both depending on the tissue being studied and on the animal's habitat. The iron content as a formed blood element is logically higher precisely in this tissue than in other biomaterials; this is also true for Ca, which forms bone tissue and Sr, which has a high affinity for bone tissue. The group of rare-earth elements is in the same group with the average coefficient of variation, lying in the range from 100-200%. The lowest concentration coefficients (59%, 88%, 85%, respectively) are observed in As, Rb, Zn, which may indicate the constant presence of these elements in the body, regardless of the environment. The highest CV is observed in Hf, Au, Cr (V> 250%), which may indicate the variety of ways in which these elements enter the body.

An analysis of the elemental composition of organs and tissues of a domestic pig reflects the basic geochemical laws: the Clarke-Vernadsky law and the Oddo-Garkins rule (Figure 16). In the studied sample of elements, a lower content of Ca, Ag and an increased content of U, Nd, Tb are noted, which indicates some deviations from the law.

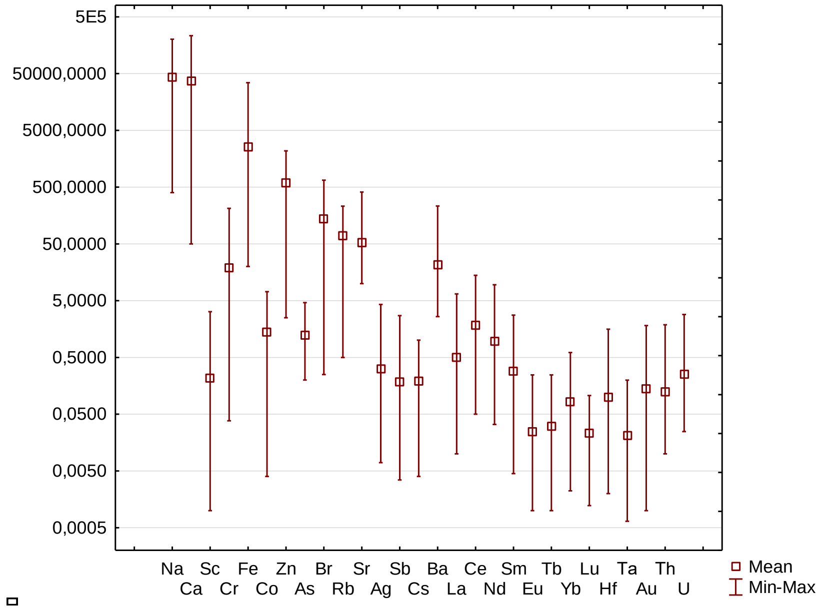

Figure 16. The content of chemical elements in the body of the domestic pig (Sus scrofa domesicus), mg/kg

Based on the research results, a correlation analysis is carried out and a diagram of associations of chemical elements is constructed. The biological material of the pig in the entire studied sample is characterized by significant positive correlation coefficients for the following pairs of elements (significant coefficient = 0.7 for 134 samples with an error level p = 0.05) (table 6):

- 0.7 Zn-Na; Ca-Sr; Co-Fe; Rb-Cs

According to significant coefficients, a correlation diagram is built, which allows the positive relationships of the elements to be seen visually, and the specifics of the ash residue of the body of the Domestic pig to be highlighted.

Table 6. The matrix of correlation interactions in the ash of the biomaterial of domestic pig (Sus scrofa domesicus), by non-parametric correlation analysis, (> 0.7 at a critical value of a coefficient of significance of 0.5)

	Na	**Ca**	**Sc**	**Cr**	**Fe**	**Co**	**Zn**	**As**	**Br**	**Rb**	**Sr**	**Ag**	**Sb**	**Cs**	**Ba**	**La**	**Ce**	**Nd**	**Sm**	**Eu**	**Tb**	**Yb**	**Lu**	**Hf**	**Ta**	**Au**	**Th**	**U**
Na	1,0																											
Ca	0,1	1,0																										
Sc	0,5	0,1	1,0																									
Cr	0,2	0,2	0,5	1,0																								
Fe	0,0	-0,1	0,2	0,4	1,0																							
Co	-0,1	0,1	0,2	0,6	0,7	1,0																						
Zn	0,7	0,1	0,4	0,3	0,1	0,0	1,0																					
As	0,2	0,1	0,1	0,3	0,2	0,2	0,3	1,0																				
Br	0,4	-0,3	0,1	-0,2	0,2	-0,1	0,0	0,0	1,0																			
Rb	0,6	-0,2	0,2	-0,1	0,0	-0,3	0,6	0,2	0,5	1,0																		
Sr	-0,3	0,7	-0,2	0,0	-0,1	0,1	-0,1	0,0	-0,3	-0,4	1,0																	
Ag	0,3	0,1	0,1	0,1	0,0	-0,1	0,3	0,1	0,1	0,3	0,0	1,0																
Sb	0,2	0,2	0,5	0,6	0,4	0,5	0,3	0,3	-0,2	-0,1	0,0	0,1	1,0															
Cs	0,6	0,0	0,4	0,2	0,1	0,0	0,6	0,3	0,3	0,7	-0,3	0,2	0,3	1,0														
Ba	0,3	0,3	0,3	0,3	0,2	0,2	0,4	0,3	0,0	0,1	0,2	0,1	0,4	0,3	1,0													
La	0,2	0,2	0,4	0,5	0,5	0,6	0,3	0,3	0,1	0,1	0,1	0,1	0,5	0,4	0,4	1,0												
Ce	0,2	0,2	0,4	0,5	0,3	0,4	0,3	0,2	-0,1	0,1	0,1	0,2	0,5	0,3	0,3	0,6	1,0											
Nd	0,1	0,4	0,1	0,4	0,4	0,5	0,2	0,2	-0,2	0,0	0,3	0,1	0,4	0,1	0,3	0,5	0,4	1,0										
Sm	0,3	0,1	0,3	0,3	0,0	0,0	0,4	0,1	-0,1	0,2	0,0	0,0	0,2	0,3	0,3	0,2	0,3	0,1	1,0									
Eu	0,1	0,2	0,5	0,6	0,3	0,5	0,2	0,3	-0,2	-0,1	0,1	0,1	0,5	0,2	0,3	0,6	0,5	0,3	0,2	1,0								
Tb	0,2	0,2	0,2	0,3	0,3	0,4	0,3	0,2	-0,1	0,0	0,1	0,1	0,3	0,2	0,5	0,5	0,4	0,2	0,3	0,3	1,0							
Yb	0,2	0,1	0,5	0,6	0,2	0,3	0,3	0,0	-0,3	-0,2	0,0	0,2	0,5	0,1	0,1	0,3	0,4	0,2	0,3	0,4	0,3	1,0						
Lu	0,4	0,4	0,3	0,2	-0,1	-0,1	0,4	0,3	-0,1	0,3	0,2	0,3	0,1	0,4	0,3	0,2	0,2	0,2	0,1	0,2	0,2	0,2	1,0					
Hf	0,2	0,0	0,6	0,3	0,2	0,2	0,1	0,0	0,2	0,1	-0,1	-0,1	0,2	0,3	0,2	0,4	0,3	0,0	0,3	0,3	0,2	0,2	0,1	1,0				
Ta	0,3	0,1	0,2	0,3	0,3	0,3	0,4	0,2	0,0	0,2	0,0	0,1	0,3	0,2	0,3	0,4	0,4	0,3	0,3	0,2	0,4	0,3	0,2	0,1	1,0			
Au	-0,1	-0,3	-0,1	-0,4	-0,2	-0,4	-0,3	-0,2	0,4	0,2	-0,3	0,0	-0,4	0,0	-0,2	-0,3	-0,4	-0,4	-0,2	-0,3	-0,3	-0,5	-0,2	0,1	-0,4	1,0		
Th	0,3	0,0	0,6	0,5	0,4	0,4	0,3	0,1	0,1	0,2	-0,2	0,1	0,4	0,4	0,4	0,6	0,4	0,3	0,3	0,4	0,3	0,4	0,2	0,5	0,3	-0,1	1,0	
U	0,4	0,2	0,2	0,2	0,1	0,1	0,3	0,1	0,1	0,1	0,0	0,2	0,3	0,2	0,2	0,3	0,4	0,2	-0,1	0,1	0,3	0,3	0,3	0,0	0,4	-0,3	0,2	1,0

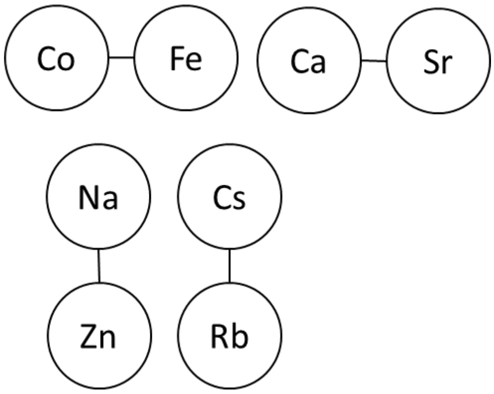

Figure 17. Chart of significant paired positive correlations for the ash residue of the biomaterial of domestic pig (Sus scrofa domesicus) (> 0.7 at a critical value of a coefficient of significance of 0.5)

The main significant positive correlation in the biological material of domestic pigs is formed by a cluster between lithophilic and siderophilic elements, according to the classification of V.M. Goldschmit, not going beyond geochemical groups. It can be assumed that these geochemical bonds fully reflect the natural interactions of elements due to their biological role and chemical properties. Strontium and calcium have the strongest correlation relationship, which is explained by the biological role of strontium and its ability to replace calcium in bone tissue. The strong correlation dependence of these metals in bone tissue is also confirmed when building a scatter plot.

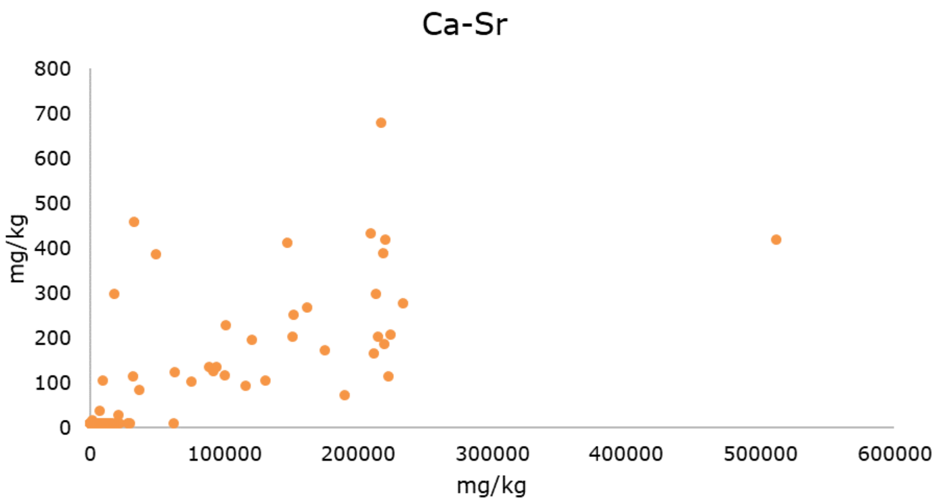

Figure 18. Diagram of paired positive correlation in bone tissue of domestic pig (Sus scrofa domesicus), (ash, mg/kg)

The same physiological reason explains the correlation the correlation between iron and cobalt. Iron is an essential element performing the function of oxygen transport in the blood, and cobalt contributes the formation of blood cells. Sodium and zinc are essential elements and are involved in the formation of organic compounds in the body. The chemistry of alkaline elements most likely explains the correlation between rubidium and cesium. Thus, it can be assumed that the correlation relationships are characteristic of a living organism in principle, and reflect its nature, regardless of its environment.

Given the physiological role of chemical elements, their distribution within the body should be considered (Figure 19). The main localization of the majority of the studied elements is found in the on the organs of the musculoskeletal, digestive and respiratory systems, with less significant indicators of the content of elements in the nervous and endocrine systems, a similar pattern has been established earlier for human organ systems (Baranovskaya, 2011, 2015; Ignatova, 2010).

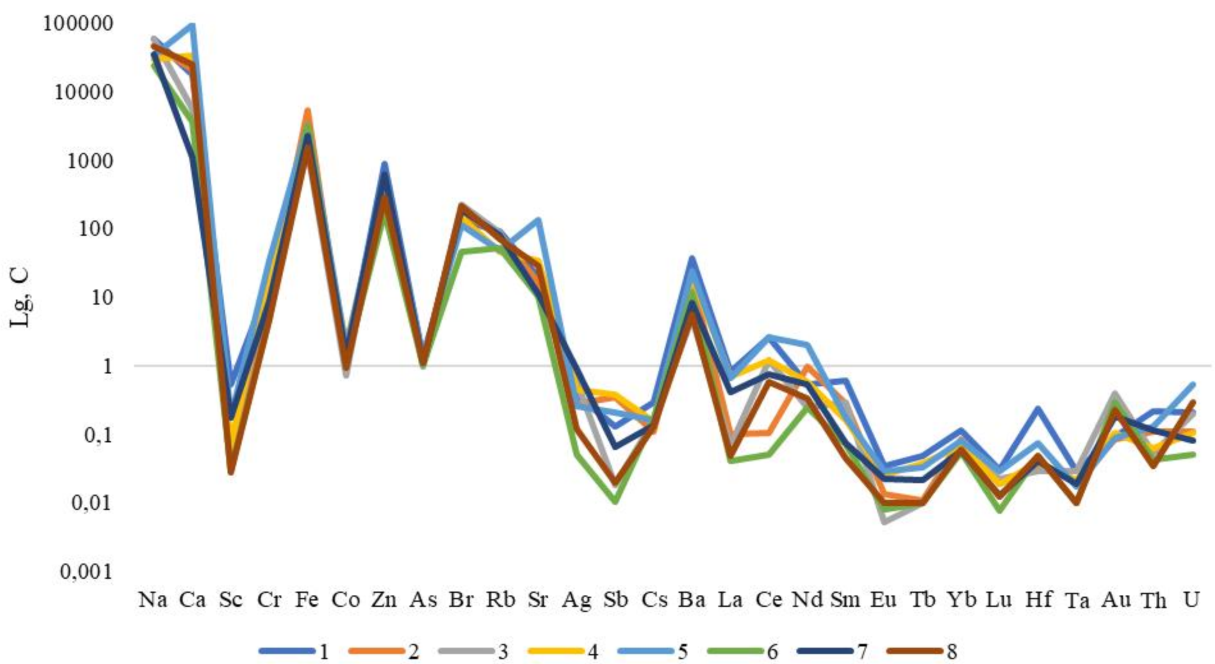

Figure 19. The content of chemical elements in the organ systems of the domestic pig (Sus scrofa domesicus), (ash, mg/kg, LgC)

Note: 1 - Digestive system; 2 - Blood circulation system; 3 - Urogenital system; 4 - Intergumentary system; 5 - Musculoskeletal system; 6 - Central nervous system; 7 - Endocrine system; 8 - The respiratory system.

A comparative analysis of the average content of elements in the studied organ systems shows a low variation of macro elements, except for elements with a pronounced physiological function, such as Fe, Ca, Sr. Trace elements, radioactive elements, and Sb vary greatly in the content within the body. Light rare earth metals and radioactive elements demonstrate a scatter of values depending on the type of system studied, clearly emphasizing their barrier role (Figure 20). As can be seen in the graph, the barriers formed by the digestive and musculoskeletal systems, accumulating all the elements considered, are visible, forming two distinctive peaks, but with some exceptions. Thus, Nd, in addition to bone tissue, accumulates in the organs of the circulatory system. Sm is precipitated most in the tissues of the digestive system and its content in other organ systems is negligible. La is deposited in the tissues of the integumentary system. Radioactive metals are accumulated in the barriers of the digestive and musculoskeletal systems: Th, U. Uranium accumulates in the tissues of the genitourinary and respiratory systems, and thorium in the tissues of the digestive and endocrine.

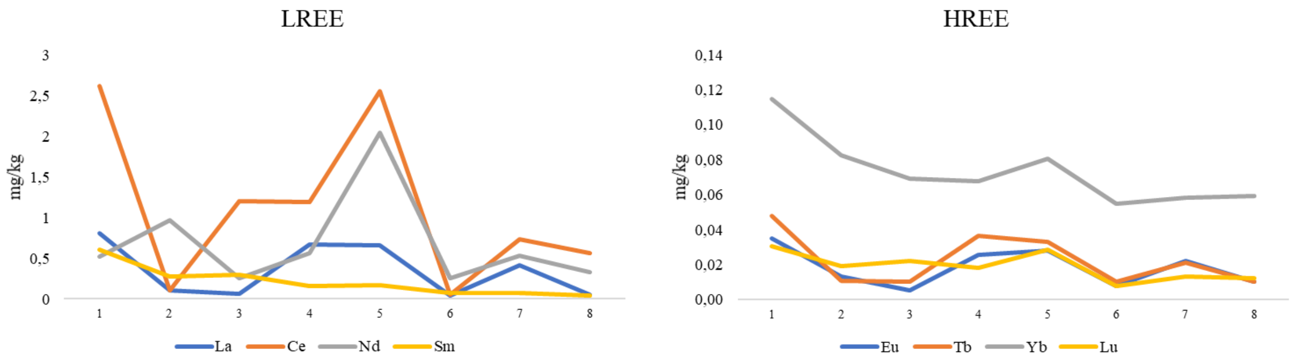

Figure 20. Distribution of LREE, RE in the organ systems of domestic pigs (Sus scrofa domesicus), (ash, mg/kg, LgC)

Note: 1 - Digestive system; 2 - Blood circulation system; 3 - Urogenital system; 4 - Intergumentary system; 5 - Musculoskeletal system; 6 - Central nervous system; 7 - Endocrine system; 8 - The respiratory system.

A study of the thorium-uranium ratio in the systems under study shows that all organ systems, except the digestive system, have a higher uranium concnetration. Therefore, thorium is actively absorbed by the tissues of the digestive system barrier. The musculoskeletal system, as the main uranium depot, stands out among other organ systems with its maximum contents.

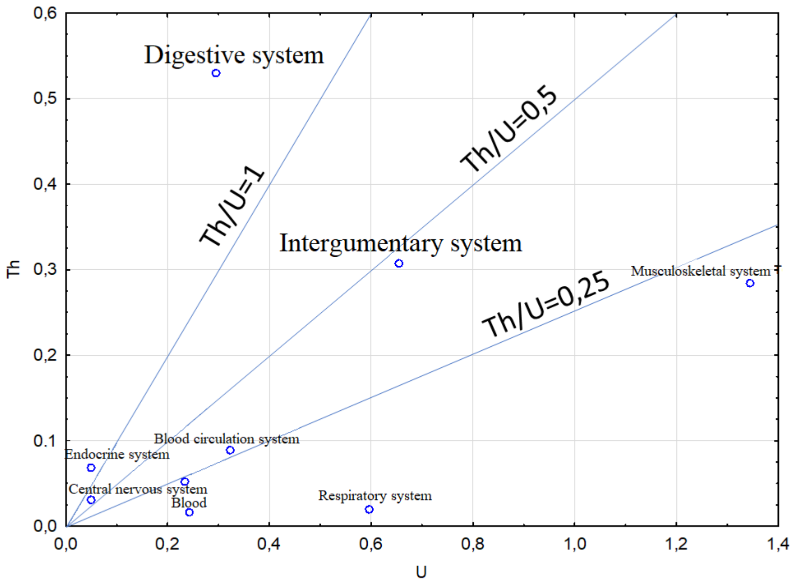

Figure 21. Th/U ratio in Domestic pig organ systems (Sus scrofa domesicus)

An assessment of the levels of accumulation of elements in the organ systems of a domestic pig (table 7) confirms that most of their maxima are found in the tissues of the leading barrier systems: the gastrointestinal tract and musculoskeletal system. Significant accumulations of macronutrients Na, Ca, Fe in the organs of the gastrointestinal tract, musculoskeletal and circulatory systems are noted. According to the analysis of the content, the elements are divided into 3 groups: 1) macro components (Na, Ca, Fe, Zn) with a content of over 600 mg/kg; 2) elements less often found in a living organism (Br, Rb, Sr, Ba, Cr, Ce, Co, As) from 20-150 mg/kg; 3) rare components (Nd, La, Ag, Sm, U, Sc, Cs, Sb, Au, Th, Hf, Yb Tb, Eu, Lu, Ta) with a content below 1 mg / kg. The analysis of concentration coefficients allows us to demonstrate the specifics of the accumulation of trace elements in various organs and systems (table 7).

Table 7. Assessment of levels of accumulation of chemical elements in the organ systems of domestic pigs (Sus scrofa domesicus), mg/kg ash residue

Chemical elements	**Max**	**Min**
Na	D.S. (59416)	C.N.S. (23850)
Ca	M.S. (92127)	E.S. (1099)
Sc	D.S. (0,5)	R.S. (0,03)
Cr	M.S. (33)	R.S. (5)
Fe	C.S. (5714)	G.U.S. (1331)
Co	I.S. (2)	G.U.S. (0,7)
Zn	D.S. (898)	M.S. (174)
As	M.S. (1,4)	M.I.S. (1)
Br	G.U.S. (224)	C.N.S. (47)
Rb	D.S. (91)	I.S. (46)
Sr	M.S. (136)	G.U.S. =E.S. (0,2)
Ag	C.N.S. (0,9)	E.S. (0,05)
Sb	I.S. (0,4)	C.N.S. (0,01)
Cs	D.S. (0,3)	C.S. (0,2)
Ba	D.S. (37)	GUS (5)
La	D.S. (0,8)	C.N.S. (0,04)
Ce	D.S (2,3)	C.N.S. (0,05)
Nd	M.S. (2,04)	GUS (0,25)
Sm	D.S (0,6)	R.S. (0,04)
Eu	D.S (0,03)	R.S. (0,01)
Tb	D.S (0,05)	GUS = C.N.S. =R.S. (0,01)
Yb	D.S (0,1)	MS (0,06)
Lu	D.S (0,03)	C.N.S. (0,01)
Hf	D.S (0,03)	C.S. (0,03)
Ta	D.S (0,03)	E.S. (0,01)
Au	G.U.S. (0,4)	C.S. (0,06)
Th	D.S (0,2)	E.S. (0,03)
U	M.S. (0,5)	C.N.S. (0,05)

Note: D.S. – digestive system, C.N.S. – central nervous system, M.S. - musculoskeletal system, E.S.- endocrine system, R.S. – respiratory system, G.U.S. - genito-urinary system, I.S. - integumentary system, B.C.S. - blood circulatory system

First, a wide range of concentration of elements in the digestive system of Pig domestic (GIT) should be noted, most of the studied trace elements and macro-components accumulate in the tissues of this system. The exceptions are Ca, Cr, As, Sr, Nd, U. The accumulation of calcium and strontium in bone tissue, as already discussed, is due to the biological role of these elements. Arsenic also accumulates in the bones and keratinized tissues when it enters the body, but only when arsenic impacts are chronic (Calatayud, Laparra Llopis, 2015). According to published data

(Барановская and Рихванов, 2011), up to 90% of uranium deposited in the body is found in the skeleton of a living organism. At the moment, the physiological function of neodymium is not fully understood. Most remarkable is the fact that no minimum concentrations of the studied elements were found in the digestive system of the body.

The integumentary system of the body accumulates Co, Sb. The genitourinary system is characterized by maxima for Au, Br, and the central nervous system for Ag. The maximum accumulation of gold by the tissues of the genitourinary system is also found in the study of the ash residue of the human body (Ignatova, 2010), from which it can be assumed that high concentrations of this element in the excretory system reflect the way it is excreted from the body. The endocrine and central nervous systems remain the most protected, demonstrating the lowest levels of elements, except for the elements mentoined above.

Analysis of the biogeochemical series of chemical elements, normalized to the arithmetic mean content of elements in the sample, confirms the results of comparing the absolute values (table 8).

Table 8. The values of the coefficients of the concentration of chemical elements relative to the average content of elements in the body of a domestic pig (Sus scrofa domesicus)

Organ system	Concentration coefficient (CC)			N° of chemical elements with CC>1
	1-2	3-6	>6	
1	2	3	4	5
D.S.	Fe_3-La_2-Eu_2-Th_2-Tb_2-Ce_2-Yb_2-Co_2-Ba_2-Sm_2-Cs_2-Hf_2-Rb_2-Ta_2-Nd_2-Cr_2-Zn_1-As_1-Lu_1-Sb_1-Na_1	Sc_3	-	22
R.S.	Rb_2-U_2	Br_4	Au_{13}-Ag_{12}	5
B.C.S.	Fe_2-Rb_2	Br_3-Ag_6	Au_7	5
Blood	Nd_2-Br_1-Ta_1-Na_1-As_1	Fe_5-Sb_3	-	7
C.N.S.	Sr_1-Co_1-Ca_1-As_1-Tb_1	-	-	5
G.U.S.	Ta_2-Sm_2 -Na_1-Au_1-Rb_1-Zn_1-Br_1	-	-	6
E.S.	Rb_1-Yb_1-Br_1	-	-	3
I.S.	U_2-Ce_2-Sb_2-Br_1-Na_1-Cr_1-Th_1-Cs_1-Fe_1-La_1-Ag_1-Rb_1-Yb_1-Co_1-Ta_1-As_1-Zn_1	-	-	17

Continuation of table 8				
1	2	3	4	5
M.S.	Nd_2-Ta_2-Eu_2-La_2-Ba_2-Cs_2-Cr_2-Tb_2-Na_2-Lu_2-As_2-Zn_1-Co_1-Hf_1-Ce_1-Th_1-Yb_1-Sm_1-Fe_1-Br_1	U_4-Ca_4-Sr_3	-	23

Note: D.S. – digestive system, C.N.S. – central nervous system, M.S. - musculoskeletal system, E.S.- endocrine system, R.S. – respiratory system, G.U.S. - genito-urinary system, I.S. - integumentary system, B.C.S. - blood circulatory system

Analysis of the concentration coefficients of chemical elements in the parts of the body of the domestic pig shows the concentration of metals such as Ag and Au in the respiratory system, these same elements show the maximum concentration coefficients. At the same time, fewer elements are concentrated in the organs of the respiratory system than in the digestive, musculoskeletal and integumentary systems. The minimum number of elements is concentrated in the endocrine and central nervous systems. According to the results of this analysis, it is possible to suggest ways of introducing and removing various elements into a living organism. Based on the example of the concentration of Au, Ag in the genitourinary, respiratory and circulatory systems, we can assume the active intake of these metals in the process of respiration with soil particles, their distribution by blood flow, and further excretion with feces and urine.

Thus, based on the data obtained during the study of the animal's organism, it can be noted that high concentrations, relatively low variation, and close correlation relationships are inherent in the group of physiologically significant macro-elements, and can be interpreted as natural. Significant barrier mechanisms of the digestive and musculoskeletal systems that accumulate most elements are revealed, which, however, requires further consideration.

Apparently, it is the habitat of animals that affects the process of accumulation of high concentrations of specific elements on the barrier organs of the animal.

CHAPTER 6. INDICATORS OF TECHNOGENESIS OF TOMSK AND PAVLODAR REGIONS BY THE EXAMPLE OF CHANGES IN THE ELEMENTAL COMPOSITION OF THE BODY OF A MAMMAL

6.1 Regional specifics of the elemental composition of the mammal in the Tomsk region

The influence of the environment on the elemental composition of living organisms is undeniable, and the geographical location of the region plays a key role in choosing a background object for research. To compare the elemental composition of the "background" zone and the territory subject to wind transfer from the industrial facility, we tested the biological material of animals from settlements with different geoecological conditions, but with the same conditions for keeping animals.

The first settlement, the village of Kizhirovo, Tomsk Region, Tomsk Region - located in the zone of influence of a powerful technogenic factor - the territory of the Northern Industrial Junction of Tomsk (SPU), is located in a wind rose 25-30 km north of SPU. This is a technologically loaded region. The second settlement is the village of Verkhnee Sechenovo, located in the southwest on the leeward side of the Tomsk region, and 45 - 50 km from the influence of the city of Seversk.

Analysis of absolute values (Figure 22) shows the territorial dependence of trace element contents in living matter. Samples from the Kizhiroso settlement are dominated by the content of the most studied elements, except for Ca, Cr, Co, Sb, Sr, Nd, Eu, Yb, Hf. The significant difference in the contents of such elements as Br, Rb, Au, - which have high concentrations in the tissues of the animal from Kizhirovo, but do not accumulate in the body of the animal from the village of Verkhnee Sechenovo - is noteworthy i.e. the main accumulation zone of these elements is in samples from Kizhirovo. In the animal from the "background" zone, on the contrary, there is a significant accumulation of Sb, Yb. The analysis of the coefficients of their concentration in a living organism in the village of Verkhnee Sechenovo shows that the circulatory and integumentary systems accumulate antimony, and the urogenital and musculoskeletal systems accumulate ytterbium.

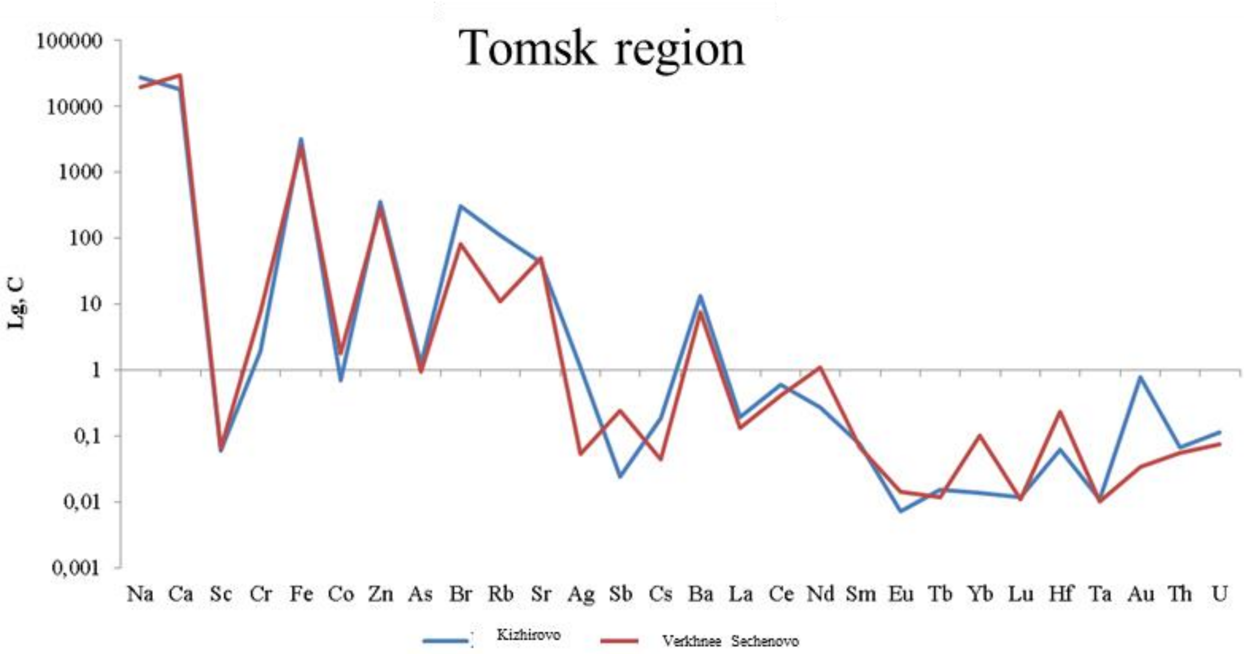

Figure 22. The elemental composition of the biological material of/from domestic pigs (Sus scrofa domesicus) in Tomsk region, LgC ash residue

Table 9.The concentration coefficient of chemical elements in the organs and tissues of domestic pigs (Sus scrofa domesicus) relative to the average content in the sample

Organ system	Verkhnee Sechenovo	Kizhirovo
Circulatory system	$Sb_{3,0}$-$Fe_{1,0}$-$Co_{1,0}$	$Rb_{1,6}$-Br_{1}-$Au_{1,1}$
Endocrine system	$Co_{1,2}$-$Fe_{1,0}$	$Au_{2,0}$-$Rb_{1,9}$-$Br_{1,0}$
Genitourinary System	-	$Ag_{5,4}$-$Au_{3,6}$-$Rb_{1,8}$-$Br_{1,5}$
central nervous system	$Co_{1,0}$	$Au_{2,6}$-$Fe_{1,5}$-$Cs_{1,3}$=Rb
Respiratory system	$Ca_{1,2}$-$Fe_{1,0}$=Co	$Br_{2,9}$-$Au_{2,7}$-$Rb_{1,9}$-$U_{1,8}$
Musculoskeletal system	$Ca_{2,5}$=Sr-$Co_{1,1}$-$Yb_{1,0}$	$Au_{5,4}$-$Ag_{4,7}$-$Ca_{1,9}$-$Sr_{1,8}$-$Br_{1,0}$
Digestive system	$Co_{1,1}$	$Fe_{3,2}$-$Au_{1,9}$-$Rb_{1,8}$-$Br_{1,6}$=As-$Cs_{1,3}$-$Sr_{1,2}$-$Ba_{1,1}$-$Co_{1,0}$
Integumentary system	$Sb_{6,4}$-$Co_{1,0}$	$Br_{1,8}$-$Au_{1,3}$-$Rb_{1,2}$
Additive indicator	13	17

The animal organism from the village of Kizhirovo accumulates elements that do not have an important physiological role. Attention is drawn to the accumulation of gold in all studied organ systems, and silver in the genitourinary and musculoskeletal systems. The main localization of Au is in the cartilage (trachea), gall bladder, brain, lungs, rectum, and ureter (Figure 23). Ag is accumulated by the same organs as Au, except for the brain, and also reaches significantly higher concentrations in cartilage (Figure 23). The accumulation of gold and silver in the tissues of the genitourinary system reflects the ways they are excreted from the body. The transition of Au, Ag to bile and their further excretion with feces determines, most likely, the accumulation of these elements in the gallbladder and rectum. The fact of the accumulation of gold by the tissues of the respiratory and integumentary systems implies their intake with air and further deposition with blood into the bone tissue.

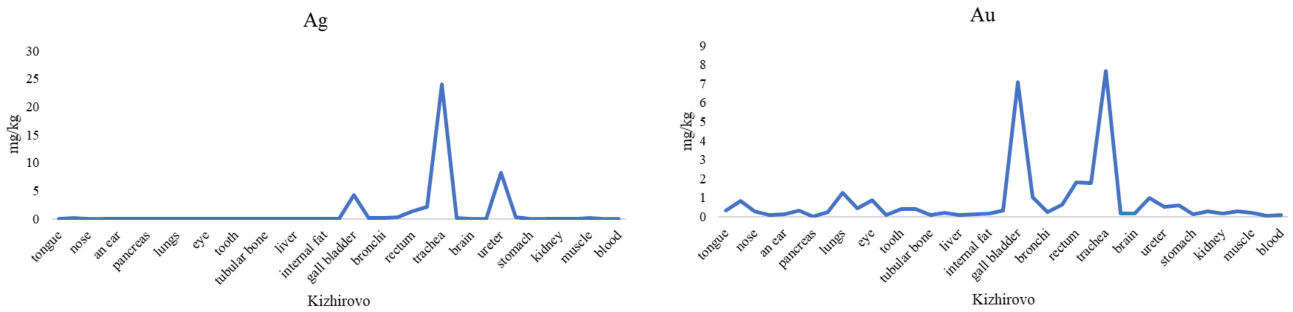

Figure 23. The content of Au, Ag in the biological material of domestic pigs (Sus scrofa domesicus) in the Kizhirovo Tomsk region, (mg / kg ash residue)

Apparently, in the village of Kizhirovo, elements such as Br, Rb, U also enter the animal organism with air. The fact of enrichment of abiotic media in the Tomsk region with bromine is confirmed by the results of previous studies (Perminova, 2017). The same studies show the presence of Rb, Au, U in the soils of the Tomsk region, and, therefore, it can be assumed that animals inhale these elements with soil particles.

A detailed examination of the target organs for uranium in the body of an animal from the village of Kizhirovo (Figure 24) shows that uranium settles preferentially in the lungs and to a lesser extent on the pleura, less significant contents are found in cartilage and blood, but in other organs this element is below the detection limit. In samples from the village of Verkhnee Sechenovo, uranium accumulates above the detection limit only in the large intestine (Figure 24).

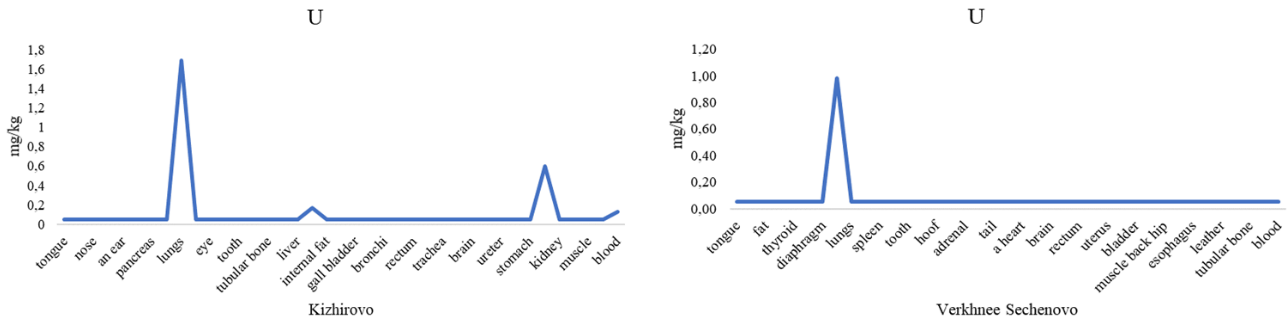

Figure 24. U content in the biological material of domestic pig (Sus scrofa domesicus) in the Kizhirovo, Verkhnee Sechenovo Tomsk Region, (mg / kg ash residue)

In general, the concentrations of elements in the background territory are much lower than in the influence zone. The high concentration coefficient of Sb in the circulatory and integumentary system draws is particularly noticeable. Localization of this element occurs in the blood and skin (ear, stubble, skin) and mucous membranes (eyeball). This feature may be associated with the intake of antimony on the skin with dust aerosols from atmospheric air and subsequent release into the blood (Figure 25). Moreover, the concentration of Sb in the blood of residents of the Tomsk region and its surrounding territories is also detected by the analysis of human blood and soil of the Tomsk region (Baranovskaya, 2011). Given the absence of industrial production facilities on the territory of the settlement, we can assume the presence of a natural factor determining the introduction of this element into the body. It is noteworthy that Sb together with U, Ag, Br does not behave in the same way as of the main factors allocated in the sample (Figure 28).

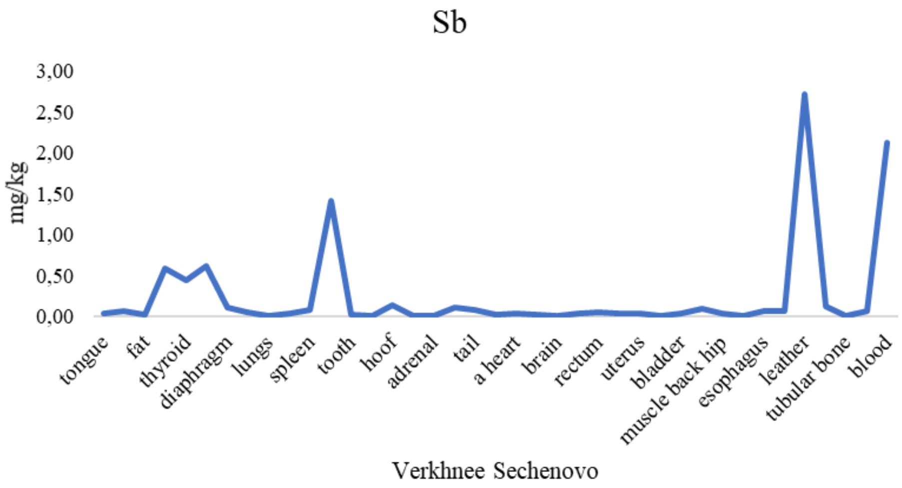

Figure 25. Sb content in the biological material of domestic pig (Sus scrofa domesicus) in the territory of the Upper Sechenovo Tomsk Region, (mg / kg ash residue)

Except for antimony, other chemical elements are contained in relatively low concentrations. However, our attention is drawn to the accumulation of cobalt by all organ systems, while the Kizhirovo animal only accumulates cobalt in the digestive system. High concentrations of cobalt are found in the blood of residents of the Tomsk region, and the Tomsk region as a whole. It is not recorded in drinking water, but it has a concentration coefficient greater than 2 in the region's soils. The accumulation of cobalt may be a consequence of the presence of brown coal deposits, for which Co is a typomorphic element (Baranovskaya, 2011). In the animal from Upper Sechenovo, cobalt has a strong correlation with europium, and with scandium in biomaterial from Kizhirovo (Figure 26). Earlier, when studying the statistical parameters of the distribution of elements in the body, a strong correlation relationship between cobalt and iron was noted, and an assumption was made about the physiological, hematopoietic nature of this relationship (Figure 26). Europium and scandium, however, do not have a pronounced physiological role and belong to the group of conditionally toxic microelements (Figure 26). These correlations probably reflect the regional aspect of the studied settlements and their introduction into a living organism and subsequent binding to blood components. Thus, according to a freshwater scale study, Verkhnee Sechenovo is located in a zone with a high content of europium (Mongolina, 2017). In Kizhirovo, the accumulation of cobalt and scandium is regulated by one factor (Figure 28).

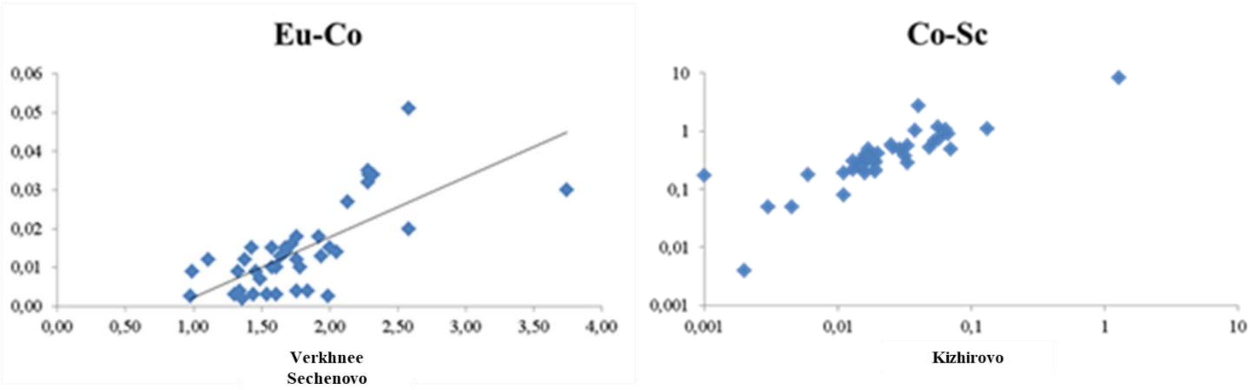

Figure 26. The correlation of elements in the biological material of domestic pigs (Sus scrofa domesicus) in the Tomsk region? (mg/kg ash residue)

Other correlation relationships in the studied settlements coincide with the analysis of the relationships in the body as a whole (Figure 27). Strong interactions between calcium and strontium stand out, demonstrating the bone component of the body. In contrast to the analysis of the entire sample, a detailed analysis of pair correlations in the Tomsk region gives rise to a strong sodium-bromine dependence, apparently characteristic of the region as a whole, and reflecting the elemental composition of the blood (Baranovskaya, 2011).

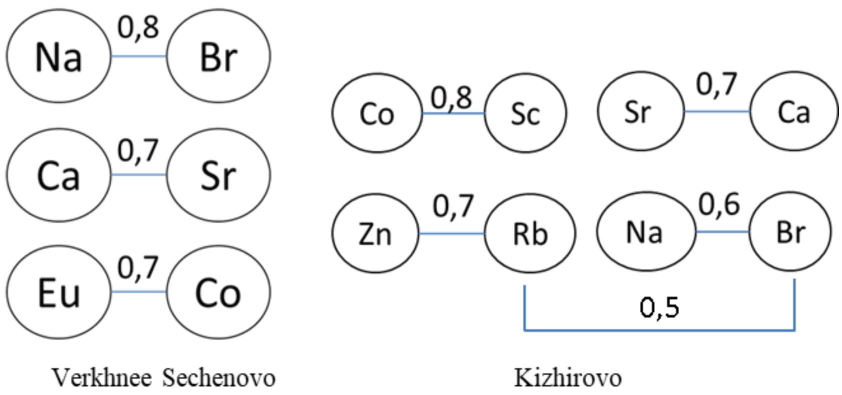

Figure 27. Significant (> 0.5) correlations of elements in the ash of biological material of Domestic Pigs (Sus scrofa domesicus) in the Tomsk Region, p = 0.05

The intake of bromine in the Verkhnee Sechenovo is regulated by the same factor as the intake of antimony and probably reflects the natural nature of both intakes (Figure 28). In Kizhirovo, one can note the emergence of a correlation between zinc and rubidium, and a relatively low, but significant, relationship between rubidium and bromine. Bromine and rubidium in this production are also regulated by one factor.

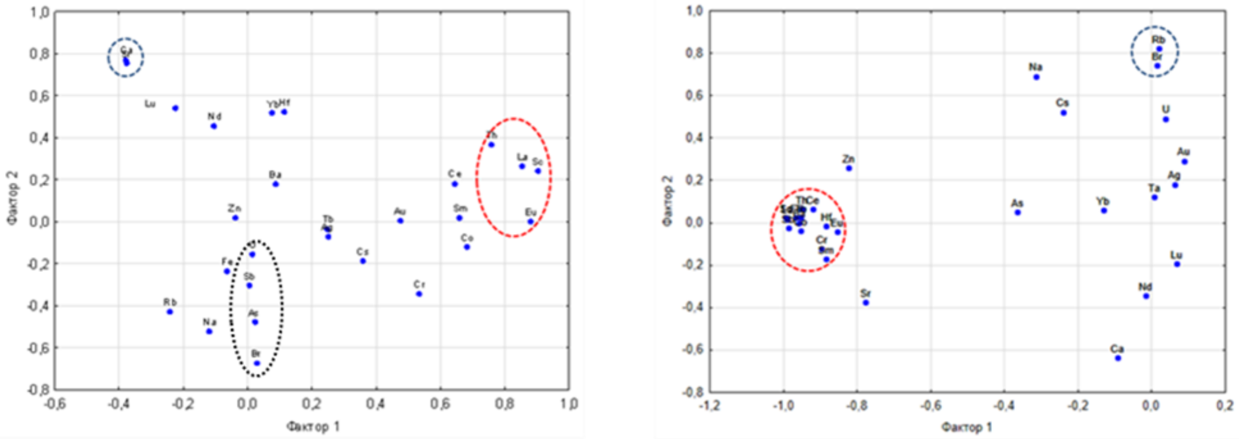

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Figure 28. The correlation relationship of Factor 1 and Factor 2, based on the results of factor analysis, of the ash of the biomaterial of the domestic pig (Sus scrofa domesicus) in the Tomsk region

The main difference between the factor loads of the two studied settlements is that the main array of elements in Kizhirovo is regulated by one factor, while the second factor regulates only the accumulation of bromine and rubidium. In biomaterial from Verkhnee Sechenovo, the same factor loads are distributed more evenly, with the separation of two main factors, one of which affects Th, La, Sc, Eu, and probably reflects the entry of these elements into the body from the external environment, and the second relates the bone nature of the studied material and affects the content of Ca and Sr (Figure 29). Comparing the content of Ca, Sr and P in the bone tissue of animals from Kizhirovo and Verkhnee Sechenovo according to the results of the ICP-MS analysis, it can be noted that the bones of the animal from Kizhirovo contain more phosphorus and strontium and less calcium.

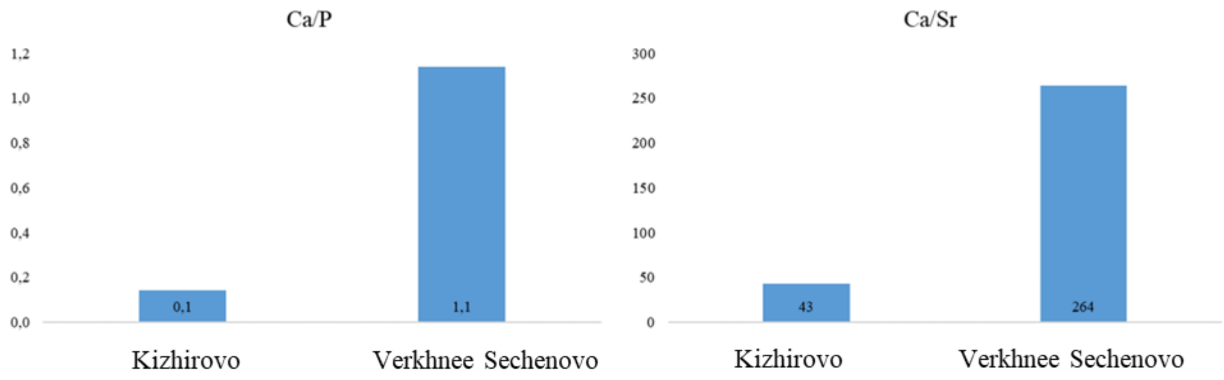


Figure 29. Ca/P, Ca/Sr ratios in the ash residue of bone tissue of domestic pig (Sus scrofa domesicus) in the Tomsk Region, according to the results of ICP-MS

In general, animal bone material from the influence zone accumulates more trace elements than in the conventional background zone. However, a piglet from Verkhnee Sechenovo accumulates more Pb, Al, Cu, Zn, Mo, Ce, Zr (concentration coefficients more than one), and Be, Sc, Cd (concentration coefficient less than one) in bone tissue. The accumulation of these elements in the bone tissue of an animal from a (conditionally) background zone probably indicates their deposition into bone tissue with blood.

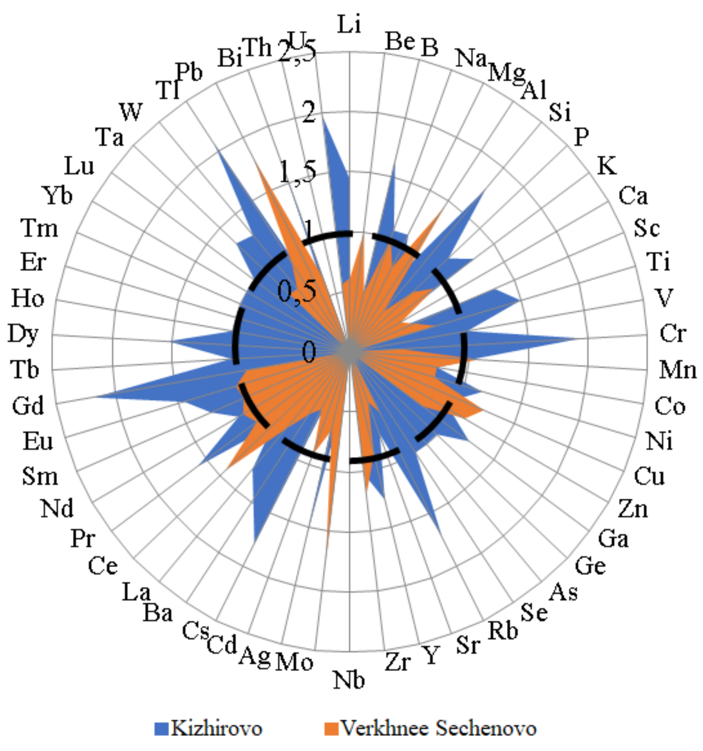


Figure 30. Concentration coefficients in the biomaterial of domestic pig (Sus scrofa domesicus) in the Tomsk region, according to the results of ICP-MS relative to the average content in the sample

When comparing the background territory - Verkhnee Sechenovo with the impact zone Kizhirovo - the first is distinguished by lower concentrations of chemical elements, although this region, due to its geographical location, also has its geochemical face. These anomalies determine the entry of certain elements into the body and their subsequent deposition in internal organs in larger quantities than in the affected area.

Considering the geochemical features of the background zone and the revealed elevated contents of elements such as Ca, Cr, Co, Sr, Nd, Eu, Yb, Hf, Sb (INAA results), and Pb, Al, Cu, Zn, Mo, Ce, Zr, Be, Sc, Cd (results of ICP-MS), it is further proposed to normalize the values to their average content in the entire sample in order to avoid artificial overestimation or underestimation of concentration coefficients.

The dependence of the chemical composition of animal biomaterial on regional effects is also confirmed by the results of the analysis of ICP-MS.

In the territory of 6 settlements of the Tomsk region and a settlement of the Pavlodar region biomaterials of the system "first cervical vertebra-spinal cord" were analyzed (table 10).

Comparing the chemical composition of hydroxylapatite as the main component of bone tissue, it can be noted that bones from Asino and Urtam, the lowest contents of this element are samples from the village Kizhirovo. The city of Ekibastuz is distinguished by finding the maximum concentrations of elements such as P, Na, Mg, K, and the village of Kizhirovo by the minimum contents of Na, K, P, Mg. The lowest P contents are found in samples from Kizhirovo, and Mg is lowest in samples from the village of Kornilovo.

Thus, the composition of the inert tissue varies significantly depending on the sampling area, which can be associated with the geoecological conditions of the sampling point.

Table 10. The content of chemical elements in the ash of the biomaterial Pig domestic (Sus scrofa domesicus), ICP-MS, (mg / kg ash residue)

C/e	Ekibastuz		Asino		Semiluzhki		Kornilovo		Urtam	Kizhirovo		Verkhnee Sechenovo	
	Vertebral	Spinal Cord	Vertebral	Spinal Cord	Vertebral	Spinal Cord	Vertebral	Spinal Cord	Vertebral	Vertebral	Spinal Cord	Vertebral	Spinal Cord
	1	2	3	4	5	6	7	8	9	10	11	12	13
Li	1,7	47,8	1,4	45,6	0,9	47,0	1,0	4,7	0,3	0,17	1,20	0,57	0,08
Be	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	BDL	BDL	BDL	BDL
B	39	1860	81	4872,0	78	1150	14	423	88	0,068	35	0,720	0,110
Na	12737	53880	12145	59329,9	10041	46056	11620	36935	8751	3052	15812	3793	2519
Mg	7579	3656	6732	3933,6	6685	1007	6090	4586	6167	535	1471	1368	162
Al	3,2	165,0	4,9	130,6	3,3	38,4	0,0	5,5	1,3	1,3	107	4,083	18
Si	35,8	1116,0	31,7	442,4	86,2	631,0	0,4	156,6	8,0	41	7 557		119,025
P	201922	141416	197369	135027,2	171546	128695	177421	164504	182667	7355	14755	11525	2169
K	17785	89836	5323	68752,2	5699	51373	3341	59371	2939	1850	18015	4900	2017
Ca	331301	8096	360324	4811,2	321234	8925	330660	5552	349091	1004	307	23573	994
Sc	0,03	0,8	0,03	0,03	0,03	0,03	0,03	0,03	0,03	BDL	5,029	BDL	0,019
Ti	3,0	27,3	2,5	14,3	2,4	4,5	1,8	3,1	2,9	0,3	43	3	1
V	0,1	0,4	0,02	0,2	0,1	0,4	0,03	0,02	0,02	BDL	97,53	BDL	BDL
Cr	0,2	14	0,01	7,2	0,3	21,7	0,1	0,4	0,1	BDL	6,00	BDL	0,11
M_n	3,2	14	1,2	9,2	1,4	14,2	0,5	6,4	1,5	0,5	5,9	0,4	0,5
Fe	2340	836	2673	895,0	2694	441	1787	38	2371	BDL	BDL	BDL	BDL
Co	4,9	0,3	4,6	0,1	5,3	0,3	4,1	0,1	6,2	0,08	0,26	0,50	0,08
Ni	0,0001	1,1	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,18	4,73	2,25	0,04
Cu	4,9	34,6	2,2	41,2	1,5	9,8	1,1	8,1	0,9	1,0	26,1	2,6	3,1
Zn	259	253	206	170,0	267	135	182	106	181	43	104	106	9
Ga	0,4	0,2	0,2	0,2	0,2	0,05	0,1	0,02	0,1	0,09	0,38	0,12	0,03
Ge	0,01	0,01	0,01	0,03	0,01	0,003	0,003	0,004	0,01	BDL	0,55	BDL	BDL
As	0,3	0,2	0,2	0,1	0,3	0,1	0,2	0,03	0,3	BDL	341	BDL	BDL
Se	0,7	0,5	1,0	0,8	1,3	0,2	0,7	0,0003	0,9	BDL	162	BDL	BDL
Rb	7,6	42,5	7,8	85,4	8,9	57,2	5,9	69,9	4,8	6,2	41,7	3,1	1,2
Sr	159	5,4	166	4,0	158,2	9,2	116,1	1,7	114,1	26,7	1,7	55,2	2,5
Y	0,005	0,036	0,01	0,01	0,004	0,01	0,002	0,001	0,002	BDL	0,03	0,004	0,001
Zr	0,0	0,5	0,02	0,4	0,04	0,2	0,003	0,03	0,01	0,01	0,47	BDL	0,40
Nb	0,0	0,2	0,1	0,01	0,1	0,01	0,1	0,005	0,04	BDL	BDL	BDL	BDL

Continuation of table 10

	1	2	3	4	5	6	7	8	9	10	11	12	13
Mo	0,1	0,5	0,1	0,3	0,1	0,3	0,1	0,2	0,1	0,02	0,30	0,06	0,01
Ag	0,01	0,04	0,01	0,003	0,005	0,0001	0,003	0,0001	0,0001	0,002	0,06	0,004	0,005
Cd	0,005	0,03	0,005	0,02	0,0003	0,01	0,01	0,04	0,004	0,0003	0,15	0,004	BDL
In	0,001	0,002	0,001	0,001	0,001	0,001	0,001	0,0002	0,001	BDL	BDL	BDL	BDL
Sn	0,01	0,03	0,01	0,1	0,009	0,1	0,01	0,03	0,01	BDL	BDL	BDL	BDL
Sb	0,005	0,02	0,01	0,02	0,003	0,1	0,01	0,01	0,002	BDL	BDL	BDL	BDL
Te	0,005	0,04	0,01	0,01	0,01	0,01	0,01	0,01	0,01	BDL	BDL	BDL	BDL
Cs	0,0	0,1	0,01	0,2	0,02	0,1	0,0	0,1	0,02	0,01	0,14	0,003	0,001
Ba	20,2	2,2	11,8	2,8	11,3	1,0	4,2	0,2	6,0	2,3	15,4	4,3	0,2
La	0,0	0,1	0,002	0,02	0,004	0,01	0,0001	0,001	0,001	BDL	0,21	0,04	0,02
Ce	0,0	0,1	0,002	0,1	0,01	0,025	0,001	0,001	0,002	0,002	0,041	0,01	0,015
Pr	0,001	0,02	0,001	0,01	0,001	0,002	0,0001	0,0004	0,0002	BDL	0,01	0,005	BDL
Nd	0,002	0,04	0,003	0,01	0,004	0,007	0,0002	0,001	0,0003	0,0004	0,06	0,01	0,0039
Sm	0,0001	0,01	0,0001	0,001	0,001	0,001	0,001	0,0001	0,0005	BDL	0,004	BDL	BDL
Eu	0,0001	0,001	0,0001	0,0002	0,001	0,0001	0,0001	0,0001	0,0001	BDL	0,005	0,002	BDL
Gd	0,0002	0,01	0,001	0,001	0,001	0,001	0,0001	0,0001	0,0001	BDL	0,011	BDL	BDL
Tb	0,001	0,003	0,001	0,002	0,001	0,0003	0,001	0,0001	0,0009	BDL	0,001	BDL	BDL
Dy	0,0004	0,006	0,0003	0,001	0,0001	0,0002	0,0002	0,0001	0,0001	BDL	0,010	BDL	BDL
Ho	0,0001	0,003	0,0003	0,001	0,0001	0,0001	0,0001	0,0001	0,0002	BDL	0,001	BDL	BDL
Er	0,0002	0,002	0,001	0,001	0,0003	0,0002	0,0001	0,0002	0,0002	BDL	0,01	BDL	BDL
Tm	0,0001	0,001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	BDL	0,001	BDL	BDL
Yb	0,001	0,004	0,001	0,0004	0,001	0,0003	0,0001	0,0001	0,0003	BDL	0,003	BDL	BDL
Lu	0,002	0,001	0,001	0,0001	0,001	0,0002	0,001	0,0001	0,001	BDL	0,001	BDL	BDL
Hf	0,001	0,01	0,001	0,005	0,002	0,004	0,0001	0,0003	0,0002	BDL	BDL	BDL	BDL
Ta	0,0001	0,0001	0,025	0,0001	0,009	0,001	0,02	0,02	0,01	0,002	BDL	BDL	0,005
W	0,003	0,001	0,004	0,03	0,01	0,03	0,02	0,01	0,01	BDL	0,16	BDL	0,011
Au	0,0001	0,01	0,001	0,01	0,0001	0,0001	0,0001	0,0001	0,0001	BDL	BDL	BDL	BDL
Hg	0,0001	0,01	0,0001	0,002	0,002	0,0001	0,0001	0,002	0,0001	BDL	BDL	BDL	BDL
Tl	0,003	0,01	0,00003	0,02	0,001	0,002	0,001	0,002	0,002	BDL	0,028	BDL	BDL
Pb	2,6	0,3	1,0	0,2	0,2	0,9	0,3	0,2	0,1	0,25	0,92	2,06	0,27
Bi	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,001	0,003	0,0001	0,01	0,62	0,01	0,05
Th	0,0001	0,02	0,01	0,01	0,002	0,003	0,0004	0,0003	0,001	BDL	BDL	BDL	BDL
U	0,005	0,05	0,1	0,01	0,1	0,02	0,04	0,002	0,03	0,004	0,21	0,02	BDL

To identify the features of the distribution of elements in bone tissue, their concentration coefficients were calculated relative to the arithmetic mean content of elements in the sample. With a large number of metals accumulated by bones, most of them coincide for each studied region and are probably physiological for bone tissue.

The geochemical feature of the bones taken in the Tomsk Region is the accumulation of rare-earth metals Ta, Sm, while the heavy metal Pb specifically accumulates in samples from the city of Ekibastuz. Lead air pollution with its subsequent accumulation in biomaterials is usually associated with the automotive industry, which is logical given the fact that Ekibastuz is a large industrial center for coal mining, and a large number of vehicles are also actively used in this city.

Table 11. The concentration coefficients of elements in the bone tissue of domestic pigs (Sus scrofa domesicus) in the Tomsk and Pavlodar regions, relative to the average content in the sample

Region		Vertebral			Spinal cord		
		Biogeochemical series	Common chemical elements	Regional chemical elements	Biogeochemical series	Common chemical elements	Regional chemical elements
1		2	3	4	5	6	7
Tomsk oblast, Russia	Asino city	$Lu_{2,7}$-$Ca_{2,6}$=Sr-$Ta_{2,5}$-$Ba_{1,9}$-$Co_{1,5}$-$Th_{1,3}$=Ho-$Yb_{1,2}$-$P_{1,0}$-Sc=Be=Ni	Lu, Ca, Sr, Ba, Co, Yb, Sc, Be, Ni	$Ta_{2,5}$	$Tl_{4,9}$-$Zr_{3,6}$-$Pr_{3,0}$-$Ho_{2,5}$-$Er_{1,6}$	Zr	Tl
	Semiluzhki village	$Sr_{2,4}$-$Ca_{2,3}$-$Sm_{2,0}$-$Ba_{1,8}$-$Co_{1,8}$-$Lu_{1,5}$-$Yb_{1,4}$-$Sc_{1,0}$-Be=Ni		$Sm_{2,0}$	$Sb_{1,8}$-$Zr_{1,5}$		Sb
	Kornilovo village	$Lu_{2,6}$-$Ca_{2,4}$-$Ta_{2,0}$-$Sr_{1,8}$-$Co_{1,3}$-$Sm_{1,2}$-$Sc_{1,0}$=Be=Ni		$Ta_{2,0}$	$Ta_{2,2}$		Ta
	Urtam village	$Lu_{2,5}$-Ca-$Co_{2,0}$-$Sr_{1,8}$-$Sc_{1,0}$=Be=Ni=Ba		-	-		-
Pavlodar oblast, Kazakhstan	Ekibastuz city	$Ba_{3,3}$-$Lu_{3,1}$-$Sr_{2,5}$-$Ca_{2,4}$-$Co_{1,6}$-$Pb_{1,1}$=Yb-$P_{1,0}$=Sc=Be=Ni		$Pb_{1,1}$	$Sc_{30,7}$-$Sm_{16,4}$-$Ho_{11,6}$-$Yb_{6,8}$-$Pr_{6,4}$-$Gd_{5,8}$-$Nd_{5,2}$-$Zr_{5,1}$-$Tm_{4,3}$-$Er_{3,9}$-$Th_{3,8}$-$Y_{2,9}$-$La_{2,5}$-$Lu_{2,5}$-$Tl_{2,3}$-$Nb_{1,5}$		Sc, Sm, Yb, Ho, Gd, Nd, Tm, Th, Y, La, Lu, Nb

Analyzing the chemical composition of the spinal cord, one can also note a certain specificity of the concentration of elements depending on the sampling zone (Figure 31, 33). The spinal cord, as part of the central nervous system, remains the body's most protected system, and as a result, it accumulates a relatively low number of chemical elements. However, samples from Ekibastuz are enriched with many chemical elements, while Urtam remains the “cleanest” region. Rare, rare-earth and radioactive elements accumulate in the spinal cord from Ekibastuz, which may be due to their release into atmospheric air during the burning of high-ash Ekibastuz coals.

Samples from the Tomsk region contain a significantly smaller number of chemical elements; however, Tl accumulates in samples from Asino, Sb in Semiluzhki, and Ta in Kornilovo.

Thallium (Tl) is a highly toxic metal that tends to accumulate in the tissues of the nervous system, and damaging them. Since the main source of this metal in the body is from the burning of natural carbon fuel, the fact that waste enters the living body can be explained by the large number of vehicles in the city of Asino. The likely source of tantalum (Ta) in the animal’s body in the Kornilovo settlement is the exhaust emissions from the Tomsk-Mariinsk motorway passing through it. The concentration of antimony in the spinal cord of the animal from Semiluzhki may be due to the presence of the Tomsk oil refinery in the settlement, and Sb is likely to come from the chemical industry. Another reason may be the presence in this region of the Semiluzhensky antimony manifestation (Parnachev, 2010).

Comparing the Tomsk and Pavlodar regions by the content of elements in the bone tissue and the central nervous system, it can be noted that, in general, the spinal cord of animals from the Tomsk region is less enriched with chemical elements. Bone tissue naturally concentrates most of them, as the physiological function of bones is to act as a kind of “depot” for chemical elements. However, it is obvious that in the organism of animals from Pavlodar region this barrier function is disrupted under the influence of technogenic impact, and the elements freely migrate to the tissues of the central nervous system. The territorial features of the concentration of elements in the bone tissue and the central nervous system of domestic pigs are also presented graphically – see (Figure 34) below - and can also be distinguished by the Ca/P and Th/U ratios (Figure 31, 32).

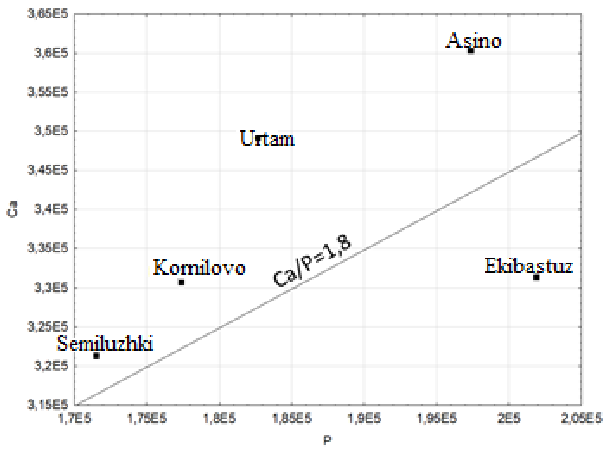


Figure 31. Ca/P ratios in the bone tissue of a domestic pig (Sus scrofa domesicus) in the Tomsk Region and the city of Ekibastuz, Lg C

A comparative analysis of the calcium-phosphorus ratio in the bone tissue of a domestic pig allows the studied territories to be grouped according to regional characteristics, separating the areas belonging to the Tomsk region from the city of Ekibastuz. According to the Ca/P value, the zone ratios are arranged as follows: Ekibastuz1.6-Asino1.8-Semiluzhki 2.0 = Kornilovo = Urtam (table 12). At the same time, the stereochemical ratio of these elements in apatite, as a mineral that forms bone tissue, ranges from 1.4 to 1.7 (Newman, 1961). The ratio of calcium to phosphorus in all samples except the material from Ekibastuz can be characterized as elevated.

In terms of the thorium content of the uranium ratio, the studied territories are also grouped according to geographical location, distinguishing Ekibastuz from other zones with the lowest Th (table 12). Besides, samples from Asino also move away from the main data group, demonstrating the high content of U and Th and the thorium nature. Semi-arms are distinguished by the uranium content in both studied components.

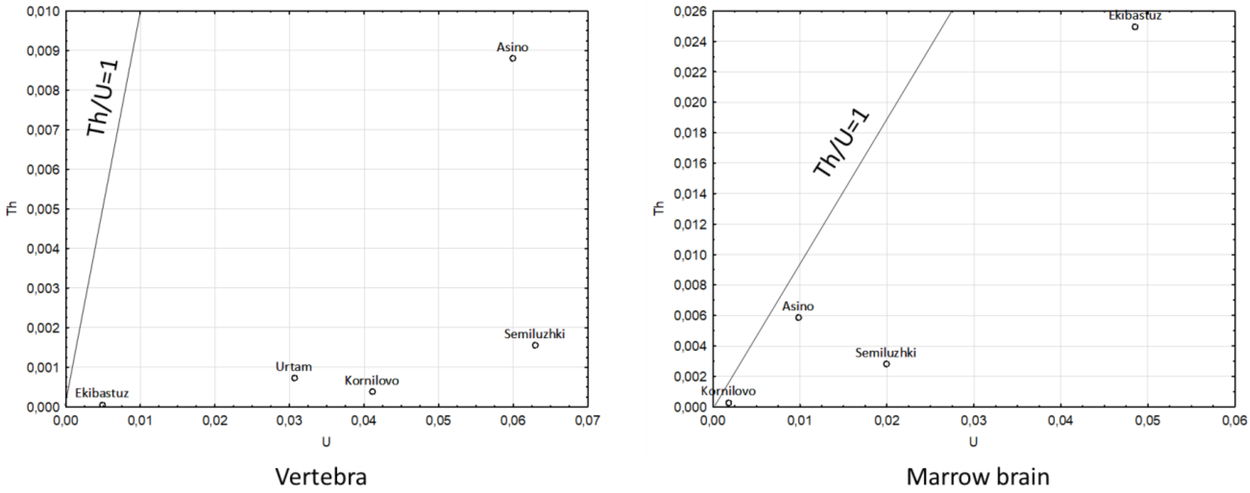


Figure 32. Thorium-uranium ratio in samples of biological material P - vertebra, SM - spinal cord of domestic pig (Sus scrofa domesicus) in the Tomsk region and the city of Ekibastuz

Table 12. Ca/P, Th/U ratios in bone tissue of domestic pig (Sus scrofa domesicus) in the Tomsk and Pavlodar regions, according to the results of the analysis of ICP-MS

Territory	Ca/P		Th/U	
	Vertebral	Spinal cord	Vertebral	Spinal cord
Ekibastuz	1,6	0,06	0,01	0,5
Asino	1,8	0,04	0,2	0,6
Semiluzhki	2,0	0,07	0,02	0,1
Kornilovo	2,0	0,03	0,01	0,2
Urtam	2,0	Н/д	0,02	Н/д

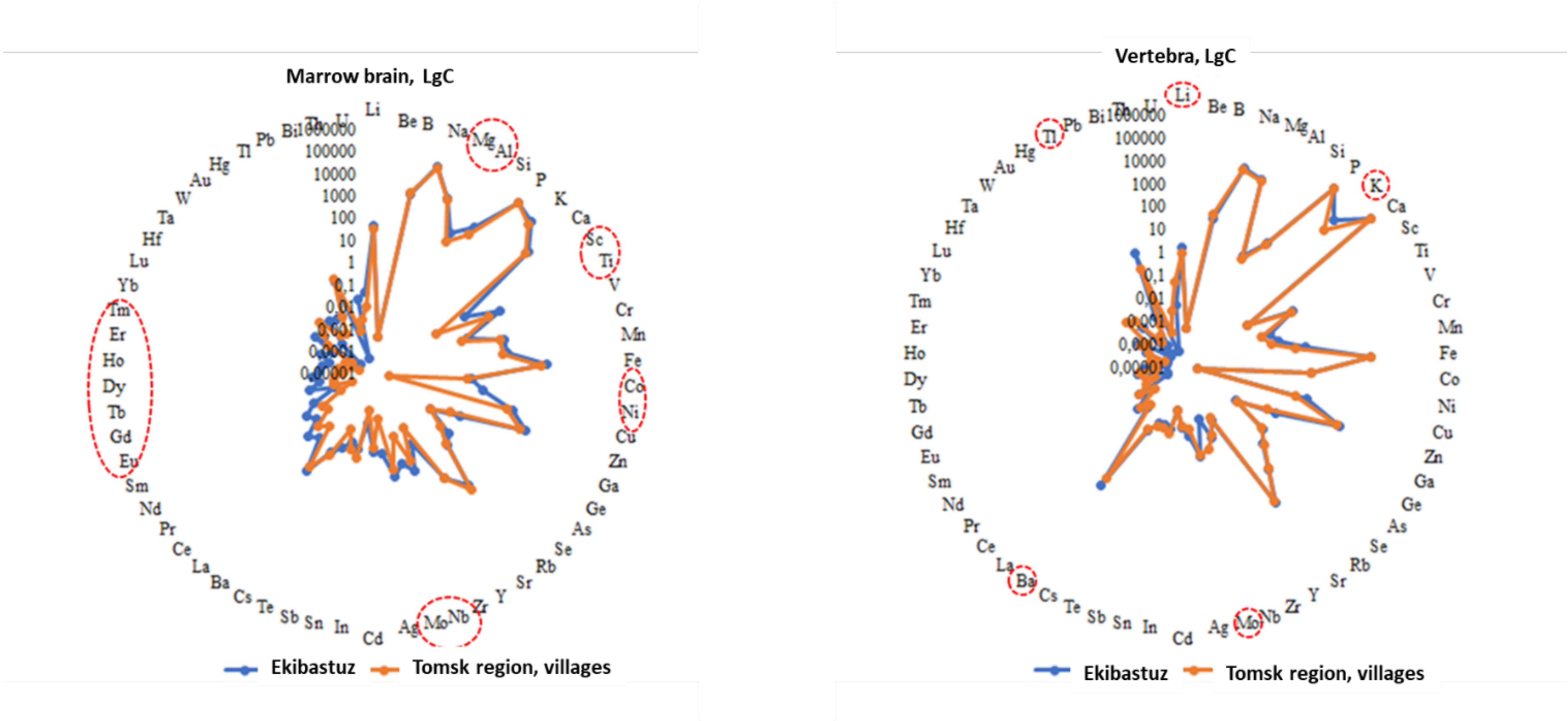


Figure 33. The content of chemical elements in the bone and spinal cord of domestic pig (Sus scrofa domesicus) according to the results of ICP-MS analysis

Thus, it can be noted that, based on the chemical composition of the biological material, it is possible to rank the territories and draw conclusions about the magnitude of the technogenic load on the region.

6.2 Change in the content and ratio of elements in the tissues and organs of the domestic pig (Sus scrofus domesticus) in the urban areas of Tomsk and Pavlodar regions

The importance of assessing the health effects on the population of urbanized or urban areas is determined primarily by the large concentration of industrial enterprises, most often near residential areas. The areas studied during the study are highly urbanized territories, such as the city of Ekibastuz, Pavlodar region, whose territory includes both urban environment objects and the mining and energy industries. Settlements of the Tomsk region and Trans-Baikal Territory are rural territories, which are, nevertheless, constantly affected by industrial facilities.

From the results of the study, summary tables of the gross contents of elements in the bone tissue, the gastrointestinal tract and the skin of the pig were compiled. The selected organ systems reflect barrier systems and systems for depositing elements of a living organism, and their composition reflects the technogenic specificity of the studied regions.

Table 13. The content of chemical elements in the ash of the biomaterial of Domestic pig, INAA, mg/kg

C/e	The villages of Kizhirovo and Verkhnee Sechenovo of Tomsk district			Ekibastuz city of Pavlodar oblast		The villages Gazimursky zavod, Urovskie kluchi, Kalga, Taina of Zabaikalsky Krai	
	Integumentary system	Digestive system	Bone	Digestive system	Bone	Bone	Integumentary system
	1	2	3	4	5	6	7
Na	$\frac{22889 \pm 7529}{400 \ldots 75400}$ 99	$\frac{27350 \pm 5268}{11000 \ldots 58300}$ 54	$\frac{18522 \pm 3200}{9300 \ldots 34600}$ 52	$\frac{81721 \pm 5629}{0,05 \ldots 0,17}$ 28	$\frac{23185 \pm 10983}{1383 \ldots 34390}$	$\frac{44664 \pm 15472}{12069 \ldots 130552}$ 109	$\frac{33398 \pm 10688}{12346 \ldots 51816}$ 64
Ca	$\frac{1800 \pm 580}{400 \ldots 4700}$ 97	$\frac{6050 \pm 3876}{500 \ldots 32500}$ 181	$\frac{109222 \pm 15978}{29000 \ldots 175000}$ 44	$\frac{14508 \pm 2103}{3791 \ldots 31969}$ 60	$\frac{205928 \pm 25242}{3322 \ldots 79903}$ 81	$\frac{98601 \pm 37961}{9538 \ldots 233591}$ 98	$\frac{116012 \pm 57197}{14364 \ldots 217184}$ 99
Sc	$\frac{0,07 \pm 0,04}{0,01 \ldots 0,37}$ 155	$\frac{0,21 \pm 0,15}{0,01 \ldots 1,28}$ 208	$\frac{0,04 \pm 0,02}{0,001 \ldots 0,18}$ 152	$\frac{0,98 \pm 0,28}{0,05 \ldots 0,17}$ 118	$\frac{0,02 \pm 0,07}{0,05 \ldots 0,25}$ 101	$\frac{0,6 \pm 0,3}{0,005 \ldots 1,8}$ 82	$\frac{0,07 \pm 0,03}{0,001 \ldots 0,16}$ 104
Cr	$\frac{7,19 \pm 2,79}{0,25 \ldots 24,20}$ 116	$\frac{11 \pm 4}{0,25 \ldots 36}$ 115	$\frac{1,54 \pm 0,65}{0,25 \ldots 4,60}$ 127	$\frac{24 \pm 5}{0,19 \ldots 71}$ 90	$\frac{6,41 \pm 0,61}{0,01 \ldots 1,86}$ 165	$\frac{48 \pm 18}{0,3 \ldots 121}$ 103	$\frac{55 \pm 17}{8 \ldots 87}$ 60
Fe	$\frac{981 \pm 340}{80 \ldots 3200}$ 104	$\frac{2198 \pm 619}{490 \ldots 6090}$ 80	$\frac{351 \pm 86}{110 \ldots 840}$ 74	$\frac{1908 \pm 664}{45 \ldots 7230}$ 143		$\frac{8058 \pm 3604}{45 \ldots 27744}$ 85	$\frac{3116 \pm 1080}{69 \ldots 5116}$ 69
Co	$\frac{1,46 \pm 0,40}{0,24 \ldots 3,74}$ 82	$\frac{1,30 \pm 0,29}{0,22 \ldots 2,58}$ 63	$\frac{0,58 \pm 0,22}{0,001 \ldots 1,76}$ 113	$\frac{1,17 \pm 0,33}{0,03 \ldots 4,48}$ 115		$\frac{3,14 \pm 0,79}{0,95 \ldots 6,03}$ 150	$\frac{3,6 \pm 1,11}{1,18 \ldots 5,85}$ 62
Zn	$\frac{154 \pm 35}{38 \ldots 341}$ 68	$\frac{607 \pm 169}{197 \ldots 1611}$ 79	$\frac{264 \pm 25}{189 \ldots 408}$ 28	$\frac{1297 \pm 60}{922 \ldots 1845}$ 19	$\frac{352 \pm 0,24}{0,29 \ldots 1,03}$ 76	$\frac{786 \pm 233}{196 \ldots 1820}$ 127	$\frac{881 \pm 439}{307 \ldots 2179}$ 100
As		$\frac{1,29 \pm 0,29}{1 \ldots 3,3}$ 63	$\frac{0,91 \pm 0,09}{0,20 \ldots 1,00}$ 29	$\frac{1,35 \pm 0,24}{1 \ldots 4,23}$ 73	$\frac{1,54 \pm 0,07}{0,51 \ldots 0,71}$ 18	$\frac{2,2 \pm 0,5}{1 \ldots 4}$ 176	$\frac{1,2 \pm 0,11}{1 \ldots 1,39}$ 19
Br	$\frac{189 \pm 56}{33 \ldots 525}$ 88	$\frac{205 \pm 51}{59 \ldots 382}$ 71	$\frac{123 \pm 35}{6 \ldots 309}$ 86	$\frac{68 \pm 9}{14 \ldots 129}$ 54	$\frac{91 \pm 0,97}{0,09 \ldots 3,05}$ 151	$\frac{75 \pm 25}{1,2 \ldots 175}$ 112	$\frac{78 \pm 38}{5 \ldots 166}$ 97
Rb	$\frac{40 \pm 19}{0,50 \ldots .139}$ 147	$\frac{83 \pm 27}{1,1 \ldots 170}$ 92	$\frac{30 \pm 10}{1 \ldots 85}$ 103	$\frac{107 \pm 4}{73 \ldots 136}$ 17	$\frac{10 \pm 0,39}{0,04 \ldots 1,22}$ 151	$\frac{77 \pm 33}{1,5 \ldots 231}$ 89	$\frac{53 \pm 29}{6 \ldots 128}$ 109
Sr		$\frac{17 \pm 7}{10 \ldots 64}$ 114	$\frac{168 \pm 27}{10 \ldots 269}$ 48	$\frac{18 \pm 6}{10 \ldots 115}$ 145	$\frac{274 \pm 2,18}{0,35 \ldots 7,24}$ 81	$\frac{229 \pm 58}{10 \ldots 411}$ 149	$\frac{95 \pm 68}{10 \ldots 297}$ 144
Ag	$\frac{0,07 \pm 0,02}{0,05 \ldots 0,22}$ 81	$\frac{0,21 \pm 0,16}{0,02 \ldots 1,3}$ 221	$\frac{0,06 \pm 0,02}{0,02 \ldots 0,19}$ 80	$\frac{0,4 \pm 0,19}{0,05 \ldots 3,24}$ 200	$\frac{0,38 \pm 4,52}{0,06 \ldots 14}$ 157	$\frac{0,31 \pm 0,22}{0,05 \ldots 1,59}$ 54	$\frac{0,73 \pm 0,34}{0,05 \ldots 1,50}$ 94

Continuation of table 13

	1	2	3	4	5	6	7
Sb	$\frac{0,45 \pm 0,30}{0,001 \ldots 2,73}$ 196	$\frac{0,1 \pm 0,07}{0,005 \ldots 0,60}$ 205	$\frac{0,02 \pm 0,01}{0,00 \ldots 0,09}$ 161	$\frac{0,2 \pm 0,07}{0,005 \ldots 1,20}$ 140	$\frac{0,04 \pm 0,05}{0,03 \ldots 0,2}$ 67	$\frac{0,33 \pm 0,1}{0,07 \ldots 0,82}$ 120	$\frac{0,31 \pm 0,16}{0,001 \ldots 0,71}$ 105
Cs	$\frac{0,11 \pm 0,03}{0,03 \ldots 0,29}$ 92	$\frac{0,17 \pm 0,05}{0,02 \ldots 0,36}$ 82	$\frac{0,05 \pm 0,01}{0,00 \ldots 0,12}$ 68	$\frac{0,44 \pm 0,05}{0,16 \ldots 1,01}$ 49	$\frac{0,08 \pm 0,53}{0,13 \ldots 1,71}$ 139	$\frac{0,25 \pm 0,1}{0,05 \ldots 0,8}$ 96	$\frac{0,27 \pm 0,15}{0,05 \ldots 0,68}$ 108
Ba	$\frac{6,70 \pm 1,61}{5,00 \ldots 19,6}$ 72	$\frac{28,13 \pm 23,13}{5 \ldots 190}$ 233	$\frac{9 \pm 3}{5 \ldots 32}$ 101	$\frac{57 \pm 17}{5 \ldots 233}$ 126	$\frac{25 \pm 0,39}{0,08 \ldots 1,33}$ 80	$\frac{24 \pm 6,8}{4,7 \ldots 46}$ 131	$\frac{55 \pm 15}{30 \ldots 96}$ 53
La	$\frac{0,14 \pm 0,09}{0,04 \ldots 0,85}$ 187	$\frac{0,63 \pm 0,51}{0,05 \ldots 4,21}$ 232	$\frac{0,10 \pm 0,04}{0,04 \ldots 0,38}$ 115	$\frac{1,24 \pm 0,49}{0,05 \ldots 6,59}$ 162		$\frac{1,7 \pm 0,8}{0,06 \ldots 6}$ 78	$\frac{2,02 \pm 1,46}{0,08 \ldots 6,35}$ 144
Ce	$\frac{0,34 \pm 0,18}{0,05 \ldots 1,57}$ 157	$\frac{1,49 \pm 1,23}{0,05 \ldots 10,1}$ 234	$\frac{0,05 \pm 0,001}{0,05 \ldots 0,07}$ 13	$\frac{4,28 \pm 1,12}{0,05 \ldots 13,15}$ 107	$\frac{2,41 \pm 0,76}{0,01 \ldots 2,60}$ 92	$\frac{5,6 \pm 1,7}{0,7 \ldots 14}$ 125	$\frac{3,37 \pm 2,24}{0,05 \ldots 9,54}$ 133
Nd			$\frac{1,87 \pm 1,62}{0,25 \ldots 14,80}$ 260	$\frac{0,57 \pm 0,15}{0,25 \ldots 2,28}$ 111	$\frac{2,98 \pm 0,26}{0,21 \ldots 0,99}$ 95	$\frac{6 \pm 1,1}{2,5 \ldots 10}$ 204	$\frac{1,35 \pm 0,67}{0,03 \ldots 2,50}$ 98
Sm	$\frac{0,1 \pm 0,04}{0,05 \ldots 0,44}$ 131	$\frac{0,15 \pm 0,08}{0,05 \ldots 0,69}$ 153	$\frac{0,08 \pm 0,04}{0,02 \ldots 0,40}$ 149	$\frac{1,02 \pm 0,18}{0,04 \ldots 2,66}$ 74	$\frac{0,341 \pm 22}{0,04 \ldots 3,89}$ 147	$\frac{0,5 \pm 0,2}{0,005 \ldots 1,26}$ 81	$\frac{0,31 \pm 0,11}{0,001 \ldots 0,47}$ 68
Eu	$\frac{0,01 \pm 0,004}{0,001 \ldots 0,04}$ 94	$\frac{0,02 \pm 0,01}{0,002 \ldots 0,06}$ 114	$\frac{0,01 \pm 0,001}{0,00 \ldots 0,03}$ 113	$\frac{0,06 \pm 0,02}{0,003 \ldots 0,25}$ 113	$\frac{0,04 \pm 0,11}{0,04 \ldots 0,38}$ 111	$\frac{0,07 \pm 0,02}{0,03 \ldots 0,15}$ 140	$\frac{0,06 \pm 0,03}{0,001 \ldots 0,12}$ 105
Tb	$\frac{0,01 \pm 0,001}{0,001 \ldots 0,01}$ 33	$\frac{0,03 \pm 0,02}{0,01 \ldots 0,17}$ 187		$\frac{0,07 \pm 0,02}{0,004 \ldots 0,25}$ 110	$\frac{0,02 \pm 0,50}{0,19 \ldots 1,69}$ 126	$\frac{0,07 \pm 0,03}{0,01 \ldots 0,25}$ 84	$\frac{0,11 \pm 0,03}{0,04 \ldots 0,18}$ 66
Yb	$\frac{0,06 \pm 0,02}{0,01 \ldots 0,1}$ 79	$\frac{0,06 \pm 0,02}{0,01 \ldots 0,1}$ 80	$\frac{0,05 \pm 0,02}{0,01 \ldots 0,17}$ 126	$\frac{0,16 \pm 0,04}{0,01 \ldots 0,61}$ 94	$\frac{0,08 \pm 0,19}{0,57 \ldots 1,13}$ 43	$\frac{0,11 \pm 0,02}{0,04 \ldots 0,24}$ 164	$\frac{0,07 \pm 0,02}{0,03 \ldots 0,10}$ 45
Lu	$\frac{0,01 \pm 0,003}{0,002 \ldots 0,03}$ 112	$\frac{0,01 \pm 0,001}{0,01 \ldots 0,01}$ 34	$\frac{0,03 \pm 0,01}{0,01 \ldots 0,08}$ 88	$\frac{0,04 \pm 0,01}{0,004 \ldots 0,11}$ 60	$\frac{0,03 \pm 0,01}{1,00 \ldots 1,05}$ 2	$\frac{0,03 \pm 0,01}{0,001 \ldots 0,08}$ 101	$\frac{0,04 \pm 0,01}{0,01 \ldots 0,05}$ 51
Hf	$\frac{0,06 \pm 0,03}{0,05 \ldots 1,57}$ 137	$\frac{0,12 \pm 0,06}{0,005 \ldots 0,53}$ 146	$\frac{0,85 \pm 0,80}{0,00 \ldots 7,29}$ 285	$\frac{0,41 \pm 0,12}{0,005 \ldots 1,57}$ 122	$\frac{0,01 \pm 0,56}{0,02 \ldots 1,70}$ 168	$\frac{0,13 \pm 0,05}{0,005 \ldots 0,3}$ 101	$\frac{0,01 \pm 0,01}{0,001 \ldots 0,03}$ 107
Ta	$\frac{0,01 \pm 0,001}{0,003 \ldots 0,01}$ 25	$\frac{0,02 \pm 0,001}{0,01 \ldots 0,04}$ 76		$\frac{0,05 \pm 0,01}{0,001 \ldots 0,2}$ 116		$\frac{0,04 \pm 0,01}{0,01 \ldots 0,1}$ 102	$\frac{0,05 \pm ,02}{0,01 \ldots 0,08}$ 66
Au	$\frac{0,15 \pm 0,05}{0,02 \ldots 0,41}$ 91	$\frac{0,29 \pm 0,22}{0,001 \ldots 1,82}$ 219	$\frac{0,21 \pm 0,09}{0,00 \ldots 0,84}$ 127	$\frac{0,01 \pm 0,002}{0,001 \ldots 0,04}$ 79	$\frac{0,001 \pm 0,69}{0,06 \ldots 2,23}$ 140		$\frac{0,01 \pm 0,01}{0,001 \ldots 0,03}$ 120

Continuation of table 13

	1	2	3	4	5	6	7
Th	$\frac{0{,}06 \pm 0{,}02}{0{,}02 \ldots 0{,}17}$ 94	$\frac{0{,}15 \pm 0{,}10}{0{,}02 \ldots 0{,}87}$ 200	$\frac{0{,}05 \pm 0{,}03}{0{,}02 \ldots 0{,}26}$ 156		$\frac{0{,}05 \pm 0{,}09}{0{,}07 \ldots 0{,}36}$ 77	$\frac{0{,}3 \pm 0{,}2}{0{,}02 \ldots 1{,}3}$ 64	$\frac{0{,}08 \pm 0{,}05}{0{,}02 \ldots 0{,}24}$ 138
U		$\frac{0{,}17 \pm 0{,}12}{0{,}05 \ldots 0{,}98}$ 198	$\frac{0{,}06 \pm 0{,}01}{0{,}05 \ldots 0{,}17}$ 63		$\frac{0{,}44 \pm 0{,}75}{0{,}11 \ldots 2{,}37}$ 151	$\frac{0{,}1 \pm 0{,}3}{0{,}02 \ldots 2}$ 109	$\frac{0{,}13 \pm 0{,}08}{0{,}05 \ldots 0{,}35}$ 120

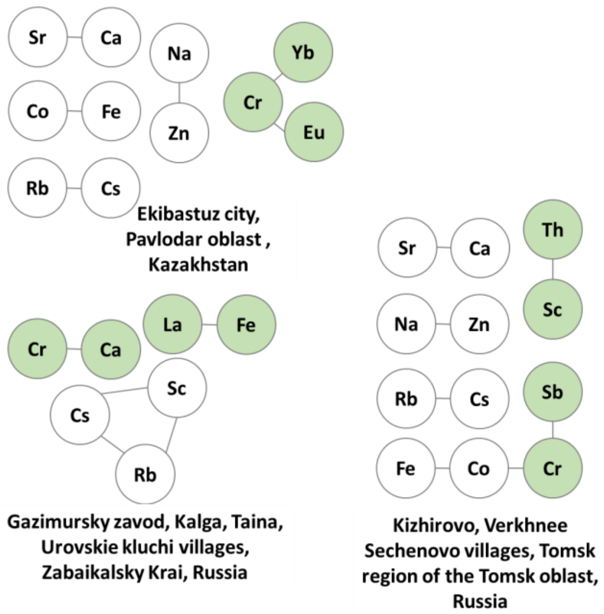


Figure 34. Correlation of chemical elements in the ash residue of a domestic pig, (> 0.7 at a critical value of a coefficient of significance of 0.5)

The construction of significant correlations of elements (> 0.7) in the ash residue of the biomaterial shows that, in samples from the Tomsk region, chromium is the main element that forms the most bonds. The positive correlation connections it forms are explained by natural protagonism within the group of cyclic elements, which is which is particularly well demonstrated by the example of the highest Sb – Cr – Co – Fe correlation in the sample (> 0.7) (Vernadsky, 1922). In addition to the internal attraction between cyclic elements, the Fe-Co affinity is explained by the similar physiological role of these elements in hematopoiesis. Another feature of the Tomsk region is the presence of the Th-Sc bond, which is most likely due to the content of this element in the natural environment and its bioavailability for organisms.

Samples from Ekibastuz and the Tomsk Oblast are similar in types of relationships being formed, for example, in both settlements, correlations of strontium with calcium, cobalt with iron and sodium with zinc are identified.

The sodium-zinc relationship most likely represents the organic component of the body, since both metals are essential biogenic elements.

In three samples chromium behaves differently, depending on the sampling zone, in Ekibastuz with rare earth elements, and with heavy metals in the Tomsk region. In a living organism, this metal plays a crucial physiological role in the regulation of fat synthesis in the body, and, in this sample, reflects the accumulation of elements in the subcutaneous fat layer (integument system).

Since the physiological role of Sb and rare earth elements remains unclear in this case, we can assume an active supply of these elements from the outside, depending on the territory of the animal.

A point of interest is the fact that, if the calcium-strontium association represents the normal bone component of the body, then chromium binds to calcium in samples from the Trans-Baikal Territory. In this region, there is a strong negative relationship between chromium and calcium, which is probably a consequence of the anthropogenic load on the region under study and an increased intake of chromium in living organisms, as a result of which this metal begins to displace calcium.

At the same time, examining in detail only the correlation interactions of elements in bone tissue, it can be noted that significant negative correlation relationships of elements with calcium are only observed in the bone tissue of an animal from settlements of the Trans-Baikal Territory (Figure 35). Here, calcium is antagonized by elements such as bromine in combination with thorium and, as already noted, chromium. Moreover, each region retains its "geochemical face" and with a separate examination of the bone component. Samples from the city of Ekibastuz are represented by interactions of rare-earth elements with hafnium and cesium, and in the Tomsk region by associations of elements with bromine and antimony.

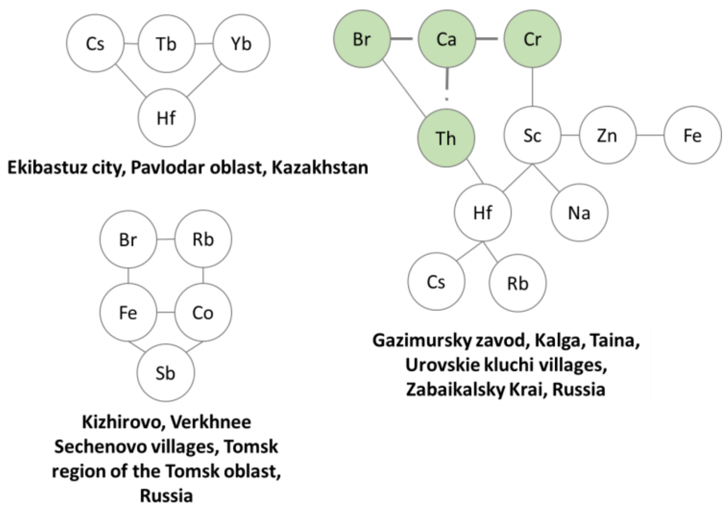
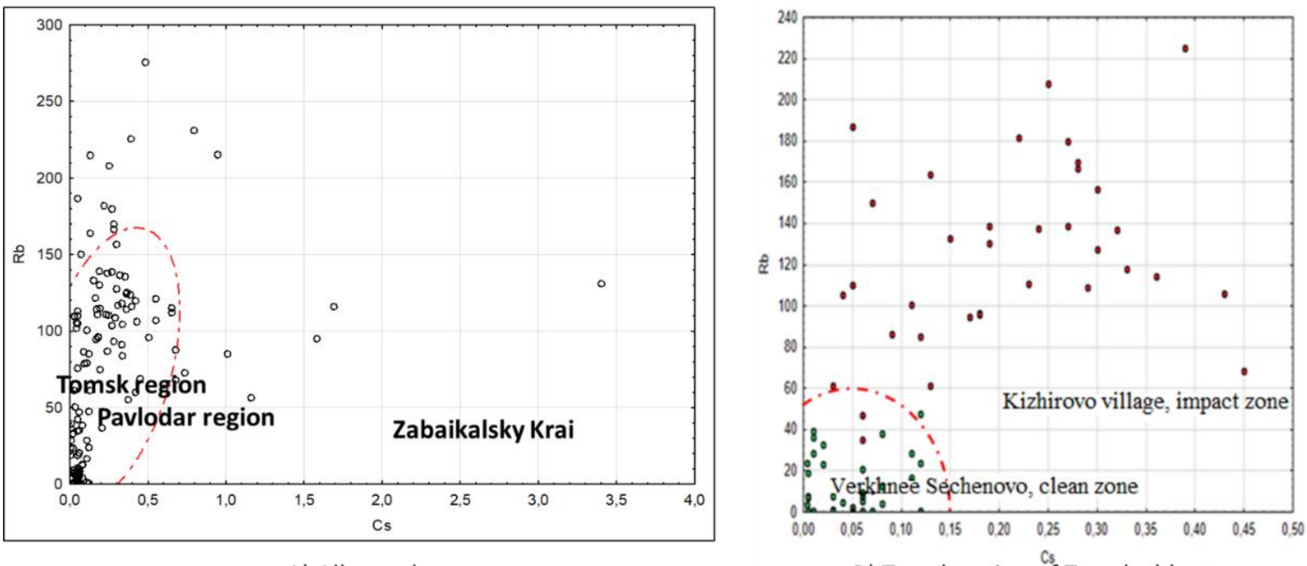


Figure 35. Significant correlation of elements in the bone tissue of domestic pigs (Sus scrofa domesicus) in territories with different geo-ecological situations, (> 0.7 at a critical value of a coefficient of significance of 0.5)

In all studied samples, a strong correlation between rubidium and cesium is noted. Rubidium and cesium, as alkali metals, are chemically close to each other and also belong to the same geochemical lithophile group of elements. The Rb-Cs ratio is informative when ranking territories according to the degree of environmental load, where rubidium is a natural factor of elemental composition, and cesium is technogenic. Samples from areas with a greater anthropogenic load Ekibastuz and Zabaikalsky Krai have higher cesium contents than samples from the Tomsk region.

Although the samples from the Tomsk region have a natural rubidium nature when compared with samples from the village of Kizhirovo, where the industrial impact is higher, and also the background territory of Verkhnee Sechenovo, the indicator role of biomaterial in the assessment of technogenic impact becomes apparent (Figure 36). Most samples from Kizhirovo exhibit a technogenic cesium nature, while samples from Verkhnee Sechenovo are rubidium.



A) All sample B) Tomsk region of Tomsk oblast

Figure 36. Scatter diagram of Rb-Cs in samples from all studied territories, mg/kg ash residue

Note: B) The zone of influence of the agricultural complex - Kizhirovo is highlighted in red, the background zone is Verkhnee Sechenovo in green

Another significant ratio of chemical elements: the thorium-uranium ratio in the studied samples also varies (Figure 37). All studied samples are in the region with Th / U <1, which indicates higher concentrations of uranium in the selected biomaterial. However, in samples from the Pavlodar region, the ratios of thorium to uranium approach 1 (Th / U = 0.9). The lowest ratio of these elements is found in samples from the Tomsk region (Th / U = 0.7). It can be noted that the ratio of thorium to uranium increases in samples taken from territories under the influence of the mining industry (Pavlodar region, Trans-Baikal Territory). In biomaterials selected in other studied zones, a lower ratio of thorium to uranium is noted. So, in the village of Putintsevo, East Kazakhstan region, this ratio reaches a minimum for this sample and is 0.1. Most samples of the biomaterial concentrate more uranium, which can be explained by the peculiarities of the local ecological and geochemical situation.

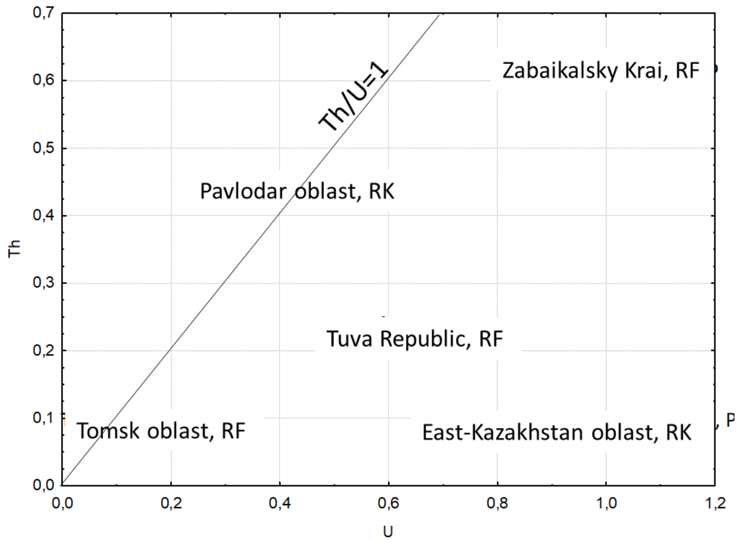


Figure 37. Scatter plot of Th / U distribution in samples of organs and tissues of domestic pigs (*Sus scrofa domesticus*) from all studied territories, (mg / kg ash residue)

Note: Tomsk oblast, RF Th / U = 0.7; Pavlodar oblast, RK Th / U = 0.9; Trans-Baikal Territory, RF Th / U = 0.7; Tuva Republic Th / U = 0.3; East Kazakhstan oblast Th / U = 0.1.

In total concentrations, the organs and tissues of an animal from the Trans-Baikal Territory differ from the Tomsk region of Tomsk oblast (Russia) and Ekibastuz city of Pavlodar oblast (Republic of Kazakhstan) in higher concentrations of all the elements studied, with some exceptions (Figure 38). The Tomsk region is characterized by increased concentrations of Br, Au, which is noted in all studied samples, and mainly in the respiratory and circulatory systems. Samples of organs and tissues of an animal taken in the city of Ekibastuz, Pavlodar region, accumulate Na, Zn, Rb, Ag, Sm, Lu, these elements accumulate mainly in the organs of the digestive and musculoskeletal systems. The distribution of specific elements within the body depends on the regional aspect. Br, Au, specific for the villages of the Tomsk region of the Tomsk oblast, selectively accumulate in the organs of the respiratory system and on the open skin and mucous tissues, and in the samples from Ekibastuz, these elements are concentrated in the blood and the gastrointestinal tract. The same principle is found for elements specific to the city of Ekibastuz. The localizing organs Na, Zn, Rb, Ag, Sm, Lu in different studied regions do not coincide. The differences in concentrations described above are probably associated with different routes of entry of elements.

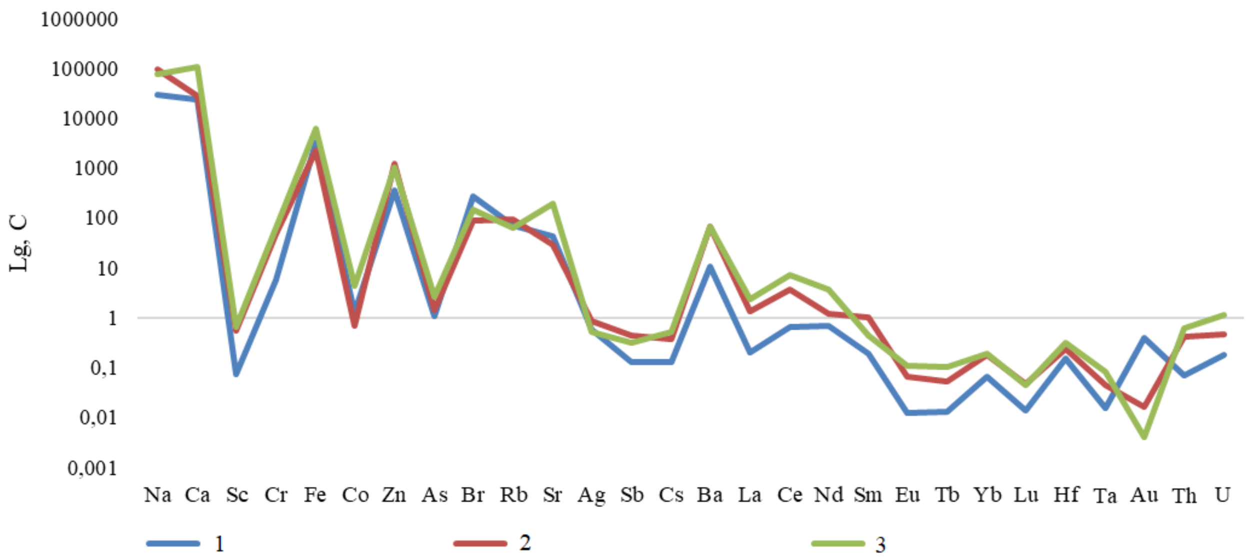


Figure 38.Indicator changes in the content of chemical elements in samples and tissues taken in the studied local territories (mg / kg of ash residue, logarithmic scale)

Note: 1- villages of Tomsk region, 2 - city of Pavlodar region, 3 - villages of Zabaikalsky Krai

The studied samples significantly differ in the elemental contents, however, in general, the macro-component composition of the gastrointestinal tract and integument can be noted to a lesser extent than in bone tissue (Figure 39, 40). So, in the example of a bone, it can note the regional specificity of each studied region. The bone tissue of an animal from the settlements of the Zabaikalsky Krai territory accumulates more elements in general, and heavy and light lanthanides. The bones from Ekibastuz city are the most calcified; they also contain more barium and strontium (Figure 39).

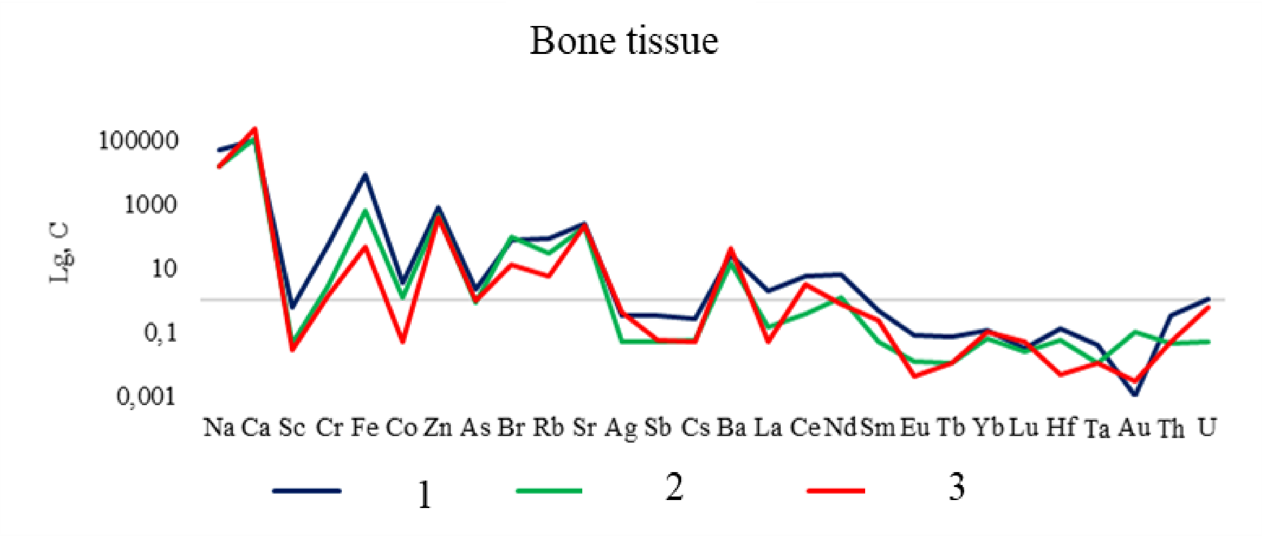


Figure 39. The content of chemical elements in the bone tissue of the domestic pig (*Sus scrofa domesticus*) on the territory of Transbaikalia, Tomsk region, Ekibastuz, mg/kg

Note: 1 – villages of Zabaikalsky Krai; 2 – villages of Tomsk region; 3 – city of Pavlodar region

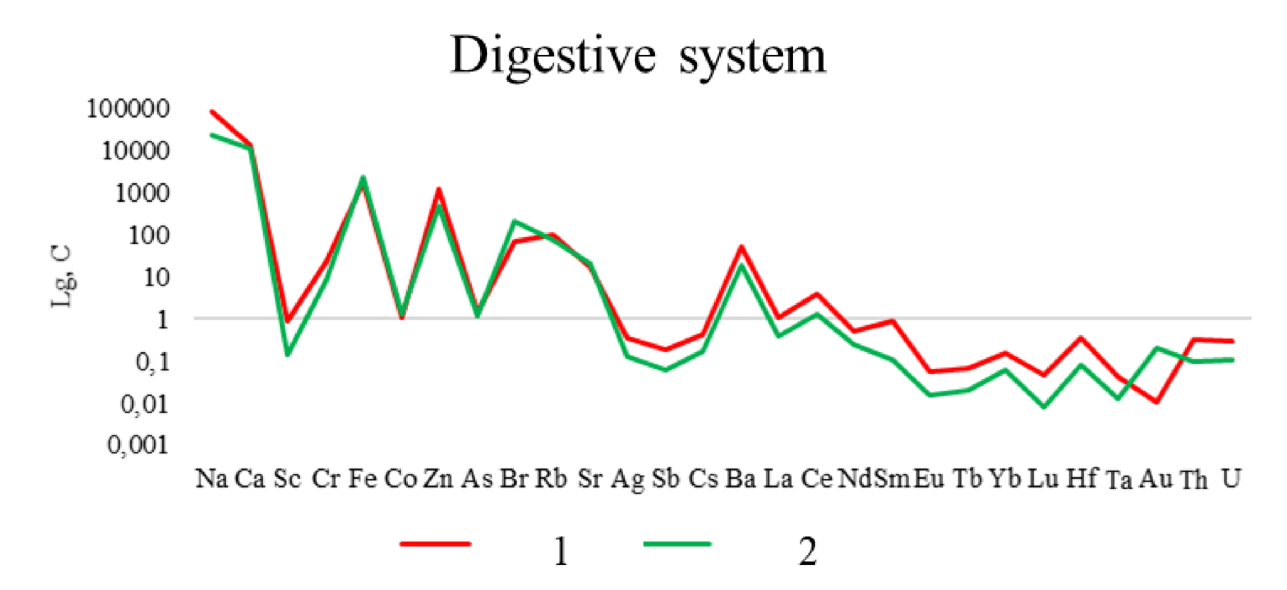


Figure 40. The content of chemical elements in the gastrointestinal tract of domestic pigs (*Sus scrofa domesticus*), mg/kg

Note: 1 – city of Pavlodar region; 2 – villages of Tomsk region

The gastrointestinal tract of an animal from Ekibastuz accumulates a larger number of elements than tissues selected in the Tomsk region, except for Fe, Br, Sr, Au. The concentration of groups of rare-earth and radioactive elements is visible. It should be noted that the elemental composition of coal from the Karazhar deposit used in the city of Ekibastuz is similar to this spectrum (Figure 40).

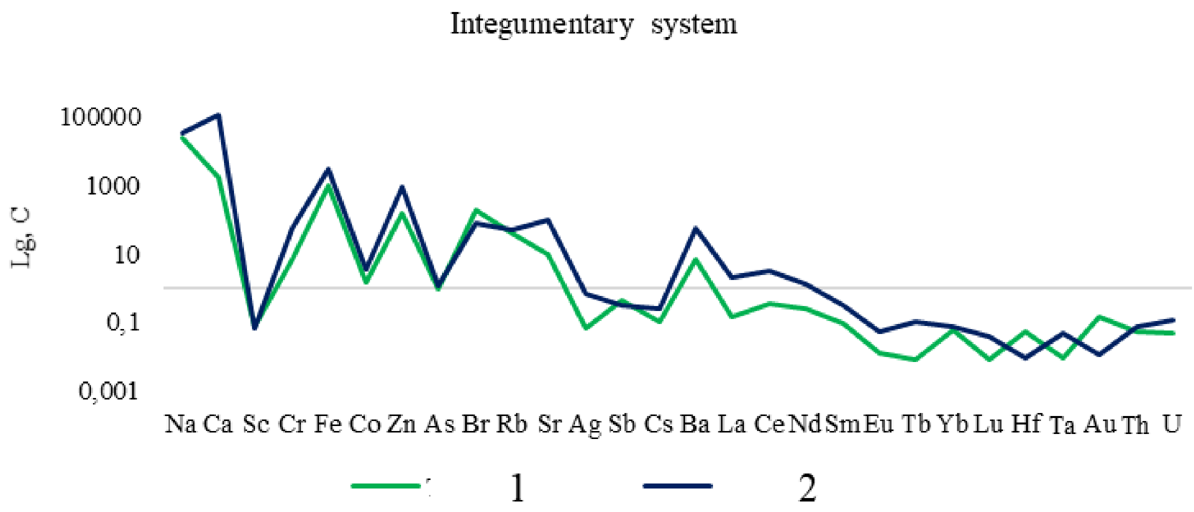


Figure 41. The content of chemical elements in the integumentary system of the domestic pig (*Sus scrofa domesticus*), mg/kg

Note: 1 – villages of Tomsk region; 2 – villages of Zabaikalsky Krai

Comparison of the Pig integument system (Figure 41) of a house selected in the settlements of the Tomsk region and the Zabaikalsky krai demonstrates that the tissues of a mammal living in the Tomsk region accumulate smaller amounts of chemical elements, but can accumulate large concentrations of Br, Sb, Hf, Au.

According to the results of the study of the three systems of the body (musculoskeletal system, the coating system, the digestive system), it may be noted that each of the studied areas shows the specific features of a concentration of chemical elements, regardless of the type of biological material.

Total concentrations of chemical elements in samples from Zabaikalsky krai differ from the Tomsk region and Ekibastuz in having higher concentrations of all chemical elements, with a few exceptions. The Tomsk region, in turn, is characterized by increased concentrations of Br, Au, noted in all the samples studied. Sb accumulates selectively in the tissues of the skin of pigs in this territory, and Fe in the intestinal tract.

The analysis of element concentrations for the selected organ systems made it possible to identify "physiological" elements for each of them that accumulate in these systems, regardless of the territorial aspect (table 14). Comparing the total concentration coefficients in the studied organ systems, one can also distinguish a significant accumulation of elements in the barrier systems.

Table 14. General and specific elements of all studied regions (CC relative to the average of the sample) in the ash residue of the gastrointestinal tract (GT), bone, skin, (domestic pigs - *Sus scrofa domesticus*)

Sampling zone, type of biomaterial		Elements accumulating in biomaterial from all studied regions	Elements accumulating in biomaterial depending on sampling territory	Sum of the concentration ratios
The villages of Kizhirovo and Verkhnee Sechenovo of Tomsk district	GT	Rb	Fe, Br, Co	14
	Bone	Ca, Sr, Lu,	Hf	13
	Skin	Sb, Br	-	11
Ekibastuz city of Pavlodar oblast	GT	Rb	Sc, Sm, Ba, La, Eu, Th, Cr, Sb, Lu, Tb, Yb, Cs, Hf, Ce, Zn, Na, Rb, Ta, U, Nd, As	34
	Bone	Ca, Sr, Lu,	Ag	22
The villages Gazimursky zavod, Urovskie kluchi, Kalga, Taina of Zabaikalsky Krai	Bone	Ca, Sr, Lu,	Nd, Ta, Eu, Tb, Co, Th, Fe, Br	42
	Skin	Sb, Br	Ce, Cr, Th, La, Ta, Sb, Co, Br, Fe, Nd, Sc, Eu, Tb, Rb, Ba, Ag, U, Na, Zn, Lu, Cs, Yb	34

The content of macro components in all the studied territories is repeated, differing only quantitatively, but the content of rare-earth and radioactive metals varies more significantly depending on the sampling zone. Within the body systems, there is also a difference in the contents of rare-earth metals, Th, U.

Intestinal tissues have the greatest similarity in the distribution of elements, and the concentration of elements in the bone tissue differs the most. Samples from Ekibastuz and Transbaikalia have a significantly larger number of specific elements than samples from the Tomsk region. To differentiate the samples by the degree of homogeneity, discriminant analysis is used, which showed that, depending on the sampling zone, the values are grouped in different ways (Figure 42, table 15,16).

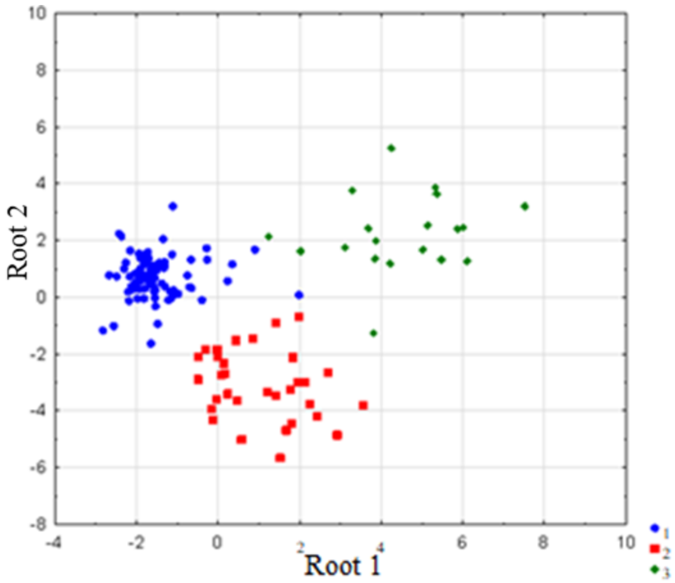


Figure 42. The location of the geochemical clusters of biomaterials according to the results of discriminant analysis
Note: 1 - The villages of Kizhirovo and Verkhnee Sechenovo of Tomsk district, 2 - Ekibastuz city of Pavlodar oblast, 3 - The villages Gazimursky zavod, Urovskie kluchi, Kalga, Taina of Zabaikalsky Krai and standardized coefficient table

Thus, samples from the Tomsk region that are distinguished by the first root are more homogeneous, except for some samples that remain outside the model, while the remaining samples are scattered along the root axis 1. The sample from the Ekibastuz city is less homogenous and is grouped relative to the second root, and samples from Zabaikalsky krai are also distinguished by the second root. According to standardized coefficients and analysis of the significance of the discriminant function, elements such as Lu, Hf, Ta make a significant contribution to the separation of samples. According to the concentrations analysis, these elements are specific for each region, accumulating in each type of test tissue. Moreover, lutetium accumulates in the bone tissue of animals in all studied territories.

Table 15. Table of standardized coefficients based on the results of discriminant analysis

N	C/e	Root 1	Root 2	N	C/e	Root 1	Root 2
1	2	3	4	5	6	7	8
1	Na	0,000004	-0,00002	15	Ba	0,01	0,0001
2	Ca	-0,00002	0,000001	16	La	-0,14	-0,12
3	Sc	0,97	1,34	17	Ce	-0,07	-0,07
4	Cr	-0,01	0,02	18	Nd	-0,38	0,04
5	Fe	-0,00002	0,00003	19	Sm	-0,78	-0,43
6	Co	-0,18	0,73	20	Eu	-6,61	10,56
7	Zn	0,00	0,00	21	Tb	-5,74	1,39
8	As	-0,26	0,18	22	Yb	-3,17	-4,25
9	Br	0,001	0,001	23	Lu	-17,97	-13,63
10	Rb	-0,005	0,01	24	Hf	0,14	-4,75
11	Sr	0,01	0,01	25	Ta	-1,92	-12,53
12	Ag	-0,38	-0,04	26	Au	0,56	0,55
13	Sb	-0,22	-0,05	27	Th	1,83	-0,18
14	Cs	-0,48	-1,29	28	U	-0,88	-0,26

Table 16. Analysis of the significance of discriminant function

C/e	Wilks'	Partial	F-remove	p-value	Toler.	1-Toler.
Na	0,02	0,9	4,3	0,01	0,5	0,5
Ca	0,03	0,7	17,8	0,000000002	0,2	0,8
Sc	0,02	0,9	2,9	0,04	0,1	0,9
Cr	0,02	0,9	5,9	0,001	0,4	0,6
Fe	0,02	1,0	0,8	0,5	0,5	0,5
Co	0,02	0,8	10,3	0,00001	0,3	0,7
Zn	0,02	0,9	5,9	0,001	0,5	0,5
As	0,02	1,0	1,1	0,3	0,6	0,4
Br	0,02	0,9	4,5	0,01	0,5	0,5
Rb	0,02	0,9	2,3	0,1	0,2	0,8
Sr	0,02	0,8	6,2	0,001	0,3	0,7
Ag	0,02	0,9	6,0	0,001	0,7	0,3
Sb	0,02	1,0	0,6	0,6	0,7	0,3
Cs	0,02	1,0	1,1	0,3	0,4	0,6
Ba	0,02	1,0	1,2	0,3	0,5	0,5
La	0,02	1,0	0,7	0,6	0,3	0,7
Ce	0,02	0,9	2,2	0,1	0,5	0,5
Nd	0,02	0,9	4,7	0,004	0,6	0,4
Sm	0,02	0,9	2,6	0,1	0,5	0,5
Eu	0,02	0,9	2,4	0,1	0,4	0,6
Tb	0,02	1,0	1,3	0,3	0,4	0,6
Yb	0,02	0,9	2,2	0,1	0,5	0,5
Lu	0,02	0,9	4,1	0,01	0,7	0,3
Hf	0,02	0,9	3,7	0,01	0,1	0,9
Ta	0,02	0,9	4,9	0,003	0,5	0,5
Au	0,02	1,0	1,4	0,2	0,6	0,4
Th	0,02	0,9	2,3	0,1	0,3	0,7
U	0,02	0,9	3,6	0,02	0,6	0,4

Note: Elements with significant differences for this discriminatory function are highlighted in red.

Thus, comparing the contents and ratios of elements in areas with different levels of ecological burden, one can note indicator indicators such as the accumulation of rare-earth metals, the change in the Rb-Cs ratio, and also the correlation relationships of elements with chromium.

CHAPTER 7. THE INFLUENCE OF TECHNOGENESIS ON THE FORMATION OF BIOGEOCHEMICAL BARRIERS IN THE BODY OF A MAMMAL

Under conditions of technogenesis, the individual role of biomaterial increases due to the high sensitivity of living systems. The concentration of metals in animals and humans depends not only on the type of nutrition (Zhao et al., 2016), the physiological function of organs and tissues (Carpenè et all, 2017) and the genetic characteristics of the organism (Demirezen, Uruç, 2006), but also on the anthropogenic load on the body's habitat (Durkalec et all, 2018). In the example of small mammals (Myodes glareolus), the relationship between the accumulation of chemical elements on the placenta is traced as it moves away from the source of pollution (Figure 43).

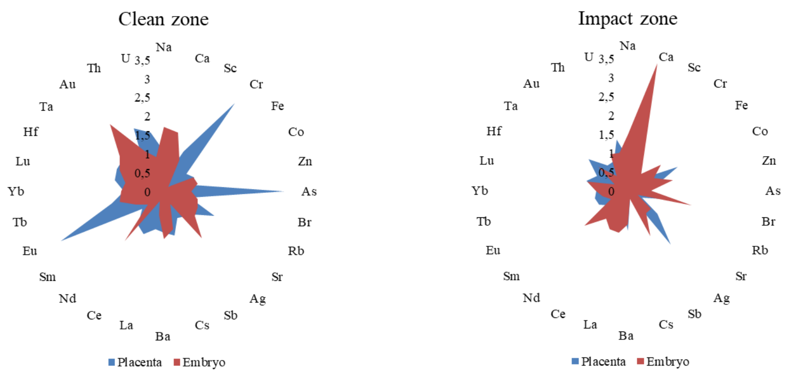


Figure 43. Geochemical specifics of the biological material of small mammals (Myodes glareolus), concentration coefficient is normalized to arithmetical mean value of the sample

Using the example of constructing biogeochemical series, it can be noted that the total concentration coefficient in the mammalian embryo is much lower in the zone remote from the source of pollution than in the territory close to the enterprise.

Table 17. Biogeochemical series of the concentration of elements and the total concentration coefficient in the biomaterial of small mammals

Biomaterial	Zone	Elements	CC_{sum}	Zone	Elements	CC_{sum}
Placenta	Impact zone	$Ba_{1,9}$-$Yb_{1,8}$-$Ag_{1,7}$-$Sm_{1,6}$-$Ta_{1,4}$=Co=$Lu_{1,3}$-$U_{1,2}$-$Br_{1,1}$=Ca - Zn_1 =Au	27	Clean zone	$As_{1,5}$=Ce=$U_{1,3}$=Sb=Cr=$Eu_{1,2}$=Th=Yb=Sm-$Lu_{1,1}$-La=Rb=Fe-$Ta_{1,09}$-$Ca_{1,08}$-$Na_{1,06}$- $Zn_{1,01}$-Tb_1	30
Embryo		$Fe_{2,7}$-$Sb_{2,2}$=Cr - $Ca_{1,9}$-$Sm_{1,8}$-$Ce_{1,7}$-$La_{1,5}$-Zn $_{1,3}$=Br-$U_{1,1}$=Lu	30		$Au_{1,3}$=Nd-$Rb_{1,2}$-$Ag_{1,1}$=Hf=Tb=Th=Cs-$Ba_{1,09}$=Ta-$Eu_{1,07}$-$Na_{1,03}$=U-$Sr_{1,01}$=Lu	26

The same tendency is also observed when considering the influence of the ecological-geochemical situation on the elemental composition of the placenta in Tomsk's human population (Figure 44). The distribution diagram of the content of chemical elements in the placenta of women living in different districts of Tomsk identifies the Leninsky district as an area where the samples have higher chemical contents than in samples of residents of other regions.

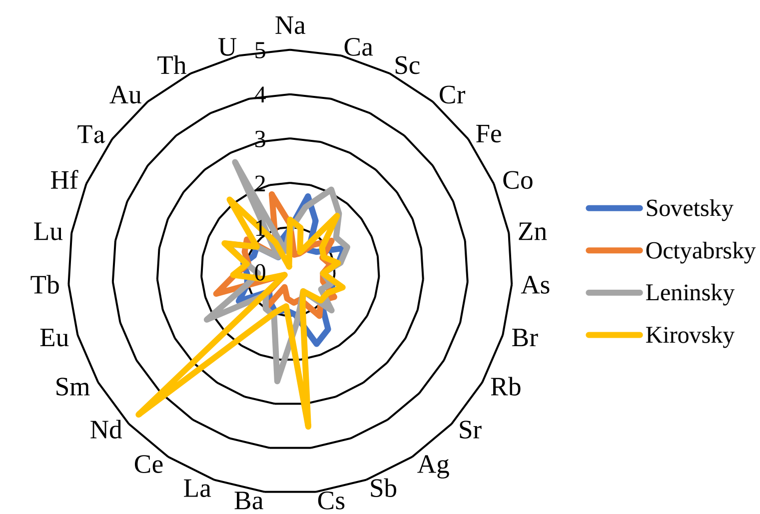


Figure 44. Geochemical specifics of the biological material of human placentas sampled in 4 districts of Tomsk residents (Sovetsky, Leninsky, Octyabrsky, Kirovsky districts) concentration coefficient is normalized to arithmetical mean value of the sample

Samples from the Leninsky district contain more Ca, Sc, Cr, Fe, Co, Zn, Ba, La, Hf, Th. Samples from the Kirovsky district show differences in the contents of Na, Br, Cs, Ce, Nd, Eu, Au, from Oktyabrsky this occurs with Ta and U. A feature of the Leninsky district is a higher content of Rb, Ag, Lu. Probably the reason for the increased contents of chemical elements in the placental tissues of women living in the Leninsky and Kirovsky districts (in comparison with other areas of the city) is their relative ecological disadvantage: local boiler houses and the private sector - which are sources of slag particles - are concentrated in the northern part of the city, also ash (Na, Ca, Fe, Zn, Cr, Co). In the assessment of the ecological and geochemical state of the city of Tomsk according to the study of dust aerosols and soils, the Leninsky and Kirovsky districts stand out as anthropogenically loaded, and the largest concentration of soot and slag is found in the dust aerosols selected in this region's territory.

The formation of the elemental composition of the domestic pig also occurs under a complex influence of factors. According to the results of factorial analysis, the formation of the elemental composition of the biomaterial selected in the city of Ekibastuz is influenced by two main factors. The first factor affects most of the elements studied: the group of rare-earth metals La, Ce, Eu, Tb, Yb, as well as Sc, Co, Cs, Ba, Hf, and the radioactive element Th. At the same time, rare earth elements and thorium make up a subgroup. Elements under the influence of the second factor - Sr, Ca; Na, Rb are more heterogeneous and are grouped in pairs, reflecting the positive and negative correlation relationships.

Three factors also have a major influence on the composition of organs and tissues of a piglet from the Tomsk Region (Figure 45). The first factor, similar to the results of the analysis of samples from Ekibastuz, affects elements such as Sc, Fe, Co, Ba, La, Ce, Sm, Tb, Th. This set of elements probably reflects the technogenic impact on organisms, i.e. the heat and power industry in both regions. Presumably, this factor reflects the contribution of elements during the combustion of high-ash coal (Sembaev, 2014).

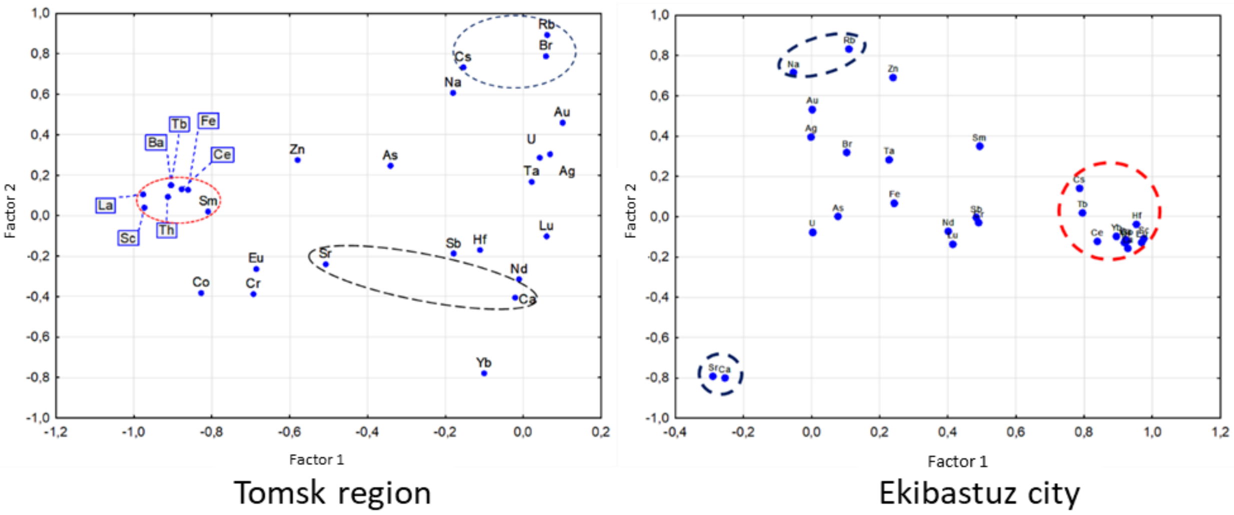


Figure 45. The correlation of Factor 1 (highlighted in red) and Factor 2 (highlighted in blue), based on the results of factor analysis, the biomaterial of domestic pig (*Sus scrofa domesticus*) in Ekibastuz and the Tomsk region

The second significant factor for the elemental composition of samples from Ekibastuz demonstrates the natural component of the material and its physiological functions. The negative calcium-strontium correlation is most likely dictated by the natural factor. The accumulation of alkali metals Na-Rb would be most likely to have a physiological cause, since sodium is an organogenic element, and rubidium tends to accumulate in the bones, brain and soft tissues of animals. The second factor affecting the elemental composition of an animal from the Tomsk Region regulates the accumulation of elements such as Br, Rb, Cs, Yb. This factor most likely reflects the regional specifics of the territory since the part of the Tomsk region being considered here is characterized by high concentrations of bromine in soils, and in drinking water scale and, as a consequence, the bio-substrates of residents (Perminova, 2017). The barrier organs (lungs and kidneys), selected in the Tomsk region, considered further in the study, accumulate Br, Rb, Cs in their tissues. The third factor that stands out in the Tomsk region and influences the accumulation of Ca, Sr demonstrates the physiological interaction of these elements, which has already been discussed in chapter 6.

Thus, the formation of the chemical composition of the body of domestic pigs is equally influenced by both natural components and the anthropogenic environmental conditions. The constant negative impact forces living organisms to develop protective mechanisms, the so-called barriers that prevent potentially dangerous elements entering vital organs.

Among the existing barrier systems of the body, the mucous membranes of the gastrointestinal tract and nasopharynx play a major role (Figure 46, table 18). The gastrointestinal tract, as the most active absorption zone of chemical elements, is a striking example of the barrier functions of the body. The high accumulation of chemical elements in this system, as a rule, indicates a constant supply of these chemicals from the exterior which varies depending on foodstuffs, drinking water pollution and soil composition, which in turn are affected by geographical origin (Franke et al. 2005; Kim et al., 2017; Park et al., 2018).

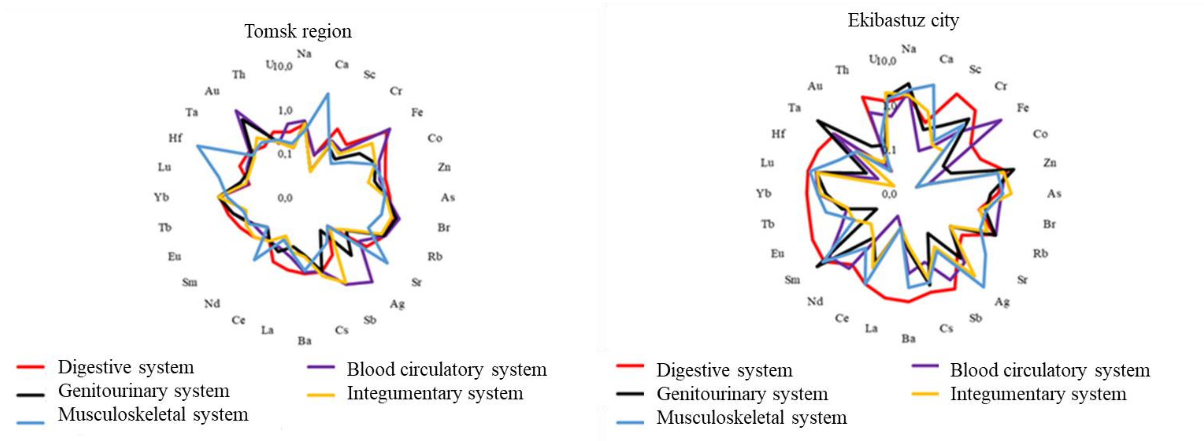


Figure 46. The concentration coefficient of chemical elements in the digestive system of domestic pigs (*Sus scrofa domesticus*) in the territory of Ekibastuz, Tomsk district, concentration coefficient relative to the arithmetic mean in the sample INAA method

Despite the fact that the biomaterials have significantly different chemical compositions, there are some similarities that are apparently characteristic of the biological material as a whole. So, the tissues of the digestive system accumulate Yb, Rb, As; the circulatory system Fe, Br; urogenital Rb; musculoskeletal Ca, Sr, Lu.

Table 18. Biogeochemical series of the concentration of elements in the ash of the biomaterial of domestic pig (*Sus scrofa domesticus*) in the territories of Ekibastuz and the Tomsk region

Organ system	Ekibastuz city, Pavlodar oblast	Kizhirovo and Verkhnee Sechenovo villages, Tomsk district
Digestive system	$Sc_{2,2}-Ba_{2}=Lu=Eu-Cr_{1,8}=Th=La-Zn_{1,7}-Sm_{1,6}=Sb-Na_{1,5}=Yb=Cs-Tb_{1,4}=Ce-Hf_{1,2}=Rb-As_{1}=U$	$Fe_{2,5}-Br_{1,1}-Co_{1,1}-\underline{Rb_{1,1}-Yb_{0,9}}=\underline{As}$
Circulatory system	$Fe_{3,5}-Na_{2}-Zn_{1,6}=Sb-Nd_{1,5}=Sm-Rb_{1,4}=Lu-Ta_{1,3}=As-Th_{1,1}=Yb=Ag$	$Au_{3,3}-\underline{Fe_{3,1}}-Ag=\underline{Br_{1,6}}=Sb-Rb_{1,1}$
Genitourinary System	$Ta_{3,9}-Sm_{3,3}-Na_{2,9}-Zn_{2,6}-Cr_{1,5}-U_{1,4}=Lu=Rb-Cs_{1,3}$	$Au_{1,9}-Br_{1,4}-\underline{Rb_{1,1}}$
Musculoskeletal system	$Ag_{5,6}-Ca_{3,4}-Sm_{2,4}-Na_{2,2}-Ce_{1,9}=Lu-Sr_{1,8}-Ba_{1,5}-U_{1,2}=As=Yb-Cs_{1,1}=Zn=Cr$	$Hf_{5,1}-\underline{Sr_{2,6}}-\underline{Ca_{2,6}}-\underline{Lu_{1,0}}$

High concentration coefficients of Th and U are found in the tissues of the digestive system of the pigs from the city of Ekibastuz, which is not observed in the biomaterial of animals from the Tomsk region. The construction of a diagram of the Th/U ratio in different organs shows that most of the studied biomaterials exhibit a uranium nature, but the digestive system of the colon and rectum are of thorium nature (Figure 47).

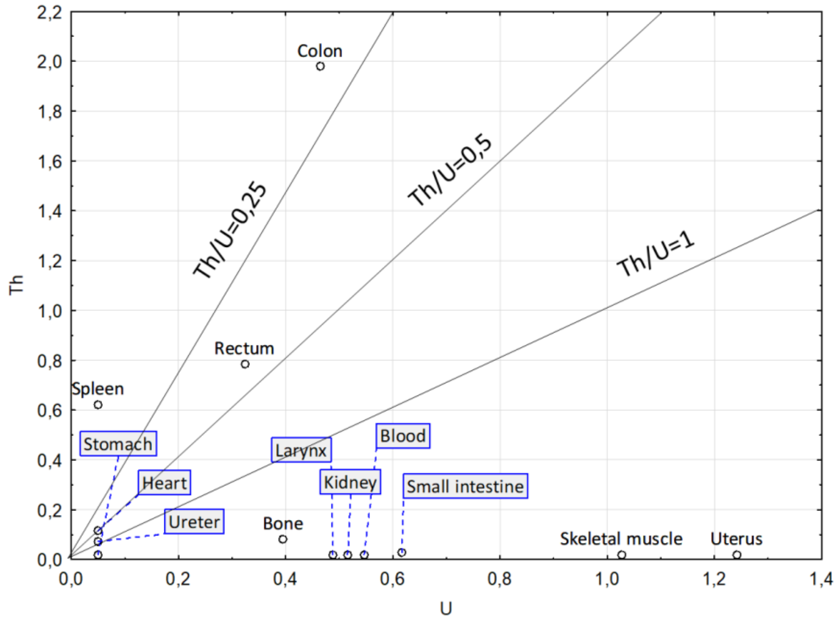


Figure 47. Th/U ratio in organs and tissues of domestic pig (*Sus scrofa domesticus*) in Ekibastuz city

Having examined the thorium-uranium ratio in samples from the Tomsk region, it can be noted that in most of the samples studied, the uranium content is below detection limits (Figure 47). Blood, as in samples from Ekibastuz, displays a uranium nature, and the large intestine is thorium. The small intestine and rectum in the Tomsk region exhibit opposite properties and contain more thorium than uranium. Such a difference in accumulations can be interpreted as different intensities of the input of these elements into the animal's body, since the content of radioactive elements in the samples from Ekibastuz is generally higher than in the Tomsk region.

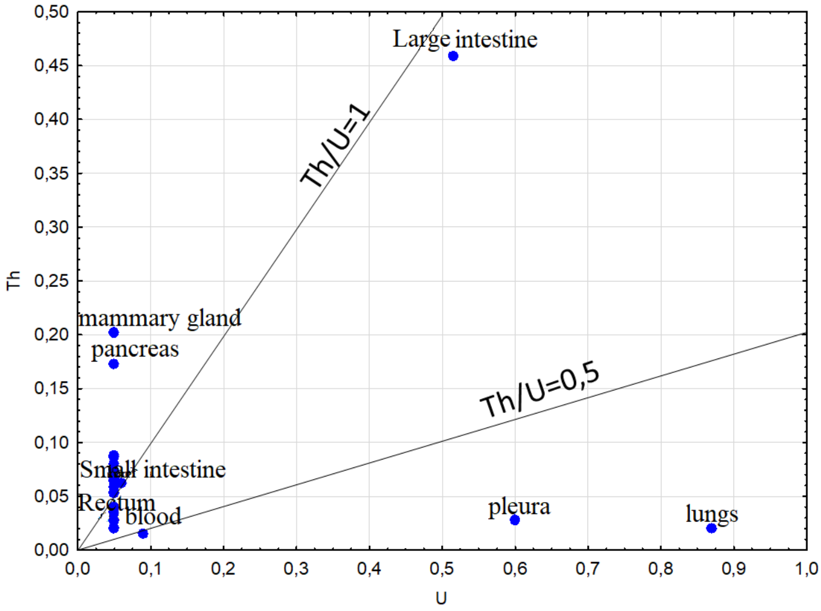


Figure 48. Th/U ratio in organs and tissues of the domestic pig (*Sus scrofa domesticus*) in the Tomsk region

Based on the organs localizing uranium, the most likely forms of its location can be assumed. In the city of Ekibastuz, where this element is retained in the bone tissue and organs of the genitourinary system (kidney, ureter, uterus), insoluble protein compounds of uranium in the tetravalent form are likely to be absorbed. Thorium, which concentrates in the spleen, probably enters through inhaled air, since the organs of the hematopoietic system are the site of its localization with daily inhalation. In the Tomsk region, uranium, which is localized mainly in the lung tissue, also appears to be part of organic components (Filov, 1990). Thorium, which accumulates in the small intestine, most likely comes in the form of highly soluble compounds. It is established that, in both samples, the organs and tissues of the digestive system (stomach, small, large and rectum) accumulate radionuclides, acting as a barrier system.

7.1 The content and ratio of elements in the gastrointestinal tract of domestic pigs (Sus scrofa domesticus) under the conditions of anthropogenic influence

To consider other features of the concentration of elements in the digestive system of the domestic pig, a detailed analysis is carried out. The distribution of elements reflects the geochemical laws of the Clark-Vernadsky law and the Oddo-Garkins rule (Figure 49). However, in the sample of elements studied, there is an increase in the concentration of elements such as Zn, Rb, Th, and U, and a decrease in the Ca content, which indicates deviations from the law.

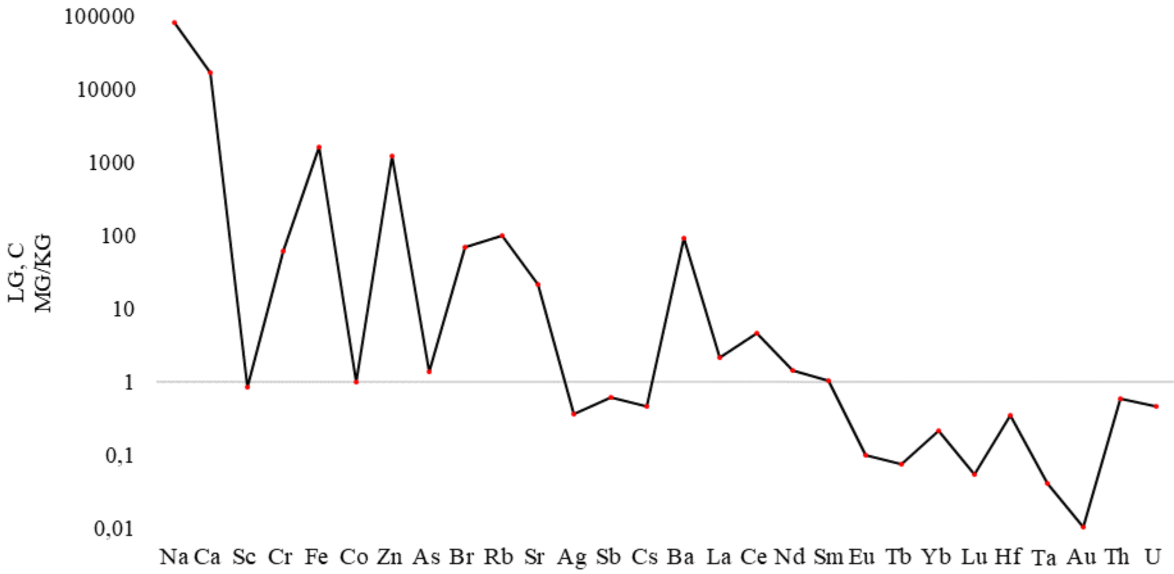


Figure 49.The content of chemical elements in the organs and tissues of the digestive system of domestic pigs (*Sus scrofa domesticus*) in the city of Ekibastuz, mg/kg of ash residue, LgC

As part of the study, 6 organs of the digestive system of the domestic pig were analyzed. We studied the change in the chemical composition of the digestive system in different parts of the gastrointestinal tract. The graph (Figure 50) demonstrates that the highest content of chemical elements is found in the tissues of the large intestine. Certain exceptions are also of interest.

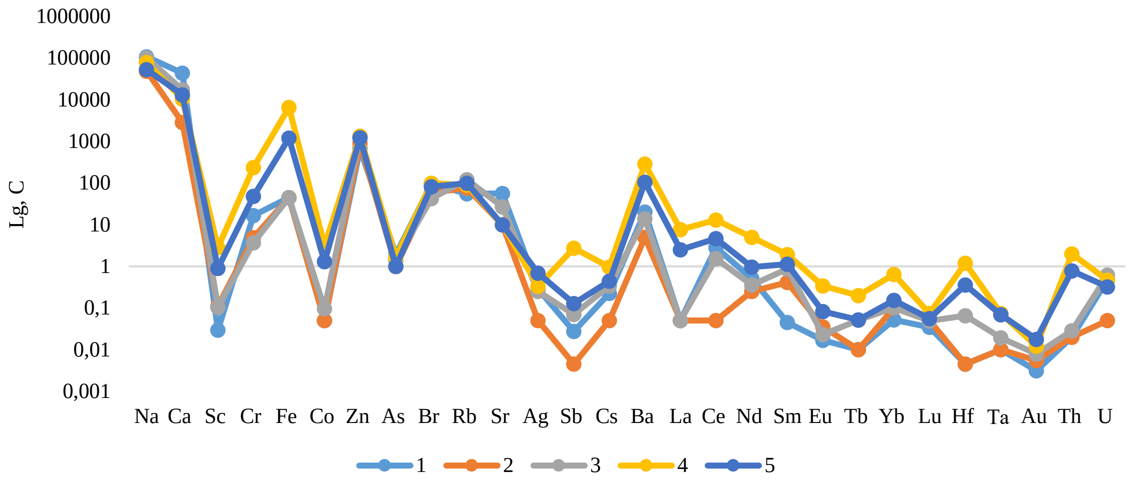


Figure 50. Distribution of chemical elements in the digestive system of domestic pigs (*Sus scrofa domesticus*) in the city of Ekibastuz, mg/kg of ash residue, LgC

Note: 1- pharynx; 2 - stomach; 3- small intestine; 4 - large intestine; 5 – rectum

The absorption of most chemical elements occurs through the bowel wall, while the stomach tissue concentrates the smallest number of chemical elements. Elements such as Na, Ca, Sr mainly accumulate in the tissues of the annular cartilage of the larynx, which is associated with the biological structural features of the cartilage. Rb and U are predominantly concentrated in the tissues of the small intestine. A similar accumulation of Rb by the tissues of the small intestine compared with other organs of the gastrointestinal tract had previously been observed according to the results of an experiment conducted by the Department of Radiological Health, Public Health Institute, Tokyo (Yamagata, 1962). Previous studies of the gastrointestinal tract Domestic pigs in the Tomsk Region (Baranovskaya, 2011; Baranovskaya, Rikhvanov, 2011) did not reveal significant differences in U contents in the components of the gastrointestinal tract, however, the small intestine and rectum were distinguished by high Rb contents.

Changes in the concentrations of chemical elements depending on the type of tissue under study can be seen by the example of elements such as Ag, Au, Br, As (Figure 51). Changes in their concentrations may reflect the routes of entry, migration, and elimination. The concentration of Br and As in the throat, which is the connecting link between the nasal and oral parts of the body, may indicate the entry of elements with air (Figure 52).

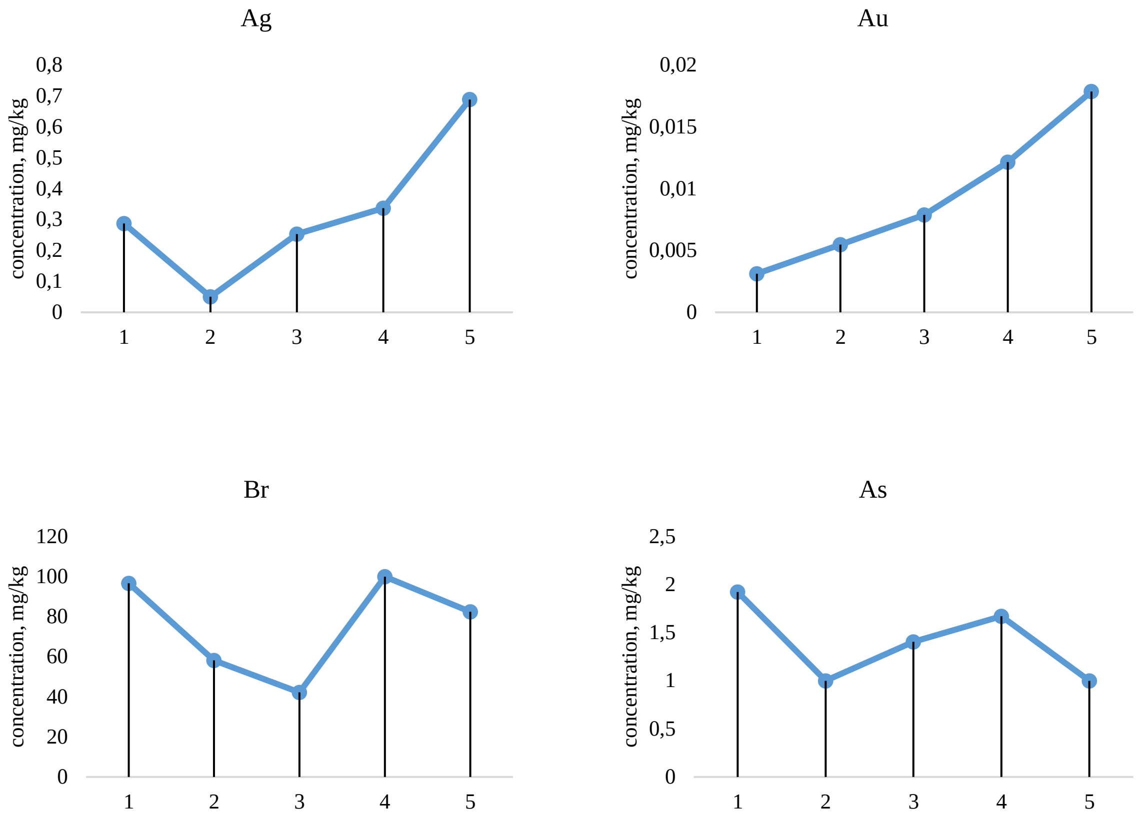


Figure 51. Distribution of chemical elements (Ag, Au, Br, As) in the digestive system of domestic pigs (*Sus scrofa domesticus*) in the city of Ekibastuz, mg/kg of ash residue

Note: 1- pharynx; 2 - stomach; 3- small intestine; 4 - large intestine; 5 - rectum

The content of Au in the tissues of the components of the digestive system gradually increases as it passes through the gastrointestinal tract from the pharynx to the intestine, and reaches its maximum in the rectum. A similar situation is observed with a detailed examination of the Ag content, however, unlike Au, which accumulates minimally in the pharynx, Ag reaches its minimum in the tissues of the stomach. It can be assumed that Au, Ag as inert metals do not enter into chemical reactions as they pass through the intestinal tract, but are excreted together with feces and urine. A similar situation is observed for bromine, however, for this element, the peak concentration is in the large intestine - the main area of fluid absorption, and the ureter where urine is stored.

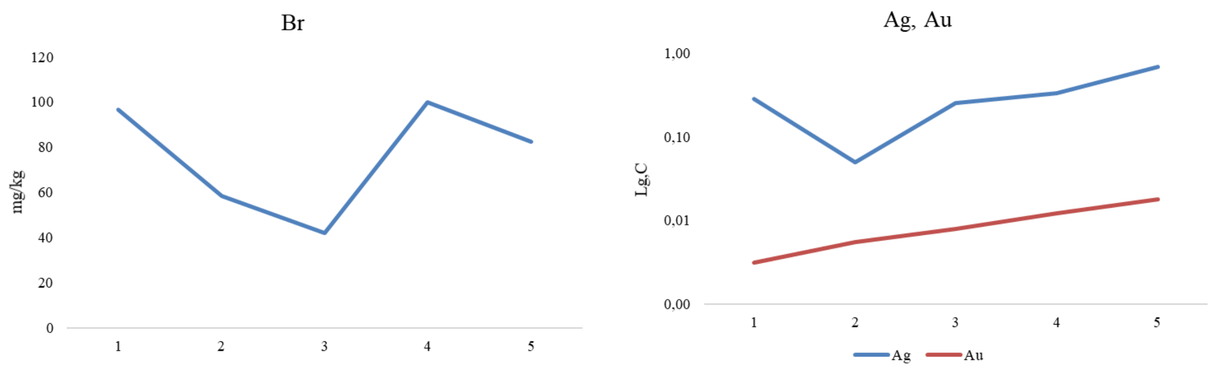


Figure 52. Distribution of Br, Ag, Au in the digestive and genitourinary systems of the domestic pig (*Sus scrofa domesticus*) sampled in Ekibastuz city, mg/kg of ash residue, Ag, Au - LgC

Note: 1- pharynx; 2 - stomach; 3- small intestine; 4 - large intestine; 5 - rectum

The study also noted that elements with different valences are concentrated in different parts of the gastrointestinal tract, depending on the pH of the medium. Thus, elements with a constant valence - alkaline and alkaline earth elements such as Ca, Na, Rb, Sr (Figure 53) are concentrated to a greater extent in parts of the intestinal tract that have a high hydrogen index, correlating with a change in pH. Elements with variable valence exhibit an inverse relationship. Therefore, in areas of the gastrointestinal tract with the highest pH (small intestine), a minimum concentration coefficient of elements with a variable valence such as Cr, Fe, Co, Yb (Figure 53) is noted. The maximum concentration coefficients of these elements are found in the tissues of the colon and rectum.

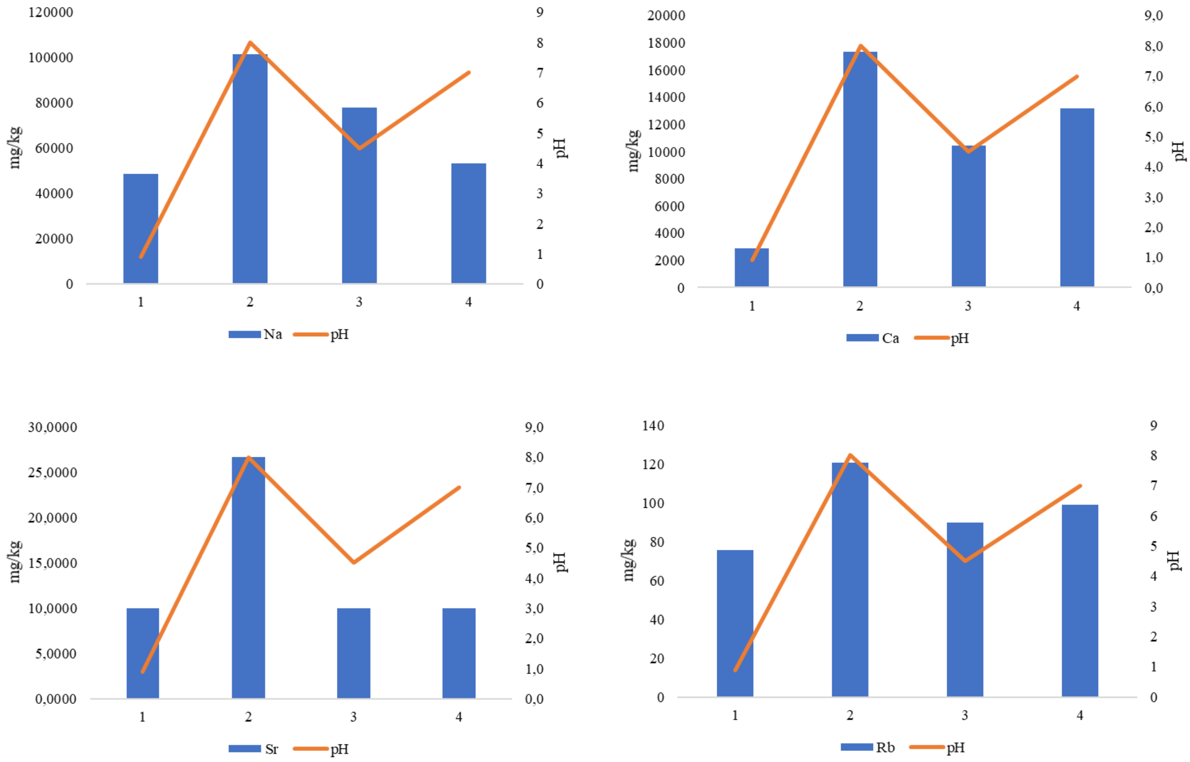


Figure 53. Distribution of chemical elements with constant valence in the digestive system of domestic pigs (*Sus scrofa domesticus*) in the city of Ekibastuz, mg/kg of ash residue

Note: 1 - stomach; 2- small intestine; 3 - large intestine; 4 – rectum

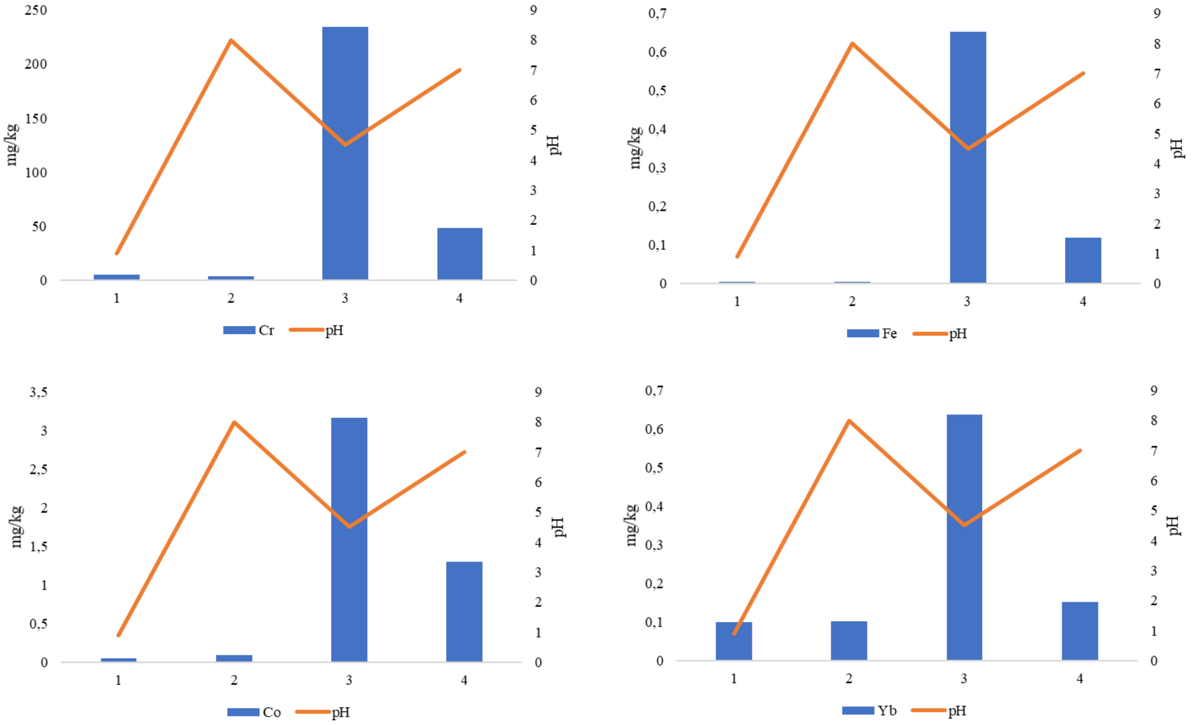


Figure 54. Distribution of chemical elements with variable valence in the digestive system of domestic pigs (*Sus scrofa domesticus*) in the city of Ekibastuz, mg/kg of ash residue

Note: 1 - stomach; 2- small intestine; 3 - large intestine; 4 – rectum

Using the above-mentioned elements as an example, we can note the influence of a biological barrier such as a sharp change in the hydrogen index on the concentration of elements of various chemical groups.

Another significant tool in studying the migration of elements within the studied organ system is the construction of biogeochemical series. In the course of the study the tissues of the gastrointestinal tract of each intestine were studied, specifically the initial and final 100 cm of section, as parts of the system responsible for the introduction and removal of elements from the organ and body (table 19).

The biogeochemical series presented in the table clearly show which elements accumulate in the digestive system and where. Chemical elements such as Sr and Ca accumulate in the oropharynx, which may be due to the cartilage structure of this organ. The accumulation of As, Br, as mentioned above, can be associated with a predominantly airborne path of these elements. The role in the accumulation of arsenic can also be a result of the lifestyle of the animal under study. Since pigs often dig the earth, they will inevitably swallow soil particles, and as a result, elements from contaminated soil will be absorbed. According to the data presented in the article by Sembaev Zh. Kh. the average arsenic content in the soils sampled in Ekibastuz city exceeds 0.5 MAC (Sembaev, 2014).

Lu, Zn, Sm, Rb are those elements whose concentration coefficient in the tissues of the stomach exceeds 1. In this case, the rare-earth metal Lu, whose biological role has not been fully clarified, has the maximum concentration. However, studies of human ash residue (Igantova, 2010) show the ability of this chemical element to accumulate in the tissues of the esophagus, and studies of organs and tissues of the domestic pig (Baranovskaya, Rikhvanov, 2011) demonstrate that lutetium has high conversion rate in the stomach-blood system. According to studies of scale from natural fresh water in the territory of Pavlodar oblast (Arynova, 2016), Lu is characteristic of scale selected in Ekibastuz city, Pavlodar oblast. This metal probably enters in the water. We can assume the presence of a barrier role of the walls of the esophagus and stomach in the migration of this metal in the body.

Table 19. The specifics of the accumulation of elements in the gastrointestinal tract of domestic pigs (*Sus scrofa domesticus*) of Pavlodar oblast relative to the average content in the body

Organ	Letter	Number of chemical elements
Pharynx	-	$Sr_{2,0}$-$Ca_{1,6}$-$As_{1,4}$-$Na_{1,1}$-$Br_{1,1}$-$U_{1,1}$
Stomach	-	$Lu_{1,9}$-$Zn_{1,4}$-$Sm_{1,1}$-$Rb_{1,1}$
Small intestine	100 sm	$Sr_{1,6}$-$Rb_{1,3}$-$Lu_{1,2}$-$Na_{1,7}$-$Zn_{1,0}$
	200 sm	$U_{1,9}$-$Rb_{1,3}$-$Zn_{1,2}$-$As_{1,2}$-$Tb_{1,0}$-$Na_{1,0}$-$Sm_{1,0}$-$Cs_{1,0}$
Large intestine	300 sm	$Sb_{10,8}$-$La_{5,5}$-$Hf_{5,2}$-$Th_{5,1}$-$Sc_{5,1}$-$Ba_{5,0}$-$Eu_{5,0}$-$Tb_{4,7}$-$Yb_{4,4}$-$Co_{3,8}$-$Ce_{3,2}$-$Cs_{2,8}$-$Fe_{2,7}$-$Lu_{2,5}$-$Ta_{2,3}$-$Sm_{2,0}$-$As_{1,7}$-$Br_{1,2}$-$Zn_{1,2}$-$U_{1,1}$-$Rb_{1,1}$
	400 sm	$Sb_{10,9}$-$Cr_{9,2}$-$Nd_{8,2}$-$La_{4,9}$-$Sc_{4,8}$-$Co_{4,8}$-$Ba_{4,8}$-$Hf_{4,5}$-$Eu_{4,2}$-$Tb_{4,1}$-$Th_{4,0}$-$Yb_{3,0}$-$Ce_{2,9}$-$Fe_{2,8}$-$Ta_{2,3}$-$Cs_{2,0}$-$U_{1,7}$-$Zn_{1,4}$-$Br_{1,1}$-$Lu_{1,0}$-$Rb_{1,0}$
Rectum	500 sm	$Hf_{2,5}$-$Sc_{2,4}$-$Co_{2,4}$-$Ba_{2,3}$-$Ta_{2,0}$-$Ag_{1,9}$-$Th_{1,9}$-$Nd_{1,7}$-$La_{1,7}$-$Eu_{1,6}$-$Au_{1,6}$-$Ce_{1,5}$-$Sm_{1,3}$-$Zn_{1,2}$-$Rb_{1,2}$-$Cs_{1,1}$-$Lu_{1,1}$-$Tb_{1,0}$
	600 sm	$La_{1,9}$-$Th_{1,9}$-$Co_{1,6}$-$Ta_{1,2}$-$Lu_{1,2}$-$Cs_{1,2}$-$Cr_{1,2}$-$Sc_{1,1}$-$Ce_{1,1}$-$Ba_{1,1}$-$Yb_{1,1}$-$U_{1,0}$-$Eu_{1,0}$-$Sm_{1,0}$-$Br_{1,0}$

Comparison of the biogeochemical series shows that each section of the intestinal tract has its own characteristics, concentrating specific elements. The large intestine remains the most active absorption zone of almost all chemical elements. In the tissues of the small intestine, the maximum U concentration coefficient is found relative to the entire sample. The upper part of the small intestine is the only part of the intestinal tract that concentrates Sr.

The highest concentration coefficients of chemical elements in the sample are observed in the large intestine, and particular interest is the fact of the abnormal concentration of thorium (CcTh> 5) only in the large intestine. The concentration coefficient of this metal is also high in other samples, but does not exceed 2. In the large intestine, we note a high Sb concentration coefficient (Cc> 10), this metal is not concentrated in other sections of the intestinal tract. Here, in the entire sample, maximum concentrations are found for all elements, Cr (Cc> 9), Nd (Cc> 8). Such high concentration coefficients are only observed in the tissues of the large intestine.

A distinctive feature of the rectum is high concentration coefficients of Hf, Sc, Co, Ba (Cc> 2) in the upper section, and La, Th, Co in the lower (CC> 1.5). The walls of the rectum actively concentrate precious metals (gold and silver), as well as rare-earth elements (La, Sm, Eu, Lu). In the whole sample, the concentration coefficient of these metals only exceeds unity in rectum samples. This can be explained by their low physiological activity.

The table (table 19) shows that U can accumulate in almost all the components of the digestive system studied, except for the stomach, and, as noted above, reaches a maximum concentration in the first 100 meters of the small intestine. The accumulation of Th by tissues of the colon and rectum, and the low concentration of this metal in other studied tissues of the digestive system can be noted. The U content in all samples is quite uniform. However, the tissues of the small intestine, as noted above, contain large concentrations of this metal.

A more detailed examination of the content of Th and U in the tissues of the intestinal tract confirms the previously noted patterns of accumulation of these elements, and shows the specifics of their distribution more clearly (Figure 55, 56).

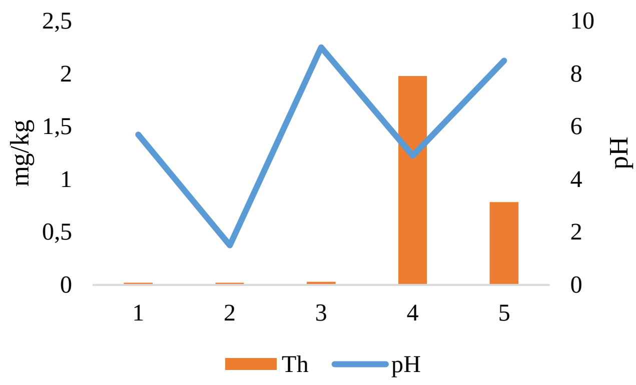


Figure 55. Th concentration coefficient in intestinal tissues of domestic pig (*Sus scrofa domesticus*)

Note: 1 – pharynx, 2 – stomach, 3 - small intestine, 4 – colon, 5 - rectum

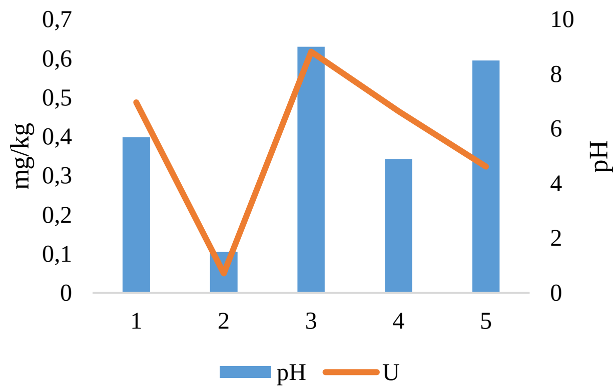


Figure 56. The concentration coefficient of U in the intestinal tissues of the domestic pig (*Sus scrofa domesticus*)

Note: 1 – pharynx, 2 – stomach, 3 - small intestine, 4 – colon, 5 - rectum

The diagrams demonstrate that the concentration of thorium remains minimal in the small intestine, then sharply increases in the large intestine, decreases in the rectum. The main function of the large intestine is the absorption of water and electrolytes, and the fact that the thorium is concentrated by this section of the intestinal tract implies that this metal is accumulated by the walls of the intestine due to the work of microorganisms forming a biochemical barrier that prevents this element from entering the blood.

U mainly accumulates in the upper part of the small intestine, the concentration of this metal in the intestinal tract is more uniform, however, it sharply decreases from the small intestine to the upper part of the rectum, and gradually increases in the lower part. Uranium compounds entering the body barrier-free enter the blood through the walls of the small intestine since the small intestine is the main absorption zone of digestion products, most of the orally administered drugs, poisons and toxins in the blood and lymph capillaries (Gastroscan.ru, 2018).

The change in the concentration coefficients Th, U reflects well the change in the internal environment of the body, namely the hydrogen index. The acid-base balance of the body changes from alkaline in the oral cavity (pH 6.35), becoming acidic in the stomach (pH 0.9), with a sharp change of medium to alkaline in the small intestine (pH 8.5), then acidifying in the large (pH 4), and returning to alkaline in the rectum (pH 7). Radioactive metals (Th, U) react differently to changes in acid-base balance. The concentration coefficient of uranium noticeably varies in direct proportion to the change in the acidity of the medium. In the departments of the gastrointestinal tract that show an alkaline environment, the CC of U is higher than in those with an acidic environment. The concentration coefficient of thorium does not change in the first two components of the digestive system, but it exhibits an inverse relationship in the tissues of the intestinal tract. So, in the small intestine, the gastrointestinal tract with the highest pH, the lowest concentration coefficient of thorium for the intestine is observed, and in the large intestine with the most acidic environment, this metal is concentrated to a greater extent. One can note a direct and inverse dependence on the value of the hydrogen index in different parts of the intestine for uranium and thorium, respectively. Thus, the acidity of the medium is another factor affecting the distribution of chemical elements in the gastrointestinal tract of domestic pigs.

Changes in the concentrations of elements in different parts of the intestine can be traced by a detailed examination of the intestinal tract and stomach. Constructed graphs of the distribution of elements show that active absorption begins in the duodenum 12, except for Yb, the accumulation of which in the first part of the small intestine and stomach is the same.

Macronutrients are actively accumulated by intestinal tissues along its entire length, in diminishing concentrations towards the end of the tract (Figure 57). Sodium, calcium, and iron as organogenic elements are excreted from the body to a lesser extent than rare earth metals and radioactive elements, due to their high physiological significance. Toxic elements for the body such as Cr, Zn, Co, Ba, As, also accumulate differently in the tissues of the gastrointestinal tract. Their maximum accumulation falls on the colon tissue (Figure 58).

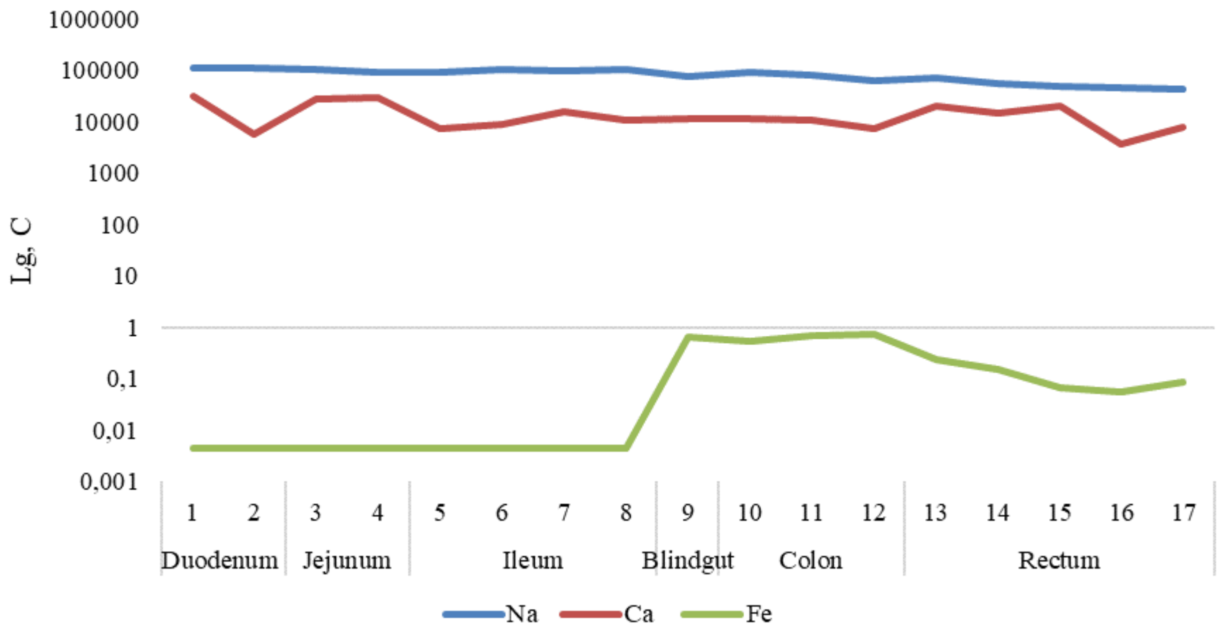


Figure 57. The content of macronutrients in the intestines of domestic pigs (*Sus scrofa domesticus*), Ekibastuz, mg / kg ash residue, LgC

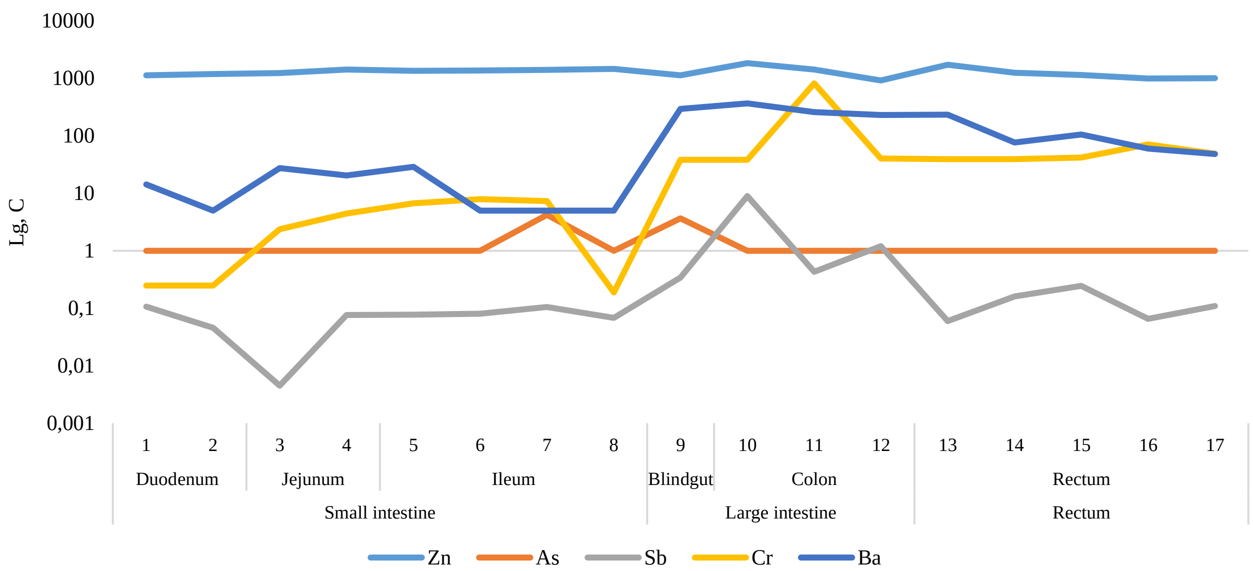


Figure 58. The content of Zn, As, Sb, Cr, Ba in the intestines of domestic pigs (*Sus scrofa domesticus*), Ekibastuz, mg/kg ash residue, LgC

The zinc content remains high and does not significantly change in the small intestine (Figure 60). The concentration of this element increases in the first section of the colon and rectum, and decreases closer to the end of the tract. Thus, the peak of zinc concentration in the pig's body is the colon of the large intestine, while according to the literature in the body of rats, the main absorption zone of this element is the jejunum (Lee, D.Y. Brewer, G.J. Wang, 1989).

The main absorption of chromium and cobalt occurs in the large intestine, these elements do not stay in the small intestine and rectum (Figure 59). Chromium is the only element that begins to be absorbed in the stomach and reaches the maximum value in the middle of the colon. Elevated concentrations of chromium in the ileum are correlated with the results of studies marking the absorption of chromium in this section of the tract (Pokrovsky, 1981). Arsenic is below the detection limit in most of the samples studied, but its concentrations increase at the end of the small to the beginning of the large intestine.

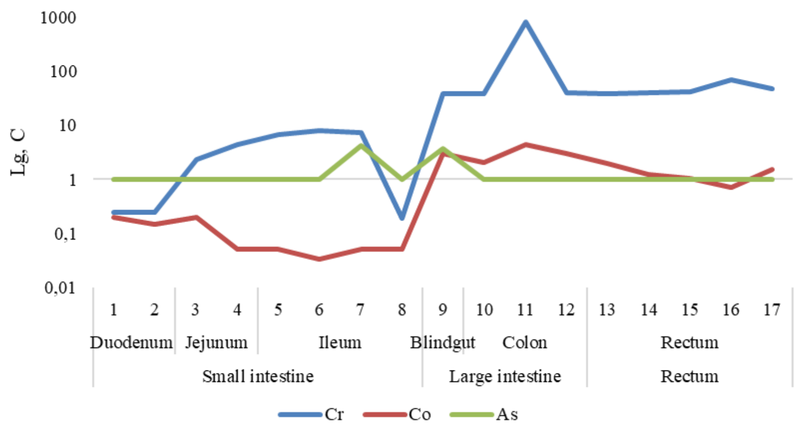


Figure 59. The content of heavy metals and arsenic in the intestines of domestic pigs (*Sus scrofa domesticus*), Ekibastuz city, mg/kg ash residue, LgC

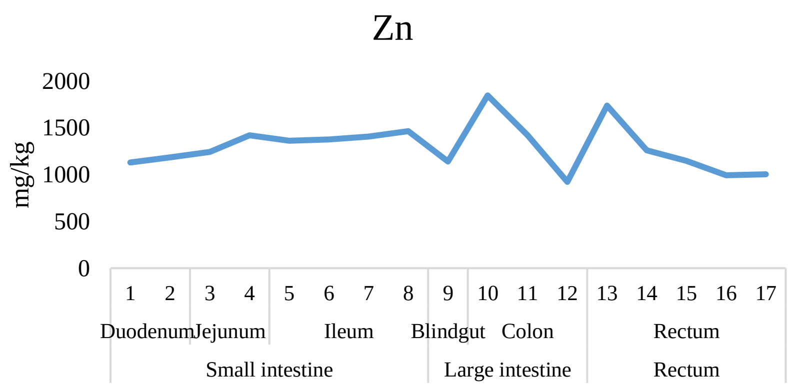


Figure 60. Zn content in the intestines of domestic pigs (*Sus scrofa domesticus*), Ekibastuz, mg/kg ash residue

Rare earth elements are mostly absorbed in the colon, starting from the end of the ileum (Figures 61, 62). The main peaks of their concentrations occur in the cecum and colon, then the concentration gradually decreases in the rectum. In the ileum, there is a sharp increase in the concentrations of Ce, Yb, Tb, probably these metals begin to accumulate in the intestinal tissues earlier than others.

The absorption of Th begins in the large intestine, then sharply decreases in the rectum, with an increase in the excretion zone (Figure 63). These organs exhibit a thorium nature, which reflects the mechanism of absorption of this element into the blood and the main route of its excretion. U accumulation continues throughout the intestinal tract, peaks of its concentration occur in the jejunum, ileum and rectum (Figure 63).

The concentrations of all the elements examined increase at the end of the rectum, which is explained by the excretory function of this part of the intestine, this is clearly shown by the example of Yb whose concentration does not change throughout the entire rectum but significantly increases in its last part.

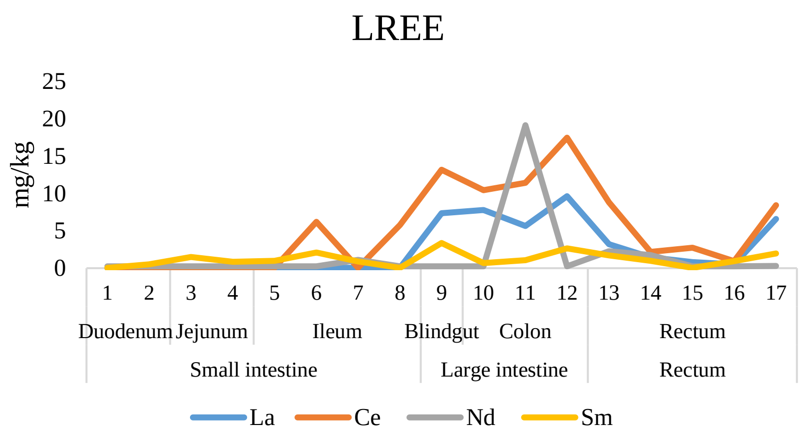


Figure 61. The content of light rare-earth metals in the intestines of domestic pigs (*Sus scrofa domesticus*), Ekibastuz, mg/kg ash residue

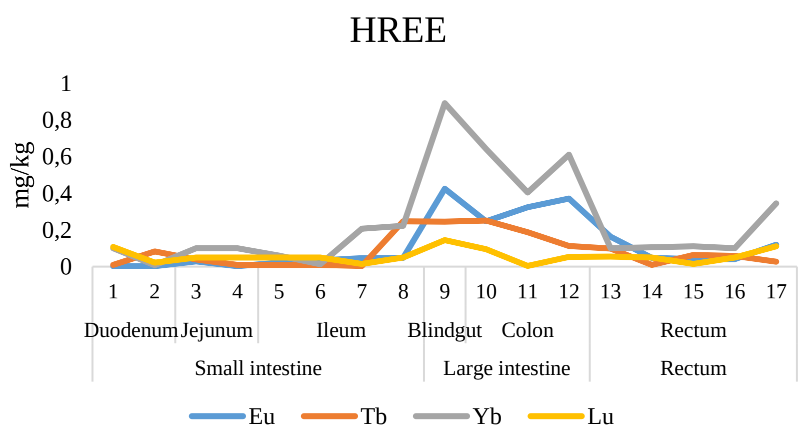


Figure 62. The content of heavy rare earth metals in the intestines of domestic pigs (*Sus scrofa domesticus*), Ekibastuz city, mg/kg ash residue

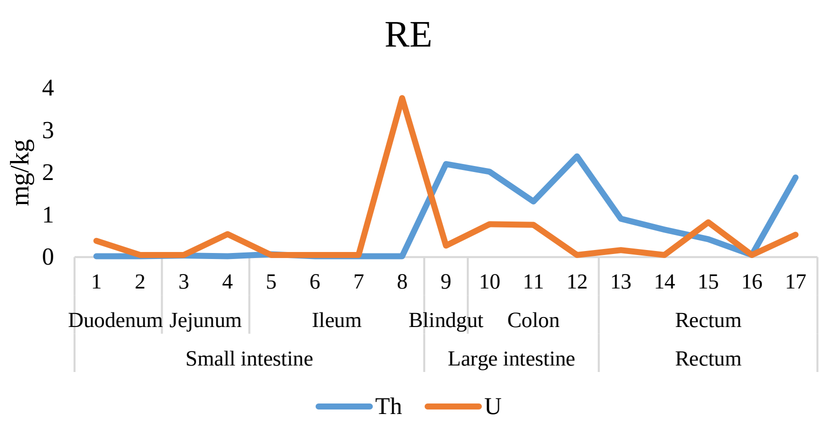


Figure 63. The content of radioactive elements in the intestines of domestic pigs (*Sus scrofa domesticus*), Ekibastuz city, mg/kg ash residue

The construction of diagrams of the relationship of heavy rare earth metals to lungs shows that most samples accumulate light rare earth metals to a greater extent, except the large intestine, as the main zone of fluid absorption (Figure 64).

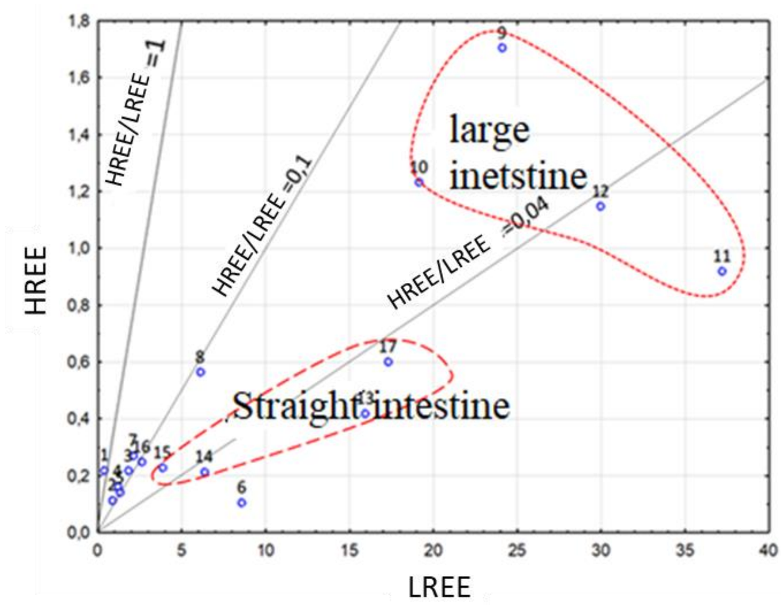


Figure 64. Correlation between concentrations of heavy rare-earth elements (HREE) and light rare-earth elements (LREE) in the intestinal tract of the domestic pig (*Sus scrofa domesticus*), Ekibastuz city

Note: The small intestine (12 duodenum 1, 2; jejunum 3.4; ileum 5-8); Large intestine (Cecum 9; Colon 10-12); Rectum 13-17.

Analysis of the thorium-uranium ratio in samples of the intestines of domestic pigs demonstrates that most of the samples studied are more likely to be of thorium nature, except samples of the small intestine, as noted above. It is seen that uranium entering the pig's body begins to be absorbed more intensively in the tissues of the small intestine, effectively not accumulating in the large intestine (Figure 65).

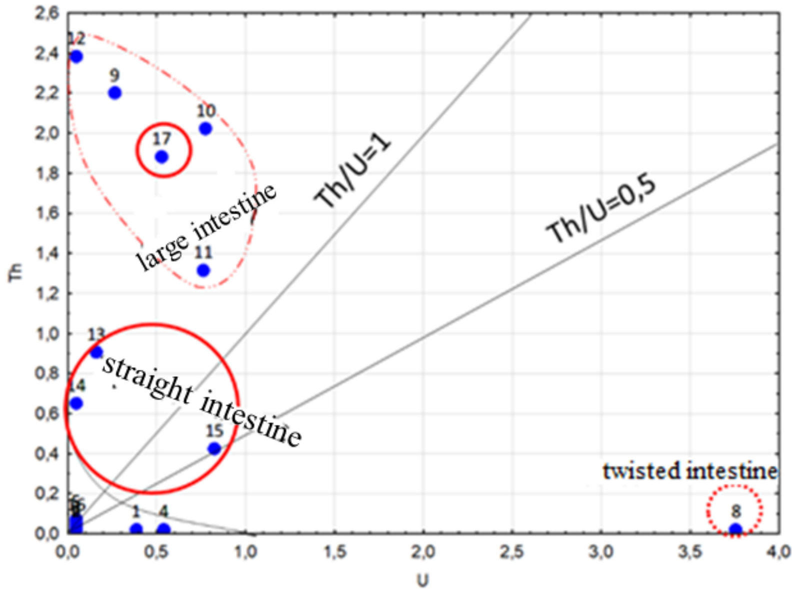


Figure 65. Th / U ratio in the intestinal tract of domestic pig (*Sus scrofa domesticus*) Ekibastuz

Note: The small intestine (12 duodenum 1, 2; jejunum 3.4; ileum 5-8); Large intestine (Cecum 9; Colon 10-12); Rectum 12-17.

7.2 Regional aspect in the functioning of the barrier systems of the gastrointestinal tract

Comparing the chemical composition of the intestinal biomaterial in the Tomsk region and Ekibastuz, one can note the barrier function of the large intestine, which is expressed in samples from both regions, accumulating in its tissues both rare-earth metals and radioactive elements. However, biomaterial from Ekibastuz city contains higher concentrations of rare earth metals and radioactive elements, which are most likely associated with varying degrees of anthropogenic impact on the region.

The zone of maximum accumulation of Yb for tissues from the Tomsk region is the 12 duodenal intestines, and to a lesser extent the large intestine. Moreover, the peak concentration of uranium in the small intestine is not recorded in the biomaterial selected in the Tomsk region. In general, the content of rare-earth components in the intestines in different territories repeats each other (Figure 66, 67) with a difference only in the individual contents of the elements, which can be attributed to different degrees of intensity of their absorption by the studied animals.

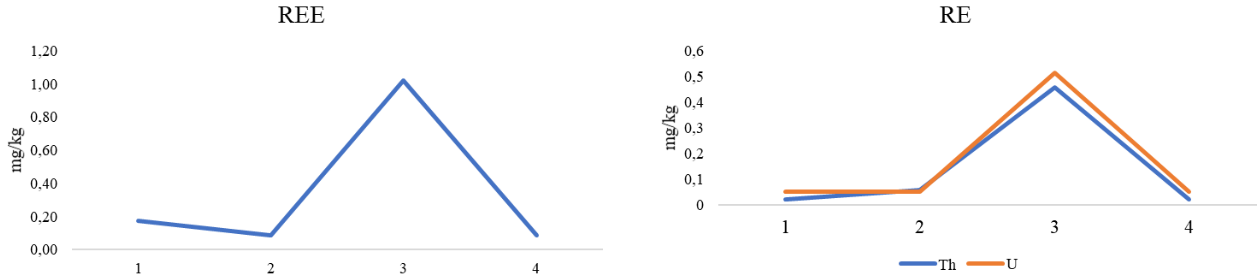


Figure 66. The concentration coefficient of rare-earth and radioactive elements in the intestines of domestic pigs (*Sus scrofa domesticus*), Tomsk region

Note: 1 – duodenum; 2 – small intestine; 3 – large intestine; 4 - rectum

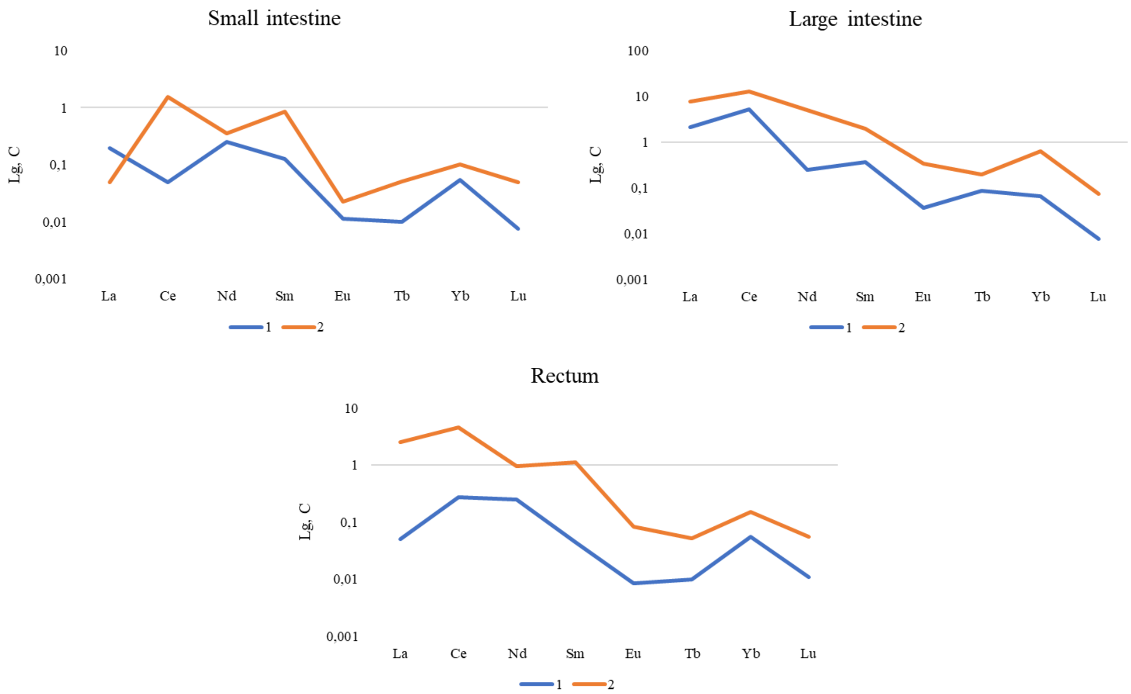


Figure 67. The content of REE in the intestines of domestic pigs (*Sus scrofa domesticus*), Tomsk region, Pavlodar oblast

Note: 1 – Tomsk region of Tomsk oblast; 2 – Pavlodar oblast

The influence of the regional aspect on the functioning of the barrier systems of a living organism can be traced within the same geographical area. Comparing the intestinal samples taken in the territory of the zone of increased technogenesis – Kizhirovo - and the zone with a slight anthropogenic influence - Verkhnee Sechenovo - it can be noted that the barrier function of the large intestine in the first case is much clearer (Figure 68-70). Samples from Verkhnee Sechenovo contain fewer elements, but also show less variability within the digestive system.

The barrier role of the large intestine can be traced in the zone remote from the source of pollution, but its elemental composition is close to other parts of the intestine. In the zone of increased technogenesis, the large intestine accumulates a large number of elements: 20 out of 28 have a concentration coefficient greater than unity. In the tissues of the large intestine from the village of Kizhirovo, the content of Ca, Ag, Nd, Yb, Lu, Ta, Au, U is reduced. In Verkhnee Sechenovo, out of 28 studied elements, the concentration coefficient is above unity only for $Co_{1.1}$, and for Cr0.9, $Yb_{0.9}$ values are close to unity.

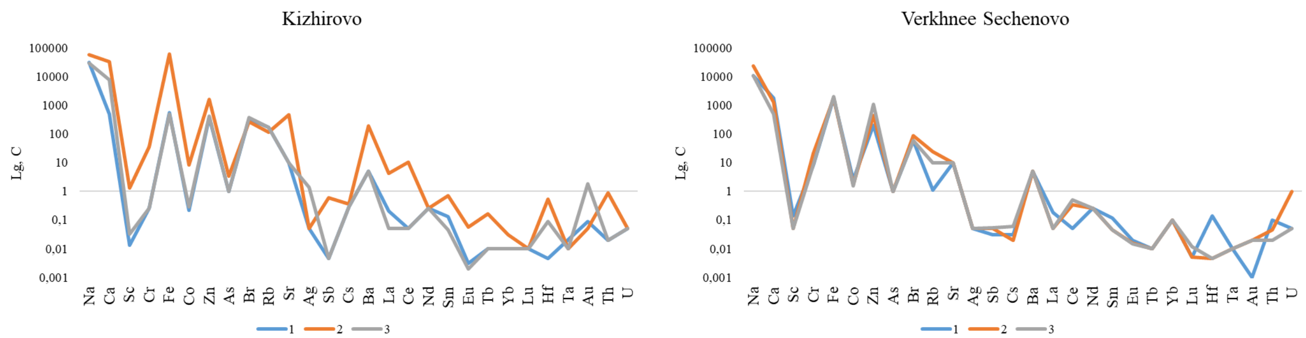


Figure 68. The content of elements in the intestines of domestic pigs (*Sus scrofa domesticus*), selected in the territories of Kizhirovo and Verkhnee Sechenovo, Tomsk region

Note: 1 – small intestine; 2 – large intestine; 3 – rectum

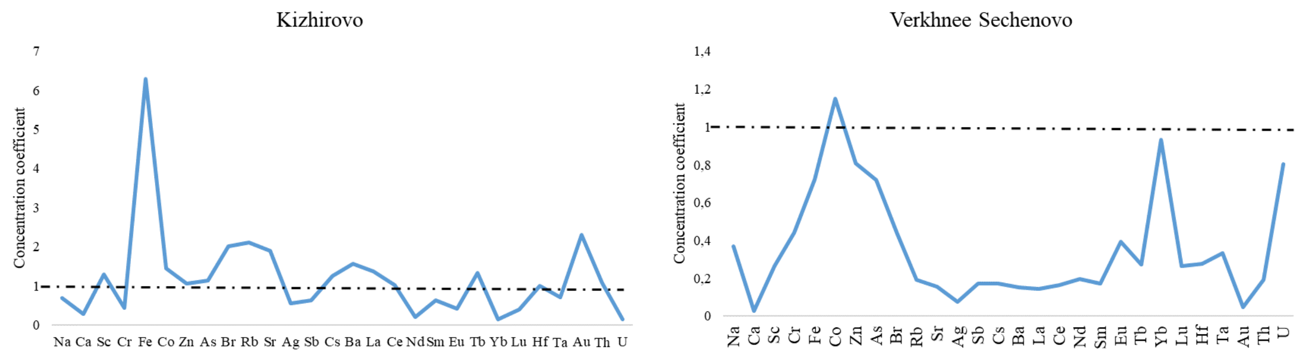


Figure 69. Content of elements in the intestines of domestic pigs (*Sus scrofa domesticus*), selected in the territories of Kizhirovo and Verkhnee Sechenovo, Tomsk region

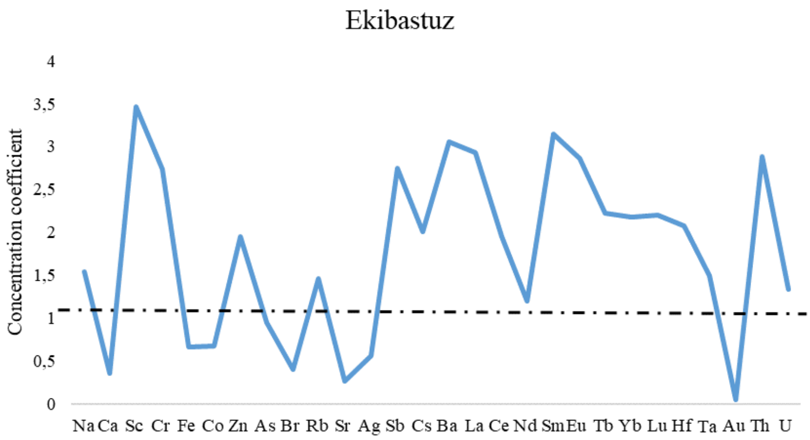


Figure 70. The content of elements in the intestines of domestic pigs (*Sus scrofa domesticus*), selected in the city of Ekibastuz city, Pavlodar region, Republic of Kazakhstan

It can be noted that regarding the degree of accumulation of elements in the intestinal tract, the village of Kizhirovo is similar to the city of Ekibastuz. Of the 28 elements studied, 22 have a concentration coefficient greater than unity, except for Ca, As, Br, Sb, Ag, Au.

Based on the diagrams of the concentration of elements in the intestines of domestic pigs, we can state that there is more intensive absorption of elements in line with the increase in anthropogenic impact.

The results show that the digestive system of a domestic pig responds to anthropogenic effects, forming powerful biochemical barriers. The concentration of chemical elements varies depending on the portion of the gastrointestinal tract, due to the acid-base balance changes and the physiological function of the organs studied.

A striking example is the increased concentration of chemical elements by the tissues of the colon, as an absorption zone of water and electrolytes, thus preventing the excessive ingress of metals into the blood. The barrier function of the large intestine is confirmed by the fact that the tissues concentrate 21 out of the 28 studied chemical elements. Arsenic and bromine, as volatile toxic elements that enter the body primarily through the respiratory system, are concentrated in the tissues of the pharynx.

The number of concentrated elements tends to increase as they pass through the intestinal tract, which may reflect the ways they are excreted from the body along with feces. Similar processes were previously noted in the works of Baranovskaya N.V. (Baranovskaya, Rikhvanov, 2011) in the study of the elemental composition of the domestic pig, raised under conditions of different technogenic loads.

The nature of the industrial impact is reflected in the chemical composition of the biological materials of the domestic pig. The organs of the gastrointestinal tract actively accumulate heavy, rare earth, radioactive metals, and arsenic. The chemical proximity of the domestic pig’s organism to that of humans, and the analogy of the behavior of chemical elements in mammalian organisms in general, suggests that the identified patterns could be attributed to humans, but this assumption requires further refinement.

7.3 The functioning of the body's barrier systems under conditions of technogenesis

In addition to the barriers that form in the digestive system of domestic pigs, regional effects on the body can also be found when considering organ systems such as the lungs, kidneys, and liver.

The content of elements in the tissues of the kidneys, liver, and lungs varies depending on the territory studied, however, if the macro component composition of the kidneys and liver is more or less homogeneous, the studies of lungs of animals from different regions are very different from each other.

Comparing the number of maximum values of the elements in the kidneys, one can note that the highest numbers are found the village of Mezheninovka and the city of Ekibastuz. The villages of Mezheninovka, Putintsevo, and Verkhnee Sechenovo are distinguished by a high number of maximum accumulations of elements in the liver, and the village of Mezheninovka is also clearly distinguished in the lungs (Figure 71, table 20).

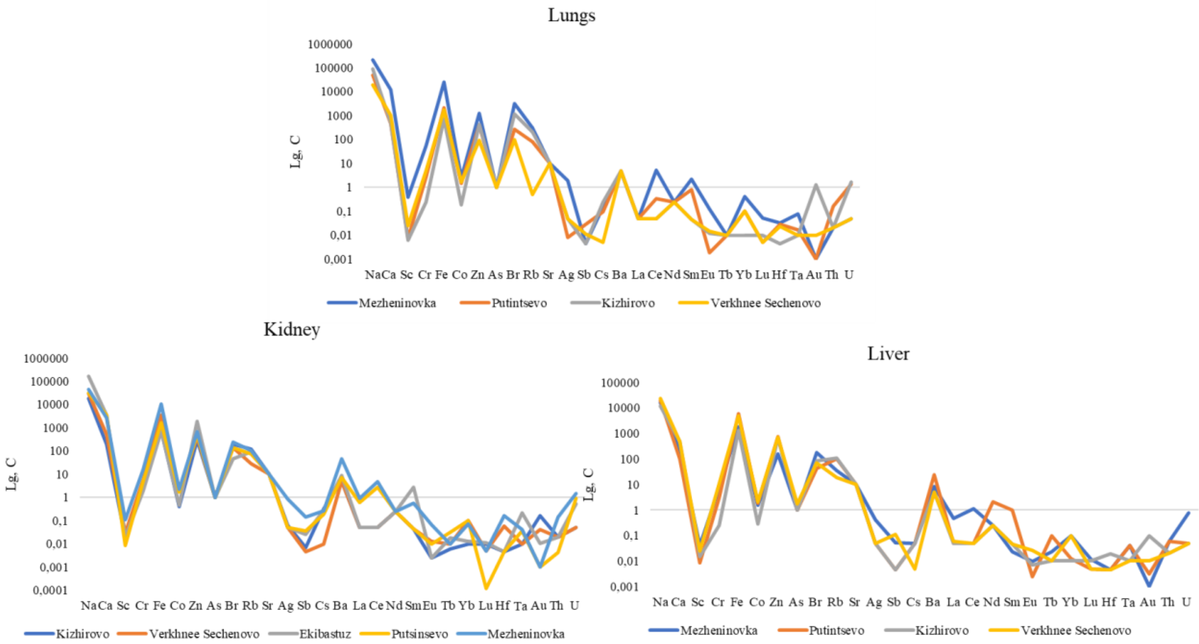


Figure 71. The chemical composition of the lungs, kidneys and liver of domestic pigs (*Sus scrofa domesticus*) in different study areas, mg/kg of ash residue

To determine the physiological and regional characteristics of the studied material, we constructed the series of element concentrations in barrier systems in the different territories (table 20).

Table 20. The concentration coefficient of chemical elements in the ash residue of organs and tissues of domestic pigs (*Sus scrofa domesticus*) in Kazakhstan and Russia

Organ	Kazakhstan	Russia		
	Putintsevo	Mezheninovka	Kizhirovo	Verkhnee Sechenovo
Liver	$Tb_{2,7}$=Sm-$Fe_{2,2}$-$Nd_{1,6}$-$Rb_{1,5}$-$Ta_{1,3}$-$Zn_{1,1}$=Co	$U_{2,3}$-$Ta_{1,3}$-$Br_{1,1}$	$Rb_{1,5}$-$Zn_{1,0}$	$Fe_{1,8}$-$Co_{1,3}$-$As_{1,2}$-$Zn_{1,1}$
Lung	$U_{4,0}$-$Sm_{2,2}$-$Br_{1,6}$-$Rb_{1,1}$	$Br_{19,3}$-$Fe_{9,6}$-$Sm_{6,0}$-$Na_{4,3}$-$Rb_{4,2}$-$Yb_{3,9}$-$Eu_{3,1}$-$Ag_{2,9}$-$Ta_{2,6}$-$Cr_{2,3}$-$Ce_{2,1}$-$Lu_{2,1}$-$Zn_{1,9}$-$Co_{1,5}$-$Sc_{1,4}$	$Br_{7,2}$-$Au_{5,3}$-$U_{4,8}$-$Rb_{2,9}$-$Na_{1,7}$-$Cs_{1,0}$	$Co_{1,0}$
Kideny	$U_{2,6}$-$Ta_{1,2}$-$Ce_{1,1}$-$Rb_{1,0}$=Co	$U_{4,3}$-$Fe_{3,9}$-$Ce_{1,9}$-$Eu_{1,8}$-$Sm_{1,6}$-$Br_{1,5}$-$Rb_{1,4}$=Ba=Co-$Ta_{1,3}$=Ag-$La_{1,1}$-Cs-Zn	$Rb_{1,6}$-$Cs_{1,3}$-$Br_{1,2}$	$Fe_{1,3}$-$Co_{1,2}$

A comparison of the concentration coefficients of elements in the kidneys and lungs of animals living in regions with different technogenic tension shows that significant differences in mammalian biomaterials, regardless of the physiological specification of the organisms living in the village. Samples from Putintsevo, East Kazakhstan region, accumulates U, Rb, as well as rare earth elements Sm, Ta, Ce. Samples from Mezheninovka accumulate U, Br, Cr, Fe, Ce, Sm, Eu; from Kizhirovo Rb, Br; and from Verkhnee Sechenovo Fe, Co.

An examination of the regional features of the concentration of elements in the barrier organs shows that, regardless of the geographical location, the lungs accumulate Br, U, Na; the kidneys accumulate Cs; and the liver accumulates Zn, with the exception for the village. Mezheninovka. The concentration of cesium by the kidneys is explained by the fact that this element is excreted from the body in the urine. The accumulation of zinc by liver tissues is explained by the binding of this element by hepatocyte compartments, and as a result, the increased accumulation of this element (Avtsyn, 1991). The high volatility of bromine explains why this element enters the lungs. Bromine always shows maximum concentrations in lung tissues, the lungs from Mezheninovka with a bromine CC equal to 19 attract particular attention. The concentration of uranium particles in animal lungs for the human body has also been noted previously by Ignatova T. (Igantova, 2010). It can be assumed that this element is deposited on lung tissue due to the insolubility of incoming forms of uranium.

Worthy of attention is the fact that the lungs of the animal from the Putintsevo village concentrate the highest uranium content, and according to the study of black poplar leaves in the assessment of the state of Ust-Kamennogorsk in whose territory the “Kazzinc” enterprise also operates, uranium concentrations that exceed the biosphere Clarke concentration (1.9 mg/kg) are found. From this, we can assume the air route of entry of this element into the body of the animal. A high concentration coefficient of uranium in the kidneys, in turn, most likely reflects the excretion route of this element from the body. If we talk about the absolute values of uranium in the biomaterial, its content in the lungs (1.4 mg/kg ash) is lower than the biosphere Clarke of concentration, however, the Clarke concentration number still exceeds the amount of U in the tissues of the kidneys (2.6 mg/kg ash).

Analyzing the chemical composition of the kidneys, as an active barrier organ of living organisms, and the organ responsible for the isolation and filtration of liquids, in addition to examining the ash residue of the biomaterial, one can pay attention to the indicator role of the liquid component of this organ.

Comparing the chemical composition of the tap water sampled in the city of Ekibastuz and the biological composition of the water evaporated from the organ of the animal, we can note the general similarity of their chemical composition. This tendency is visible in the content of macro components. This phenomenon is especially clearly observed for elements such as Fe, As, Cs, Ba, and it is also true for rare-earth metals, Au, Th (Figure 72).

The only exception is the concentration of elements such as Cr, Sb, Au whose content in biological water significantly exceeds their content in this region's drinking water. These elements have maximum biological absorption coefficients in this sample, especially antimony ($Sb_{39.9}$), and, apparently, are actively accumulated by the body from the environment.

Table 21. The coefficient of biological absorption

The coefficient of biological absorption	Biogeochemical range
Biomaterial: biological fluid	$Sb_{39,9}$-$Cr_{18,7}$-$Au_{2,8}$-$Co_{2,8}$-$Ce_{2,3}$-$La_{1,8}$-$Sm_{1,3}$-$Ba_{1,2}$=$Nd_{1,2}$=$Fe_{1,2}$

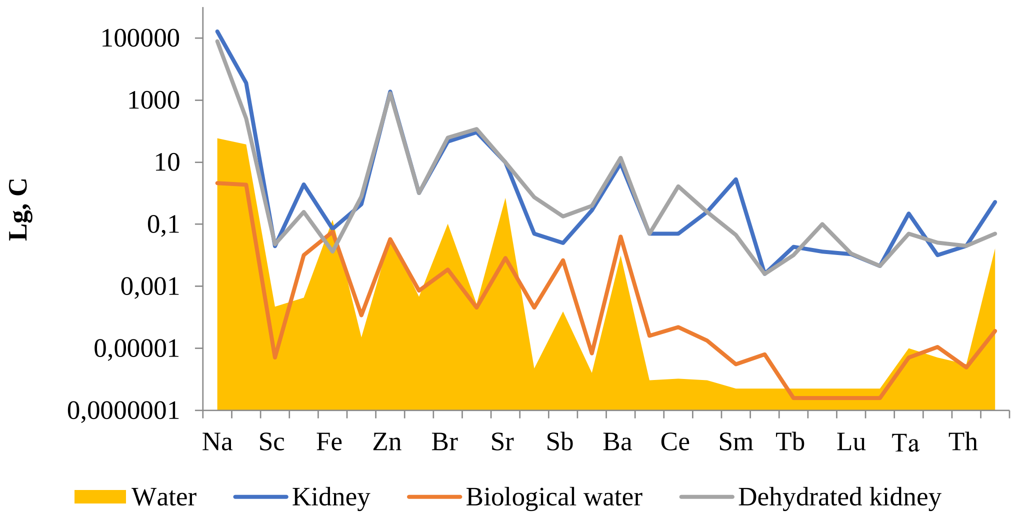


Figure 72. Distribution of chemical elements in the water-biomaterial system Ekibastuz mg/kg ash, LgC

Due to chromium entering entering the human body with atmospheric air (Antipanova, 2013), water and soil, a change in the metal content in the system, the initial substance — dehydrated biomaterial — biological water, can indicate the content of this metal in a water-soluble form. It can be noted that there is an extremely low Lu content in water and in a moist and dehydrated kidney, as an element since this element is the most likely to be excreted by the tissues of the stomach. However, according to the study of water and scale from the city of Ekibastuz (Arunova, 2016), elevated concentration coefficients of this metal were not detected, and therefore, it should be assumed that a variety of sources are the origin of meta in the animal's body. Elements such as Sb, Ce, Yb, Au are contained to a greater extent in dry matter than in raw matter, which is explained by the fact that these elements are not water migrants and have low mobility in the body. Ag, the high level of which is characterized by the scum of freshwater in Ekibastuz (Arunova, 2016), also does not migrate in biological water and is concentrated in solids.

7.4 The indicator role of the central nervous system in assessing the technogenic effects on a living organism

A comparative analysis of the concentration coefficients of elements in the complex of mammalian organs in the territory of Tomsk Oblast (Kizhirovo, Verkhnee Sechenovo villages) and East Kazakhstan Oblast (Putintsevo village) demonstrates that the anthropogenic effect on the body leads to disruption of the functioning of some barrier systems (Figure 73, 74).

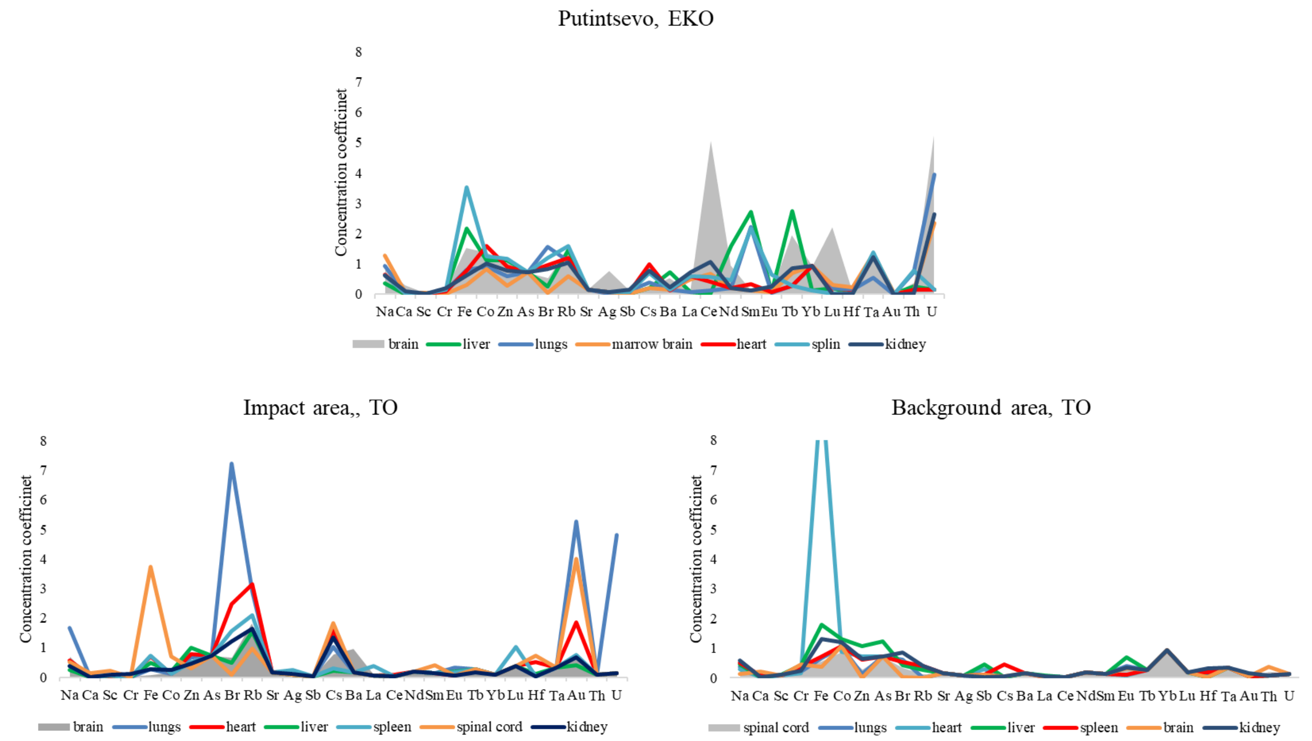


Figure 73. Distribution of chemical elements in the organs of the domestic pig (*Sus scrofa domesticus*): concentration coefficient relative to the average content in the sample

Note: East Kazakhstan region - East Kazakhstan region, TO - Tomsk region of Tomsk oblast

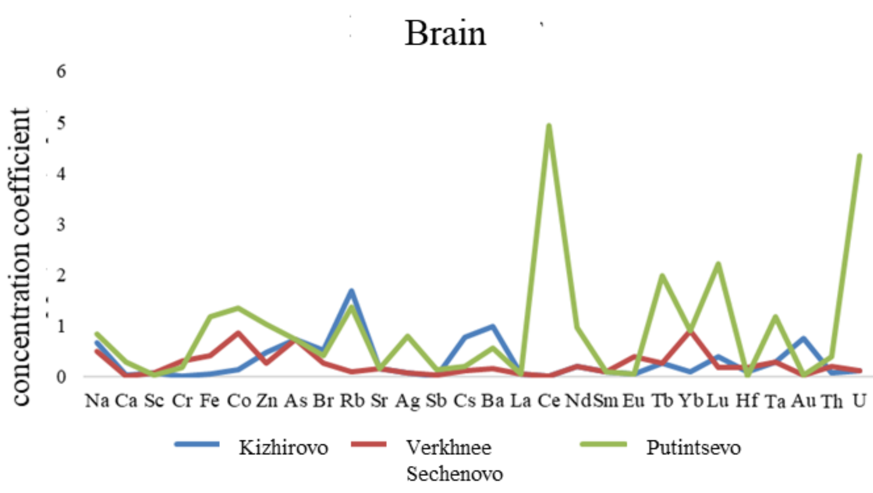


Figure 74. Distribution of chemical elements in the brain of domestic pig (*Sus scrofa domesticus*): concentration coefficient relative to the average content in the sample

The tissues of the central nervous system, normally the most protected from the negative effects on the body system from excessive technogenic effects, begin to accumulate rare and radioactive elements. Ce, Yb, Tb, Th, U accumulate in the brain of an animal from the village of Putintsevo, East Kazakhstan Region, and Lu, Hf in the spinal cord. Samples of the village of Kizhirovo, also experiencing a constant technogenic impact from the Northern industrial unit, accumulate Cs, Ba, La in the brain and Cr, Fe, Cs, Hf, Sm in the spinal cord. While the organs of the central nervous system from the background village of Verkhnee Sechenovo do not contain elements with a concentration coefficient above 1. It can be assumed that the anthropogenic effect disrupts the blood-brain barrier, which prevents metals from entering the brain.

Considering the chemical composition of the central nervous system of the domestic pig, biomaterial samples of which were taken in the villages of Kizhirovo and Verkhnee Sechenovo, Tomsk Region, some features of its chemical composition can be noted (Figure 75).

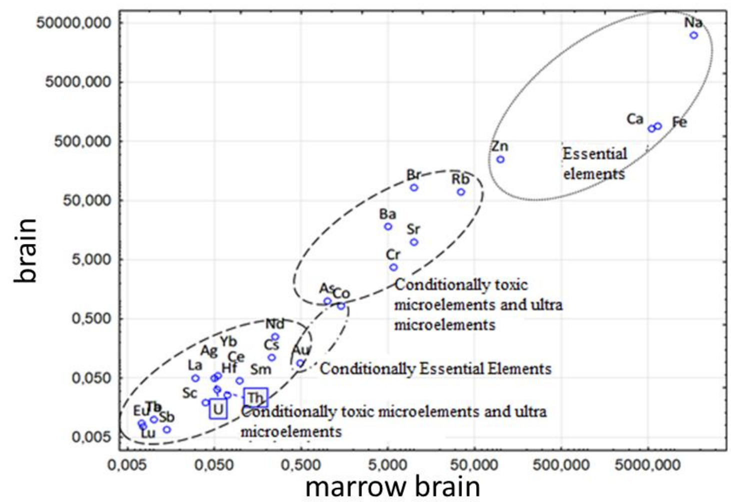


Figure 75. Distribution of chemical elements in the central nervous system of domestic pigs *(Sus scrofa domesticus*) in the Tomsk region mg/kg ash, logarithmic scale

The studied elements form groups reflecting Zhuravlev's geochemical classification of elements in a living organism (Zhuravlev, 1990). Thus, three categories are distinguished: essential structural elements, which includes all macro-elements and zinc; conditionally toxic microelements, and conditionally essential elements.

Comparing the distribution of elements in territories with varying degrees of anthropogenic load, one can note a variation in the content of elements of all geochemical groups (Figure 76). In samples from Kizhirovo the content of Zn, Rb, Ba, Sr is higher than the content of Cs, Au, Hf, whereas samples from Verkhnyee

Sechenovo are characterized by high contents of essential macro elements (Na, Ca, Fe).

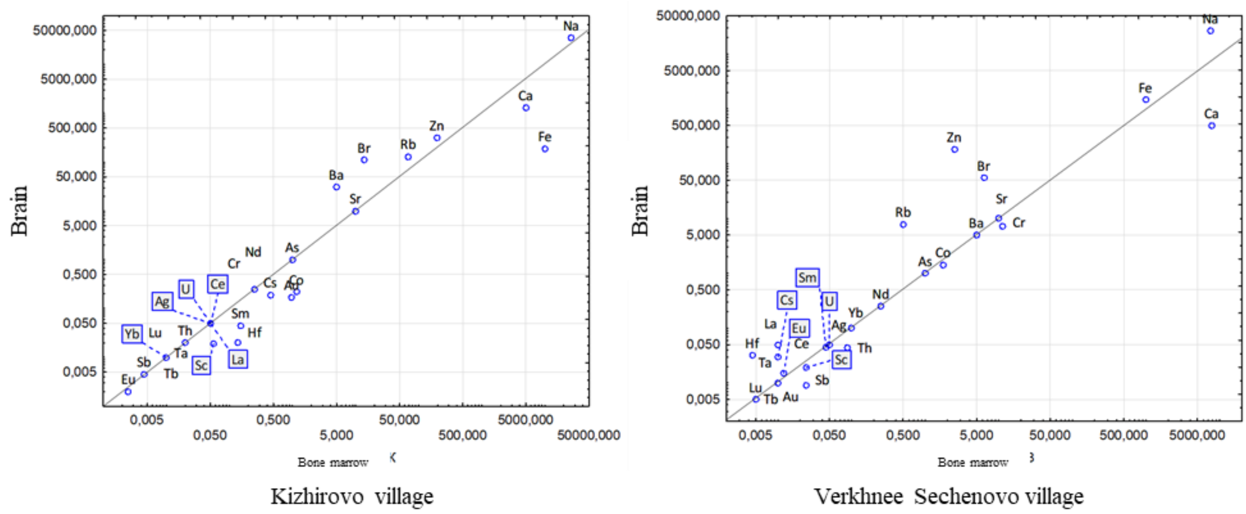


Figure 76. Distribution of chemical elements in the central nervous system of domestic pigs (*Sus scrofa domesticus*) in the Tomsk region mg/kg ash, logarithmic scale

By studying the features of the transfer of elements to the brain by blood in the three studied territories, some differences can be distinguished. The brain of an animal from Kizhirovo concentrates a larger number of elements in total, actively accumulating Na, Ca, Ba, Zn, Rb, Cs, Th, Tb, Au, while from Verkhnee Sechenovo Na, Rb, Th, Zn enter the sample (Figure 77).

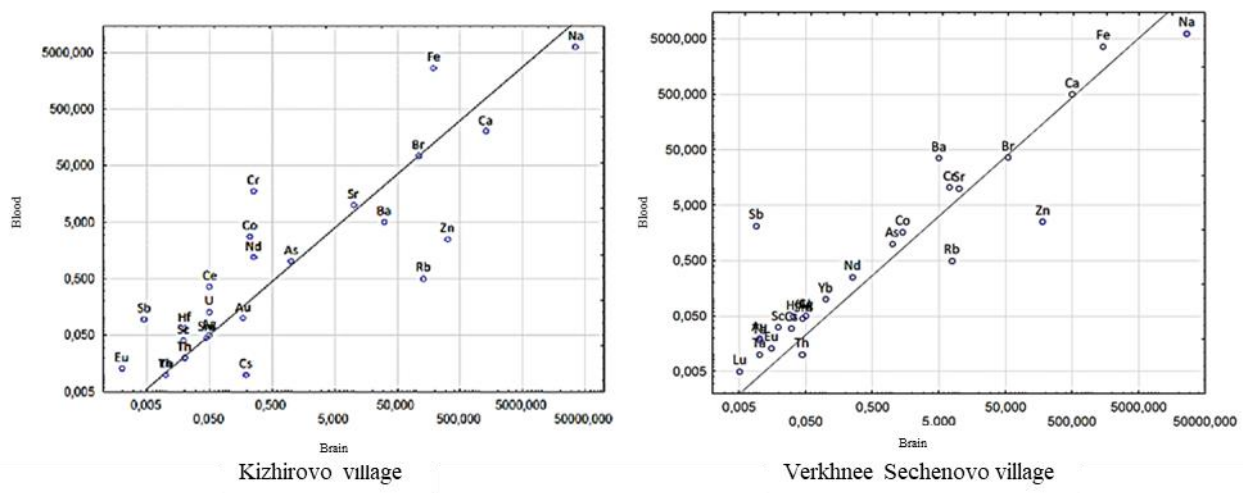


Figure 77. Distribution of chemical elements in the blood-brain system of domestic pigs (*Sus scrofa domesticus*) in the Tomsk region mg/kg ash, logarithmic scale

The transfer of elements via blood to the spinal cord also varies depending on the degree of technogenic tension in the region, so samples from Kizhirovo accumulate significantly more elements than biomaterial from Verkhny Sechenovo (Figure 78). Thus, spinal cord tissue from a technogenic transformed region, in addition to the macro components Na, Fe, Ca, concentrates Zn, Rb, Au, Cs, Hf, Sm. In the region remote from the industrial zone, the spinal cord accumulates Na, Ca, Th.

It can be noted that it is the change in the content of conditionally toxic elements and zinc that is indicative for these samples, since it varies significantly depending on the regional background.

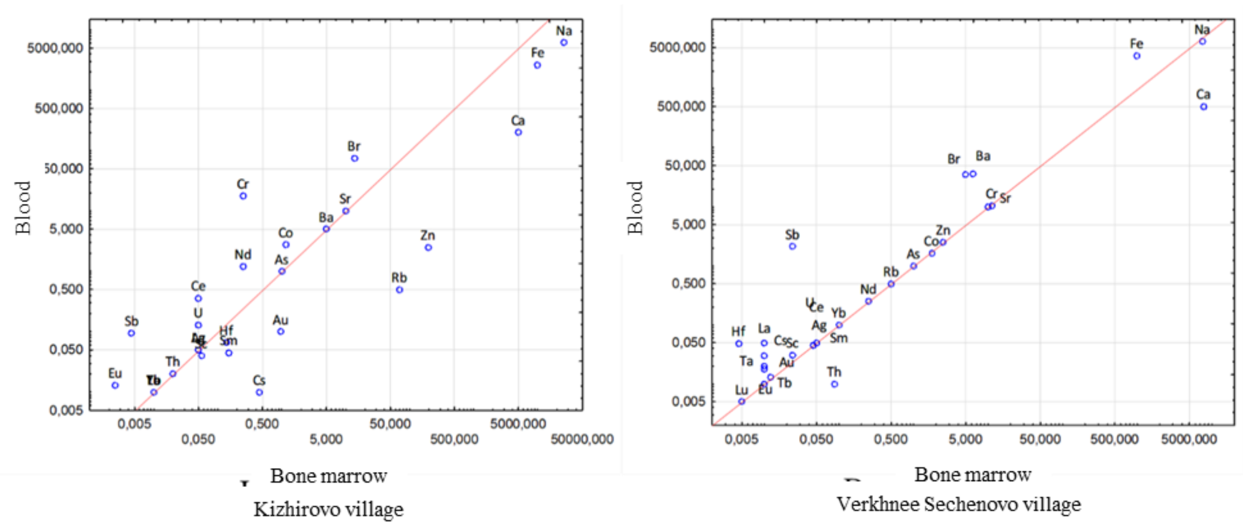


Figure 78. Distribution of chemical elements in the blood-spinal cord system in the territory of the Tomsk region mg/kg ash, logarithmic scale

Even though the tissues of the central nervous system of the animal from the village of Verkhnee Sechenovo accumulate thorium from the blood, the concentration coefficient of this element in the brain and spinal cord is very low and equal to 0.2 (table 22).

Table 22. The concentration coefficient of chemical elements in the ash residue of tissues of the central nervous system of the domestic pig (*Sus scrofa domesticus*), relative to the average content in the sample

Sampling territory	Biogeochemical range			
	Brain	N of elements with concentration coefficient higher than 1	Spinal cord	N of elements with concentration coefficient higher than 1
Verkhnee Sechenovo village	$Yb_{0,9}$=Co-$As_{0,7}$-$Fe_{0,5}$=Na-$Eu_{0,4}$-$Ta_{0,3}$=Br=Cr=Zn=Tb-$Lu_{0,2}$=Nd=Th	-	$\underline{Co_{1,1}}$-$Yb_{0,9}$-$As_{0,7}$-$Cr_{0,5}$-$Th_{0,4}$	1
Kizhirovo village	$Rb_{1,8}$-$Ba_{1,0}$	2	$Au_{4,0}$-$Fe_{3,7}$-$Cs_{1,8}$	3
Putintsevo village	$U_{5,2}$-$Ce_{5,0}$-$Lu_{2,2}$-$Tb_{1,9}$-$Fe_{1,5}$=Rb-$Co_{1,4}$-$Ta_{1,3}$=Zn	9	$U_{2,3}$-$Ta_{1,3}$=Na	3

The chemical composition of the central nervous system is thus quite informative in assessing the regional characteristics of the studied territories.

Comparison of such barrier organs as lungs, kidneys, liver, organs, and tissues of the central nervous system shows significant differences in their chemical composition depending on the sampling area.

Thus, it can be assumed that the specificity of the concentration of elements on the barrier organs in linked to the source of their entry into the living organism. So, in the animal organism from the villages of the Tomsk region, Kizhirovo and Mezheninovka, and the village of Putnitsevo of the East Kazakhstan region, an air entry route of elements is characteristic, which demonstrates a large number of elements with a high concentration coefficient in the lungs. It is noteworthy that, for an animal from Verkhnee Sechenovo - a settlement remote from areas of increased technogenesis - the whole organism, and the lungs, in particular, accumulate a minimum of elements, which are essential, with high concentration coefficients.

7.5 Features of the elemental composition of bones and blood as indicators of anthropogenic impact

Bone tissue, where a large number of chemical elements are deposited in the animal's body, is also an indicator when studying the technogenic effects on living organisms. Thus, when comparing the elemental composition of bone tissue, selected in the settlements of Russia and Kazakhstan, we find significantly increased contents of almost all the studied elements in animals selected on the territory of Russia (Figure 79).

Samples taken in the Pavlodar and East Kazakhstan regions accumulate more rare earth elements such as Sm in the bones, they also take the lead in the content of U, as well as Ag, Sr, Ca. All other elements are accumulated in the bones of animals from the regions of Russia.

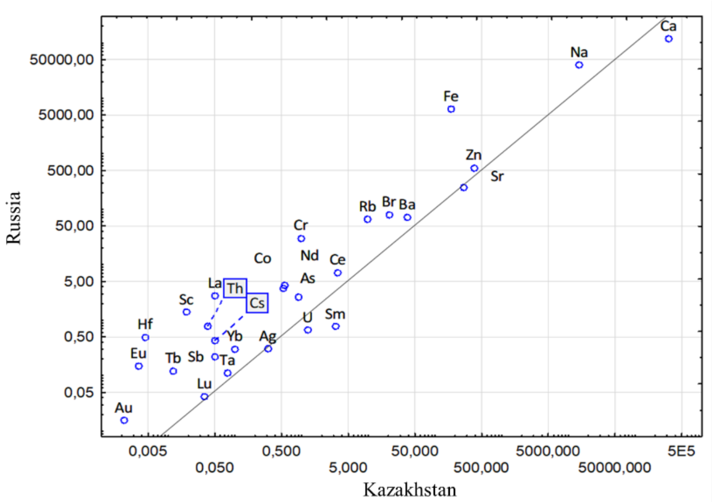


Figure 79. Distribution of chemical elements in the tubular bone in the settlements of Russia and Kazakhstan mg/kg of ash, the logarithmic scale

Since, as noted above, each studied region has its specific distribution of elements, the following comparative graphs were constructed to identify more accurately the regional specifics of their accumulation.

When comparing bones from the villages of the Zabaikalsky Krai and the Tomsk Region, a distinct division of the elements into two groups is seen (Figure 80). The elemental specifics of the bones of Zabaikalsky Krai are rare elements, rare-earth elements, radioactive elements, Ag and Cs. These bones are characterized by low content of macronutrients and calcium, as the main component of bone tissue.

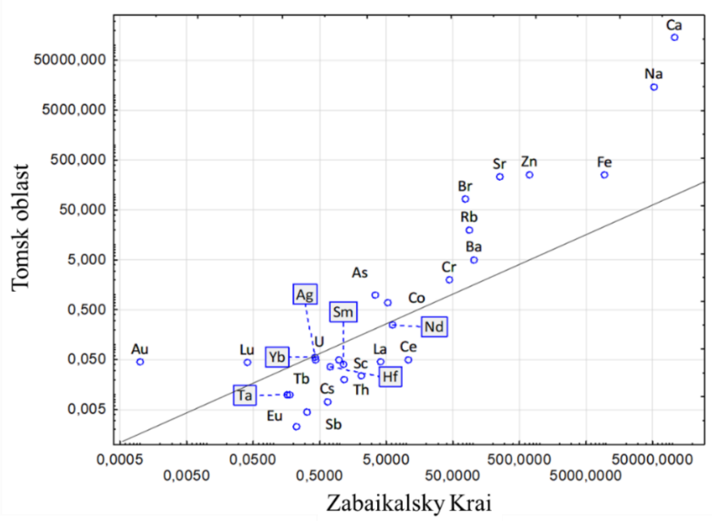


Figure 80. The chemical composition of the tubular bone of a domestic pig (*Sus scrofa domesticus*) in the Tomsk oblast and Zabaikalsky Krai, mg/kg of ash residue, the logarithmic scale

Comparing the coefficients of these elements concentrations in these regions, it can be noted that samples from the Tomsk region accumulate the average Ca content for this sample, while the bones from Transbaikalia vary (Figure 81). The tubular bone of an animal from the Gazimuromsky Zavod and Taina villages are depleted in the content of this macro element, whereas from Kalga, on the contrary, they are enriched to the maximum.

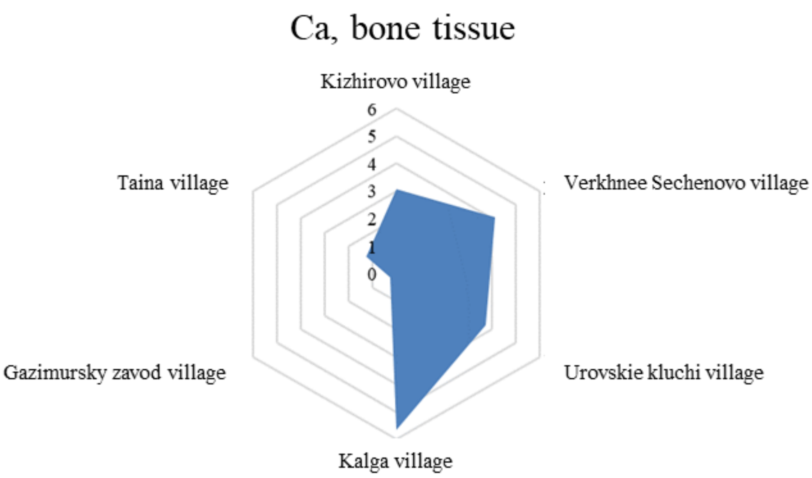


Figure 81. The coefficient of calcium concentration in the tubular bone of domestic pigs (*Sus scrofa domesticus*) in different study areas, relative to the average content in the sample

Comparing the content of chemical elements in the bone tissue of animals taken in the Tomsk Region, bones from Kizhirovo village concentrate Br, Rb, Au, Hf, and from Verkhnee Sechenovo village accumulate Fe, Zn, Co, Cr, Sc, Yb, Lu. Bones from Verkhnee Sechenovo village contain more calcium than bones from Kizhirovo village (Figure 82).

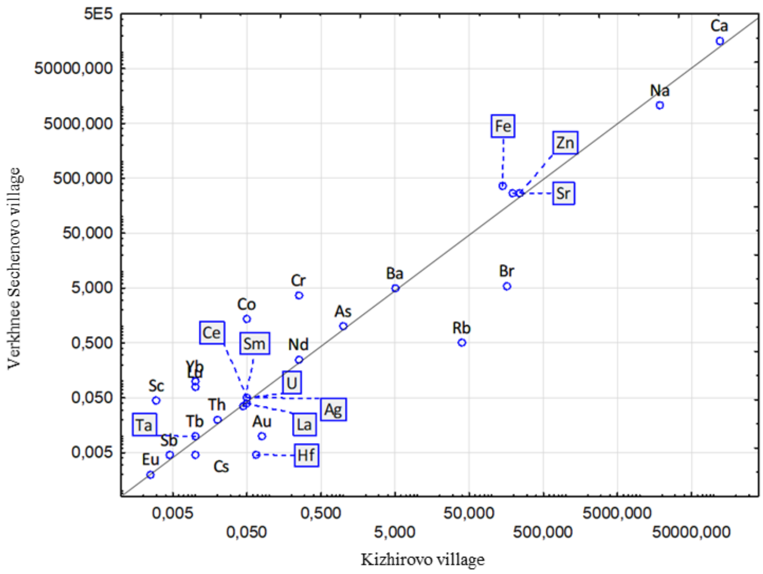


Figure 82. The chemical composition of the tubular bone of a domestic pig (*Sus scrofa domesticus*) in the Tomsk region, mg/kg of ash residue, the logarithmic scale

The general chemical composition of the tubular bones taken in Russia demonstrates that zones with low calcium content accumulate a greater number of other trace elements. This trend is noted for samples from the Gazimyromsky Zavod and Taina, which demonstrates a decrease in the calcium content in the bones and the body as a whole, provoked by excessive intake of toxic elements from the environment (Chernuh, Baeva, 2004).

The same tendency is also characteristic of animal bones from Kazakhstan (Figure 83). Although samples from the village of Putintsevo, East Kazakhstan Region, contain more calcium than samples from Ekibastuz, Ca has the highest concentration coefficient in the bones from Ekibastuz, and it is replaced by Sm in the village of Putintsevo.

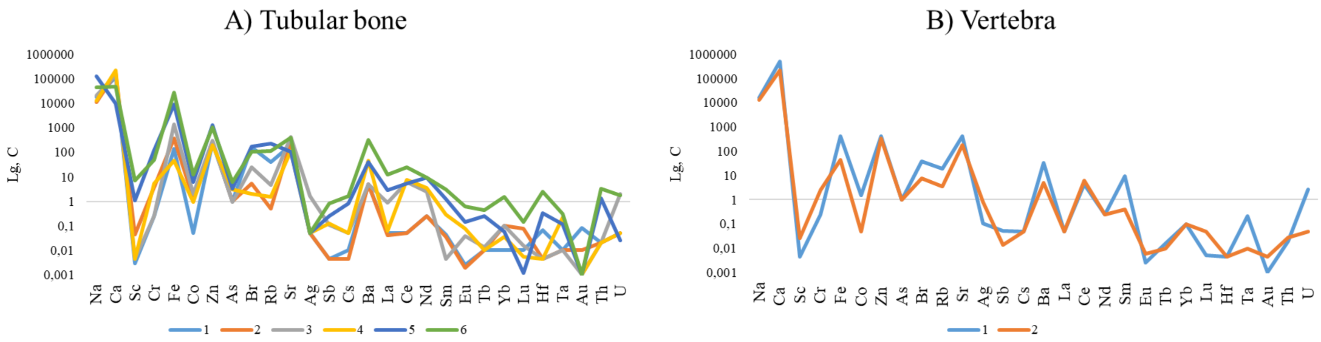


Figure 83. The chemical composition of the tubular bone of a domestic pig (*Sus scrofa domesticus*) in different study areas, mg/kg of ash residue, logarithmic scale

Note: A) Villages: 1 – Kizhirovo, 2 - Verkhnee Sechenovo, 3 - Urovskie Kluchi, 4 – Kalga, 5- Gazimursky zavod, 6 – Taina; B) 1 – Putintsevo village, 2 – Ekibastuz city

There is no doubt that technogenesis affects the natural composition of bone tissue (table 23). Calcium, as the main component of bone tissue, is replaced by other macro and microelements, depending on the sampling area. In the bones from the Urovsky Kluchi, calcium is replaced by silver, uranium and strontium. In samples from the Gazimyromsky Zavod and Taina, this macrocell has an extremely low concentration coefficient and is replaced by many elements. Ca has maximum concentration coefficients in samples from only three settlements: Kizhirovo, Verkhnee Sechenovo and Ekibastuz, but in Kizhirovo it is equal to the strontium concentration coefficient.

Table 23. The concentration coefficient of chemical elements in the ash residue of tubular bone and bone marrow of domestic pigs (*Sus scrofa domesticus*), relative to the average content in the sample

Studying territory, villages	Biogeochemical range, tubular bone	Biogeochemical range, bone marrow
Urovsky Kluchi (tubular bone)	$Ag_{3,7}$-$U_{2,1}$-$Sr_{1,6}$-$Ca_{1,4}$	$Co_{6,0}$-$Fe_{5,9}$-$Zn_{4,8}$-$Ce_{4,3}$-$Cr_{4,1}$-$Eu_{4,0}$-$Cs_{3,9}$-$Sb_{3,0}$-$As_{2,9}$-$Rb_{2,8}$-$La_{2,7}$-$Lu_{2,3}$-$Th_{1,9}$-$Nd_{1,8}$-$Ag_{1,5}$
Gazimyromsky Zavod (tubular bone)	$Cr_{2,8}$-$Rb_{2,6}$-$Na_{2,5}$-$Br_{2,3}$-$Zn_{1,8}$-$Nd_{1,5}$-…-$Ca_{0,1}$	$Ca_{5,5}$-$Nd_{5,1}$-$Ce_{4,0}$-$Sr_{3,2}$-$Co_{2,8}$-$Lu_{1,8}$-$Cr_{1,7}$
Taina (tubular bone)	$Yb_{3,5}$=Hf=Sc-$Lu_{3,4}$-$Ba_{3,1}$=La-$Fe_{2,9}$-$Th_{2,8}$=Eu-$Sm_{2,7}$-$Cs_{2,6}$-$Sb_{2,5}$=Tb-$Co_{2,3}$-$Ce_{2,2}$-$Ta_{1,9}$=As-$U_{1,8}$-$Nd_{1,5}$=Sr=Zn-…-$Ca_{0,5}$	$Co_{4,4}$-$Tb_{3,5}$-$Nd_{2,0}$-$Lu_{1,9}$=Cr-$Ta_{1,8}$=$Ag_{1,8}$-$Ce_{1,6}$
Kalga (tubular bone)	$Ta_{6,4}$-$Ca_{5,6}$-$Ce_{3,0}$-$Nd_{2,8}$-$As_{2,3}$-$Eu_{2,1}$-$Sr_{1,8}$	$Ca_{5,4}$-$Sr_{2,6}$-$Nd_{2,4}$-Co_{1}
Kizhirovo (tubular bone)	$Sr_{3,1}$=Ca	
Verkhnee Sechenovo (tubular bone)	$Ca_{4,1}$=Sr=Lu	
Putintsevo (vertebra)	Sm_{19}-Ca_{13}-$Sr_{6,7}$-$Ta_{6,4}$-$U_{6,1}$-$Ce_{1,7}$	
Ekibastuz (vertebra)	$Ca_{5,6}$-Sr_{3}-$Ce_{2,4}$-$Lu_{1,9}$	

Particular attention is drawn to the fact that uranium is concentrated in the bone tissue of an animal from the village of Putintsevo, East Kazakhstan region, and an increased accumulation of this element by lung and kidney tissues has previously been noted. Entering the body of an animal in the air, this element enters the blood from the lungs, some is excreted by the kidneys, however, a significant part of it is deposited in bone tissue.

The composition of the red bone marrow in some cases reflects the composition of the tubular tissue. So, for example, bone marrow from Kalga village accumulates the same elements that accumulate in the bone. Red bone marrow is characterized by the accumulation of Ca, Sr, Lu, Ag, Co, which are also deposited in bone tissue. The common components of the bone marrow in all the studied areas are Co, Fe, Nd, Ag, and specific Fe, Zn, Eu, Cs, Sb, As, Rb, La, Th for Level, and Tb, Ta for samples from Taina village. Considering the features of the distribution of elements in the bone marrow of an animal from the Urovsky Kluchi, one can note a high concentration coefficient of thorium, which is not in the bone tissue. This can be explained by the affinity of thorium for the adipose tissue, which makes up the red bone marrow. Deposition of thorium in adipose tissue has previously been noted in the example of the ash residue of the human body (Baranovskaya, 2011; Iganotova, 2010). In addition to thorium, the bone marrow of an animal from the Urovsky Kluchi village includes such elements as physiological macro components responsible for the function of hematopoiesis (Fe, Co, Rb, Zn), and conditionally toxic elements (rare earth metals, arsenic, antimony).

Another biomaterial indicator in assessing anthropogenic impact is blood (Figure 84). Blood, as a connective tissue with a relatively constant composition, can subtly respond to changes in the environment by changing its elemental status. The composition of the blood of the pig also varies significantly depending on the degree of anthropogenic impact. The blood of a piglet from Kizhirovo contains uranium, thorium, neodymium, rare earth elements, and bromine. These elements are indicators of anthropogenic impact previously observed in biological objects when studying the influence zone of Seversk city. Increased concentrations of uranium and rare earth elements is characteristic of amphibian organisms living in the northern part of the Tomsk region (Kuranova et al., 2003). Elevated concentrations of Br, Au, and rare earths were also recorded in the blood of residents of settlements close to Seversk city (Baranovskaya, 2011).

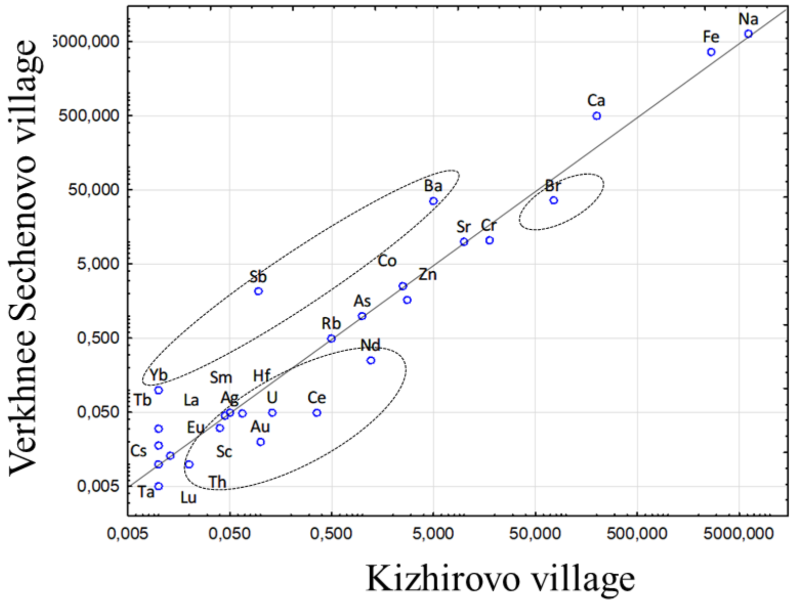


Figure 84. The chemical composition of the blood of domestic pigs (*Sus scrofa domesticus*) in the Tomsk region, mg/kg of ash residue, the logarithmic scale

Samples from Verkhnee Sechenovo village differ from samples from Kizhirovo in the antimony and barium contents. The absence of industrial facilities in the areas adjacent to the settlement territory and wind transfer leads to the conclusion that there is a natural source of these elements in the blood.

Comparing the coefficients of the concentration of elements in the blood of domestic pigs in the three studied regions (Figure 85), it is possible to note the enrichment of the blood of animals from Ekibastuz with macro- (Fe, Na, Ca, Zn, Rb) and microelements (Br, Ta, Nd, Lu, U). According to studies, the entire animal body from Ekibastuz is enriched with these elements, they are fixed in all studied organ systems, and especially in the bone tissue and the gastrointestinal tract.

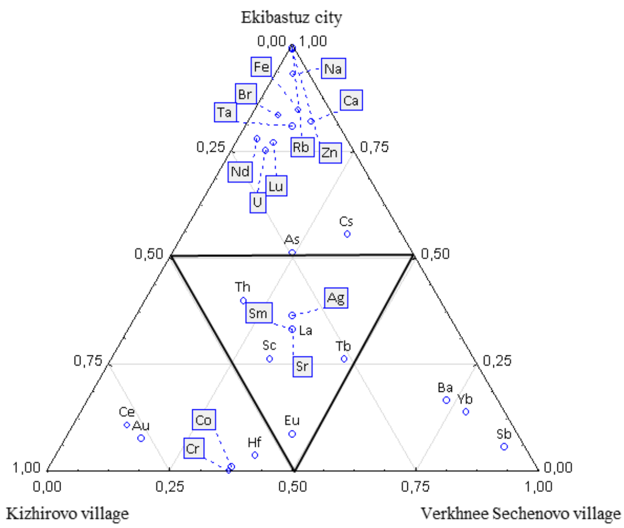


Figure 85. The chemical composition of the blood of domestic pigs (*Sus scrofa domesticus*) in the Tomsk region and the city of Ekibastuz, mg/kg of ash residue, the logarithmic scale

The high level of pressure on the ecological state of the region is also confirmed by the content of Cs, As, U in the blood of animals from Ekibastuz city. The blood composition of the piglet from the city of Ekibastuz reflects the geochemical specifics of fresh water in this settlement (according to Arynova Sh.Zh.), accumulating high concentrations of Zn, Ta, U, Fe, Lu.

CHAPTER 8. APPLICATION OF USETOX MODEL FOR ESTIMATION OF TOXICITY OF ELEMENTS IN SOIL AND AIR IN THE TERRITORY OF THE RESEARCHED REGIONS

The results of the studies show that the animal's body accumulates a significant number of elements, including toxic and conditionally toxic ones, in the area of technogenic impact, which poses a potential threat to human health. In this regard, it is necessary to assess the toxicity of individual elements for the human body. To achieve this goal, we chose the USEtox environmental model, whose advantages were discussed in detail in Chapter 2 of this work, and main methodological and technological aspects in Chapter 4.2.1.

To calculate the characteristic toxicity coefficient, taking into account the geoecological specifics of the studied region, the calculation procedure was modified using our own and published data. Heavy metal chromium (Cr) was chosen as an example.

Chromium exhibits toxic effects on living organisms through interference with metabolism and mutagenesis (Fantke et al., 2017; Guertin, 2005; Zhao et al., 2016). Cr is also an indicator of vigorous industrial activity. Pork, as an organic source of chromium, has a greater bioavailability than inorganic sources (NRC, 1997; Zhao et al., 2016). The bioavailability of chromium is associated with the ability of end-organisms of the biological migration of trace elements to concentrate it. The normal chromium content in pork is 2-3 mg / kg (Chromium Content of Meats, 2018).

8.1 Modification of the USEtox model using the results of geoecological studies

Given the need to introduce local data into the model in order to compare the toxic effects at country level, we conducted a literature review of studies of the elemental composition of pork in different geographical zones. Using scientific databases (Science Direct, Scopus, Springer, etc.), information was obtained on the Cr content in pork samples in 9 countries, analyzed by ICP-MS in 2013, 2016 and 2017.

This study presents a sample of the results of studying the chromium content in 5 of the 17 geographical areas presented in the USEtox model, which allows us to compare the characteristic coefficient presented in the model with the data obtained experimentally. The results obtained by the ICP-MS method were chosen for comparison, since this type of analysis is more common and more widely used in studies of this kind.

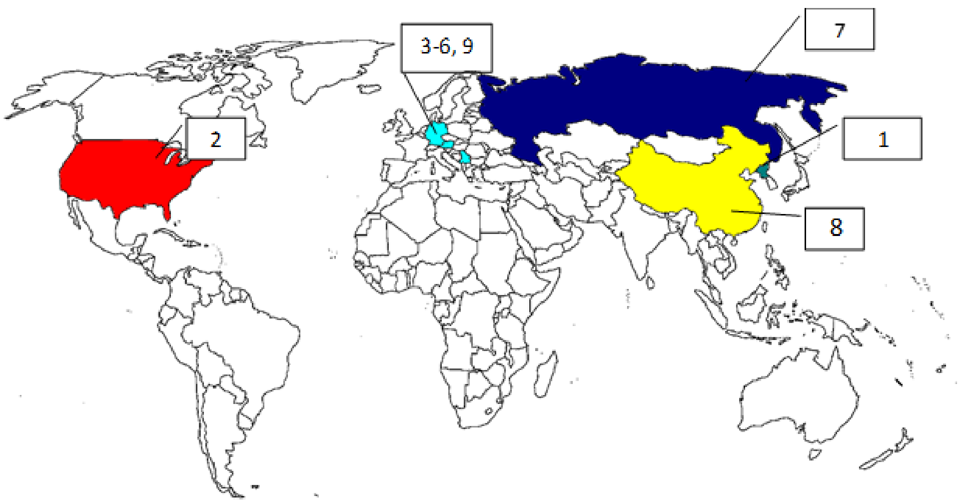


Figure 86. Map of pork sampling according to the results of our research and literature data

Note:1. Korea (Kim et al., 2017); 2. USA (Kim et al., 2017); 3. Germany (Kim et al., 2017); 4. Austria et al., 2017); 5. Netherlands (Kim et al., 2017); 6. Belgium (Kim et al., 2017); 7. Russia (Baranovskaya, 2011); 8. China (Demirezen и Uruç, 2006; Zhao et al., 2016); 9. Serbia (Nikolic et al., 2017)

Countries derived from literature represent 4 geographical areas in the USEtox model (table 24). The studied geographical zones have different environmental conditions, economics, pollution legislation and, therefore, different anthropogenic pressure on the population, and the chromium content in the meat of each geographical object also varies. The Cr content in countries belonging to the Eurozone is generally similar, except samples from Serbia. The initial data for calculating the exposure factor and the characteristic toxicity factor are presented in the tables below.

Table 24. The Cr content according to ICP-MS analysis in pork according to literature and own research, mg/kg

	1	2	3	4	5	6	7
1	Korea	0,003	0,0001	227	2016	Japan and Korean peninsula	(Kim et al, 2017)
2	USA	0,0009	0,0001	36	2016	USA and Southern Canada	
3	Germany	0,0006	0,0001	12	2016	Europe	
4	Austria	0,00007	0,00001	15			
5	Netherlands	0,0005	0,0001	14			
6	Belgium	0,0005	0,00001	19			
7	Serbia	0,08	0,01	192	2017		(Nikolic et al., 2017)
8	China	2,01	0,2	100	2016	Southeast Asia	(Demirezen, Uruç, 2006; Zhao c, 2016)
9	Russia	0,5	0,3	17	2013	Central Asia	(Belyanovskaya et al., 2019; Baranovskaya 2011; Baranovskaya, Rikhvanov, 2011)

Note: 1 -№ Country; 2 - XCr [mg/kg]; 3 – λ; 4 -N of samples; 5 - Sampling date [year]; 6 -The USEtox geo area; 7 -Reference

X_{Cr} – arithmetical mean [mg/kg], λ – standard error of the arithmetical mean

Table 25. Initial data for calculating the exposure factor, kg_{intake} /day per $kg_{in\ compartment}$

Territory	S[km^2]	Height [m]		Volume [m^3]		Population
		Air	Soil	Air	Soil	
USEtox default value	9013369	1000	0,1	9E+12	9E+08	2000000
Central Asia	16876936			2E+13	2E+09	1471446
USA and Southern Canada	14489980			1E+13	1E+09	1317367
Europe	8566214			9E+12	9E+08	1414561
Southeast Asia	6426356			6E+12	6E+08	1470937
Japan and Korean peninsula	597600			6E+11	6E+07	4557951

Data from literary sources are used to compare various geo-fences of the USEtox model based on experimental studies as mentioned in Chapter 2. The characteristic coefficient (CF) is calculated according to the USEtox documentation, it uses the default values for the fate factor (FF) and the effect factor (EF) to calculate the CF. Exposure Factor (XF) is calculated for each study area using ICP-MS analysis results; default XF values are also taken for comparison between the results obtained and the data presented by the model.

The results of calculating the characteristic toxicity coefficient for the intake of elements with soil and air for the population of the studied regions are presented in table 26.

Table 26. The characteristic coefficient of chromium in pork through soil and air, Dali/kg

N	The USEtox geo area	Country	ID in model	Soil Dali/kg		Air Dali/kg	
				CF modified	CF default	CF modified	CF default
1	Japan and Korean peninsula	Korea	JAP	6,3E-08	1,4E-07	5,4E-07	6,9E-08
2	USA and Southern Canada	USA	W10	1,4E-11	1,1E-07	8,9E-15	8,7E-08
3	Europe	Germany	W13	6,7E-11	4,3E-07	7,7E-10	1,7E-07
		Austria		7,8E-12		9,0E-11	
		Netherlands		5,6E-11		6,4E-10	
		Belgium		5,6E-11		6,5E-10	
		Belgium		8,9E-12		1,0E-10	
4	Central Asia	Russia	W1	2,7E-03	4,6E-08	1,9E-07	2,1E-08
5	Southern China	China	Southeast Asia	1,5E-09	2,4E-07	2,8E-07	2,0E-07

The results of calculating the characteristic coefficient during normalization to (local) soils show that the coefficient calculated using our data exceeds the CF proposed by the model. It can be noted that the difference between the characteristic coefficients for Cr calculated for different geographical areas is not reflected in the CFs proposed by the USEtox model. The modified values are in the following order: Europe <USA <South China <Japan and Korea <Central Asia. The model assumes the maximum CF for the territory of South China, while according to our research, the coefficient has the largest value in the territories of Central Asia and Korea (Figure 87).

When calculating the CF value for chromium during normalization to air, the model also assumes the greatest impact for the territory of Central Asia and Korea, while the maximum modified CF falls on the population of Korea and South China. This inconsistency is undoubtedly due to the lack of local data in the model that does not consider the geoecological features of the regions. Comparing the toxic effects of chromium on different geographical areas, it can also be noted that the modified coefficient, and CF proposed by the model taking into account the intake through the air, are closer to each other, unlike those for the soil.

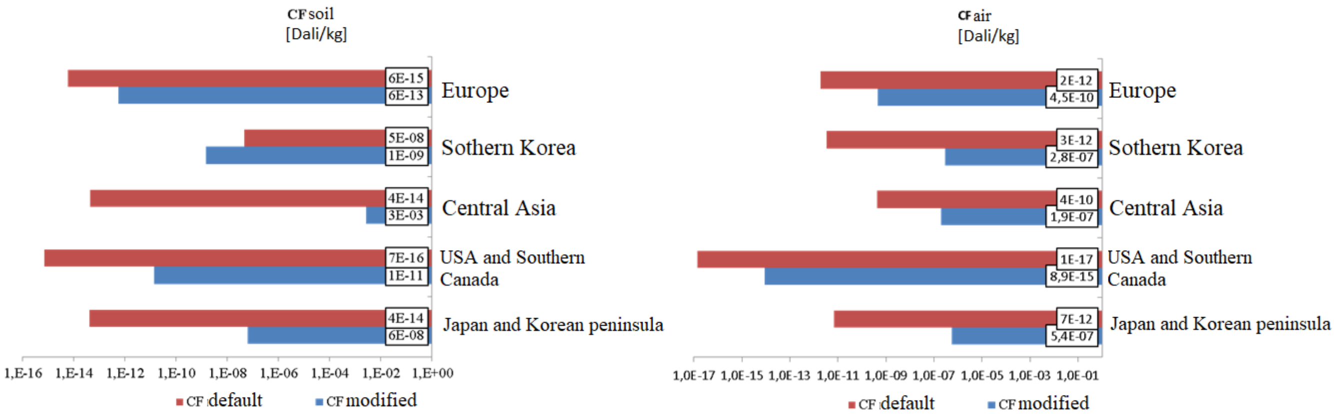


Figure 87. The characteristic coefficient calculated for Cr for the studied territories, the effect through soil and air, Dali/kg

The order of magnitude of the impact between different geographical areas is different for the modified CF and the default CF. For CF by CCCr, the default is USA <Europe <South China <Japan and Korea <Central Asia. For self-calculated CF, it is USA <Europe <Central Asia <South China <Japan and Korea. South China, Japan, and Korea have the largest CF Cr by air of all observed areas.

In a detailed study of the characteristic coefficient for countries belonging to the geographic region of Europe (Figure 88), it can be noted that European countries show similar results, which, however, are not really reflected in the model. However, different countries of the geographic region, designated as "Europe" in the model, have different CFs - despite their territorial proximity - much lower than the default coefficient of the USEtox model. This confirms the importance of local data in the impact assessment process.

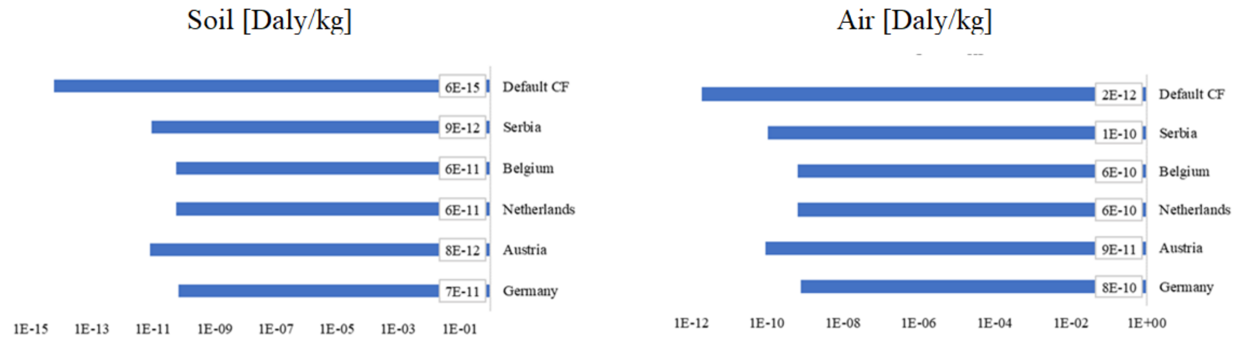


Figure 88. The characteristic coefficient calculated for Cr for the studied territories, the effect through soil and air, Dali/kg

For all studied areas, we observe that the contribution of soils to the impact of Cr is higher in comparison with air. That can be related to the main pathway of Cr and animal natural behavior. According to the toxicological investigation: the common ingestion intake pathways of Cr are food consumption, drinking water, and ingestion of contaminated soil (NRC, 1997). The behavior of pork in the natural environment includes the digging, so the ingestion of contaminated soils can be more significant then inhalation.

Results of the current investigations showcase the importance of regional aspects for the impact assessment of chromium, and highlight the significance of the utilization of proper sources in the literature.

Inside the geo-zone "Europe" we can see, as a difference between results of CFH calculations for both types of intake (via soils, via air), the high CFH for Germany, in comparison with other sampling areas, and similar characterization factors in the Netherlands, Belgium and Serbia. In contrast, the default value purposed by the USEtox is significantly lower than all values calculated manually. Differentiation between default data of the USEtox model is also visible in comparison of CFH for two current types of intake (via soils, and via air).

The information provided by the USEtox model reflects only the transfer of metals, with a certain effect in the form of dust or coal pollution, and does not cover a huge range of inorganic elements. It is assumed that the results of studies of the elemental composition of various types of meat, and especially pork, could expand the model database with more relevant information. Most likely, the discrepancy between the results of our research and the data proposed by the model may be because the model uses data on the theoretical chromium content in the polluted medium, and as a result, exaggerates or underestimates the result. Thus, the use of the results of the analysis of the elemental composition of meat products, instead of the theoretical calculation of its content, is a more effective way of assessing the biological accumulation of a given heavy metal in living matter.

8.2 Application of modified calculations of the characteristic toxicity factor to compare regional health risks

The methodology described above was applied to assess the impact on the health of the population of the different regions studied. Thus, the exposure factor was modified using data obtained by instrumental neutron activation analysis (INAA).

Since the USEtox model database includes a wide range of elements (3000 organic compounds and 25 inorganic metal elements), toxic trace elements included in the USEtox model database - Cr, Zn, Sb, As, Ba - were selected for toxicity analysis and their content was analyzed by the INAA method.

These elements were chosen for a comparative analysis due to the toxicity of their effects on living organisms, for example, all these elements, except Ba, can cause mutations in mammals (Chernuh, 2004; Vishnevetsky, 2012; Guseva, 2016). Excessive intake of zinc is an oncogenic and mutagenic hazard, leading to damage to the cardiovascular system. Prolonged inhalation of zinc leads to impaired lung function, an excess of zinc in the body can also harm the peripheral nervous system (Tubek, 2007; Tubek, 2008; Lovell, 2006; Cuajungco, 1998). Of the chromium compounds, six-valence chromium is the most dangerous, but in biological systems Cr (VI) is easily reduced to Cr (III), and the redox potential is not favorable for the reverse reaction (Fendorf, 1995; Paradise, 1989; Kotas, 2000). However, hexavalent chromium compounds are more effectively absorbed by organisms, which is associated with the high solubility of Cr (VI) at physiologically significant pH. A constant intake of chromium, has an acute toxic effect on the digestive system, leading to metabolic disorders. Chromium compounds are also recognized as potentially carcinogenic to the human body (Barceloux, 1999; Remy, 1990; Bykorez, 1989).

Excessive intake of As into mammals leads to impaired functioning and toxic tissue damage, cancerous lesions of the lymphatic, respiratory systems, urogenital and gastrointestinal tract (Chernuh, Baeva, 2004). Arsenic affects intestinal health as the main organ of absorption, disrupting barrier function and causing inflammatory reactions (Calatayud, 2015). Arsenic also a destroyer of the endocrine system of the body (On influence exerted by antimony on a human body… (in Russian), 2019). Antimony (Sb) is similar to arsenic in its properties. It has been found that antimony has an inhibitory effect on enzymes that are involved in the metabolism of carbohydrates, fats, and lipids. Just like arsenic, antimony reacts with sulfhydryl groups, has toxic properties, can cause immunodeficiency (Biological function of Sb in human organism (in Russian), 2019) and causes functional disorders in various organs (heart, kidneys, central nervous system, liver, lungs, intestines, lymphatic system, etc.) (Chonbasheva, 2014; Turbinsky, Bortnikova, 2018). Barium, belonging to the group of microelements, has a very low percentage of absorption in the gastrointestinal tract, and it is very rapidly excreted from the body (Lusikov, 2009). Nevertheless, all soluble barium compounds are highly toxic and lead to fatal acute poisoning of the body.

These elements actively accumulate in the barrier organs and tissues of the mammals in all studied territories. In samples taken in the Pavlodar region, the digestive tract, as a powerful barrier organ of living organisms contains high concentrations of all selected elements, but only As in the Tomsk region. In the deposit media, namely, in bone tissue, the selected elements are especially intensively accumulated in samples from the Zabaikalsky Krai, and samples from the Gazimur plant Cr show the maximum concentration coefficient, Zn is also actively accumulated in these samples. Ba, Sb accumulate in the bone tissue selected in the village of Taina. In the bone marrow, Sb accumulates only in the animal from the Urovsky Kluchi, while Cr accumulates in all samples of the brain. It should be noted that, in addition to bone tissue, some of the selected elements can even accumulate in the central nervous system, as Ba concentration was previously noted in the brain of an animal from the village of Kizhirovo. Elements such as Sb, Cr, Ba have a high coefficient of biological absorption, which is demonstrated by comparing the dehydrated organ and biological water obtained from the animal from Ekibastuz.

Potential toxic effects in the framework of USEtox 2.02 and their corresponding guidelines, were calculated using the results of our studies, using the calculation procedure described in Chapter 4.2.1. For these elements, we considered exceptional non-carcinogenic toxic effects due to incomplete data on the carcinogenicity of the elements. Initial data for the calculation of toxicity and registration numbers in the model are given below (tables 27, 28).

Table 27. The registration number of the element and the source data for calculating the exposure factor, the concentration coefficient relative to the noosphere Clarke concnetration kg_{intake}/day per $kg_{in\ compartment}$

C/e	The clarke concentration by Glazovsky	C_{Cr}					CAS number of element in the USEtox model
		1	2	3	4	5	
Cr	0,00007	5,75	46,75	62,24	49,97	2,73	18540-29-9
Zn	0,002	359,20	1201,73	1008,18	1063,60	535,07	23713-49-7
As	0,000006	1,08	1,41	2,67	1,33	1,00	22541-54-4
Sb	0,0000002	0,13	0,43	0,32	0,54	0,02	22537-51-5
Ba	0,0009	10,77	65,94	65,97	38,30	12,62	22541-12-4

Note: 1 - Russia, Tomsk region, Kizhirovo, Verkhnee Sechenovo villages; 2 - Kazakhstan, Pavlodar oblast, Ekibastuz city; 3 - Russia, Zabaikalsky Krai, Taina, Kalga, Zabaikalsky Krai, Urovsky Kluchi villages; 4 - Russia, Tuva Republic, Hovu-Aksy village; 5 - Kazakhstan, Eastern Kazakhstan region, Putintsevo village

Table 28. Initial data for calculating the exposure factor [kg_{intake} /day per $kg_{in\ compartment}$], tabular values proposed for calculation in the model

Studied region	Population	Meat consumption [kg/person]	Pi [kg/m3]		Vi [m3]	
			Air	Soil	Air	Soil
Russia, Tomsk region, Kizhirov, Verkhnee Sechenovo villages	1074453	0,1	1,3	1500	3E+14	3E+10
Kazakhstan, Pavlodar oblast, Ekibastuz city	749516				1E+14	1E+10
Russia, Zabaikalsky Krai, Taina, Kalga, Zabaikalsky Krai, Urovsky Kluchi villages	1065969				1E+14	1E+10
Russia, Tuva Republic, Hovu-Aksy village	171928				2E+14	2E+10
Kazakhstan, Eastern Kazakhstan region, Putintsevo village	1394000				3E+15	3E+10

A comparative analysis of the exposure factor for each studied region is presented graphically in the form of charts.

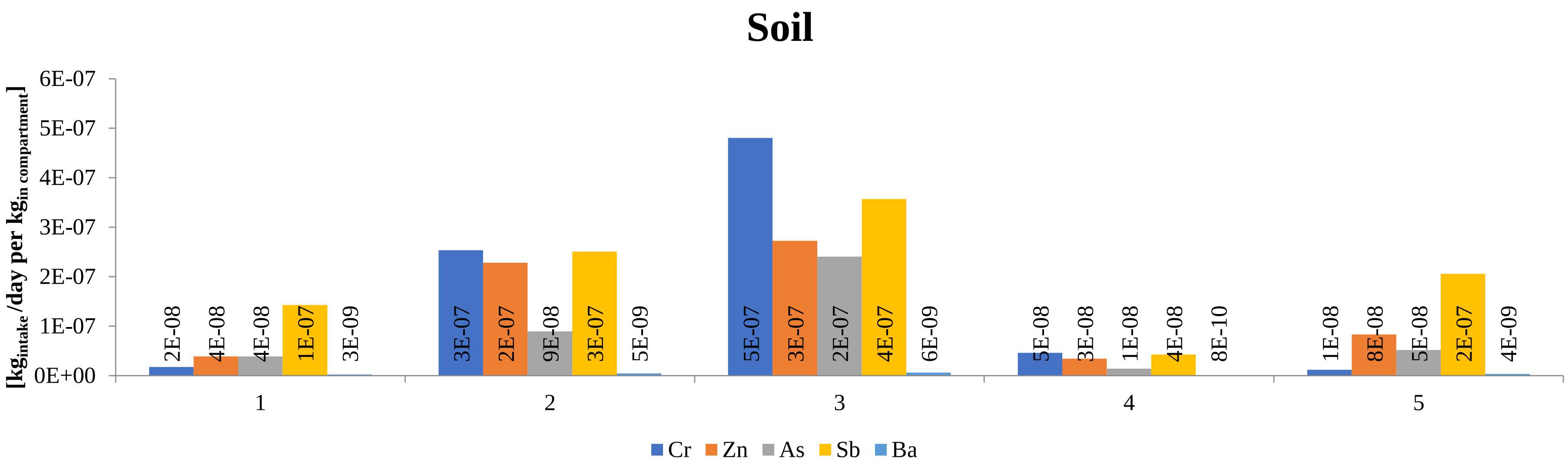


Figure 89. Exposure factor calculated for Cr, Zn, As, Sb, Ba for the surveyed areas, exposure through soil, [kg$_{intake}$ /day per kg$_{in\ compartment}$]

Note 1 - Kizhirovo village, Verkhnee Sechenovo, Tomsk Region, Russia; 2 – Ekibastuz city, Pavlodar region, Kazakhstan; 3 - villages Taina, Urovsky Kluchi, Gazimursky Zavod, Zabaikalsky Krai, Russia; 4 - village Hovu-Aksy, Republic of Tuva, Russia; 5 - village Putintsevo, East Kazakhstan Region, Kazakhstan

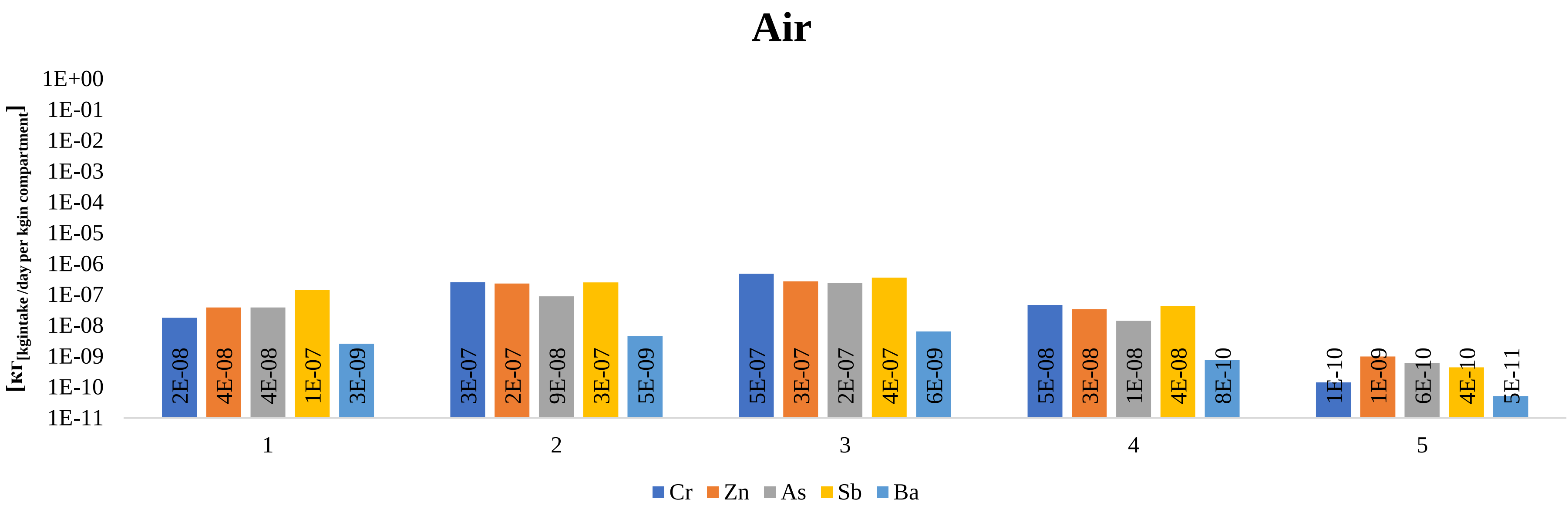


Figure 90. Exposure factor calculated for Cr, Zn, As, Sb, Ba for the surveyed areas, exposure through air, kg_{intake} /day per $kg_{in\ compartment}$, Lg scale

Note 1 - Kizhirovo village, Verkhnee Sechenovo, Tomsk Region, Russia; 2 – Ekibastuz city, Pavlodar region, Kazakhstan; 3 - villages Taina, Urovsky Kluchi, Gazimursky Zavod, Zabaikalsky Krai, Russia; 4 - village Hovu-Aksy, Republic of Tuva, Russia; 5 - village Putintsevo, East Kazakhstan Region, Kazakhstan

The villages of the Trans-Baikal Territory and the city of Ekibastuz of the Pavlodar Region are the territories with the highest effective consumption, regardless of the route of entry or the type of element being studied. The smallest exposure factor calculated during normalization to air is noted for the village of Putintsevo, East Kazakhstan region, and, for soil, for the village of Hovu-Aksy of the Republic of Tyva. The village of Putintsevo, East Kazakhstan Region, shows the greatest difference between the consumption of elements with soil and air.

It can be noted that in general, the introduction of elements into the body during normalization to the soil is much higher than during normalization to air. Upon receipt from the soil, chromium, and antimony stand out among the studied elements according to the highest exposure factors for all settlements, except in Putnitsevo village of the East Kazakhstan region, where zinc is in second place.

Calculating the factor with normalization to air gives antimony the leading position for all regions, followed by chromium, zinc, arsenic, and barium, also with the exception for the population of the village of Putintsevo, East Kazakhstan region. The highest exposure factor in this region is calculated for zinc, then arsenic, antimony, chromium, and barium. Barium has the lowest exposure factor of all the elements studied.

The tendency described above seems logical and reflects the bioavailability of elements and regional features of the studied areas. High exposure factors for Sb, Zn, As in meat selected in the village of Putintsevo, which is located in the vicinity of the Maleevsky mine, the elements of which are antimony, zinc, and arsenic. The same trend is reflected during normalization to air and soil. Similar trends in the intake of elements for the studied zones probably reflects the chemistry of elements and the activity of their entry into the body.

Comparing the results of calculating the exposure factor with the data on meat consumption by residents of different regions of Russia (Figure 91), it can be noted that there is no direct relationship between the consumption of meat products and the value of the exposure factor. From this, we can conclude that the main influence on the entry of elements into the human body is not the amount of meat consumed, but its elemental composition.

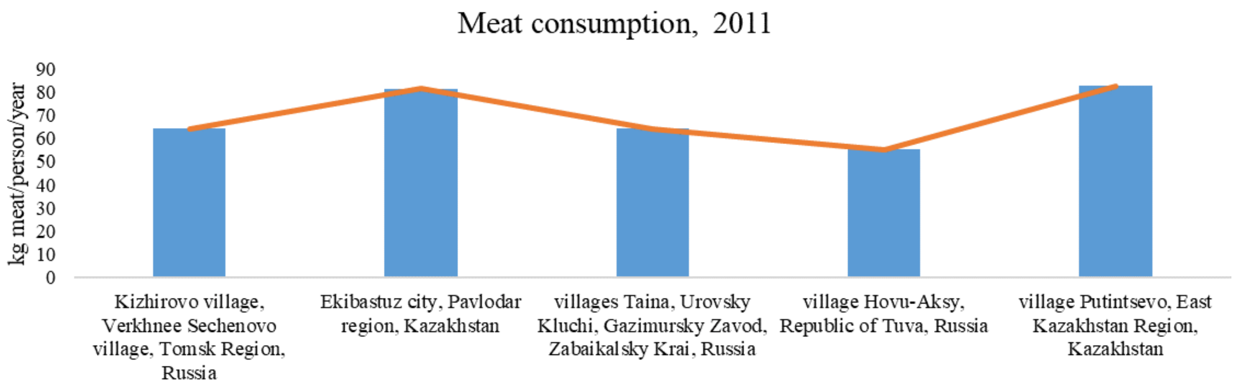


Figure 91. Meat consumption by residents of the studied regions in 2011 according to Federal Service of State Statistics

The modified exposure factor was extrapolated to the calculations of the characteristic toxic coefficient of toxic effects (CF), and comparative charts have been constructed based on its results (Figures 92, 93).

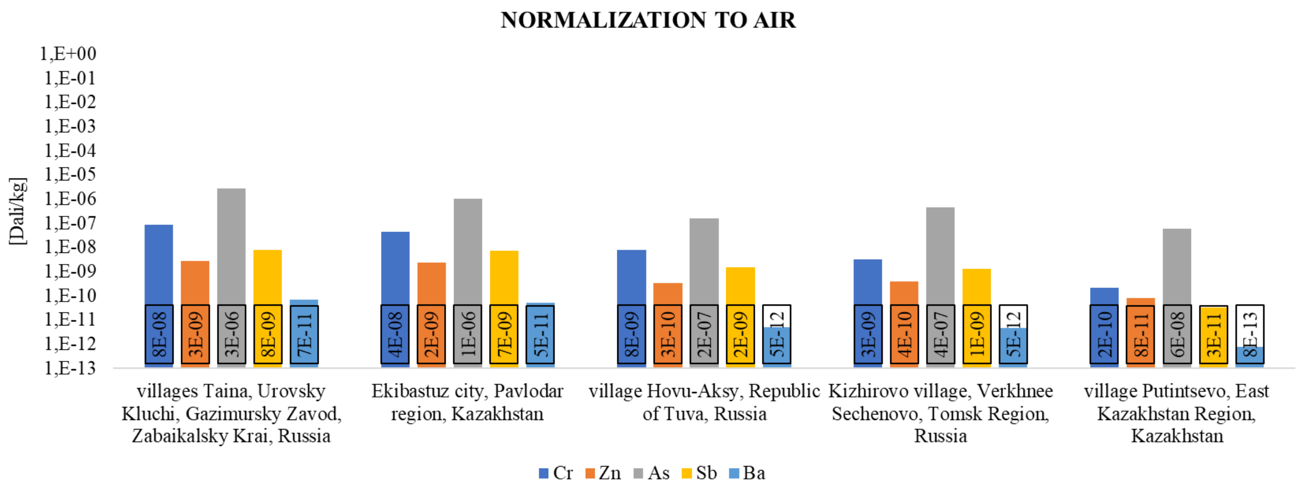


Figure 92. The characteristic coefficient calculated for Cr, Zn, As, Sb, Ba for the studied territories, normalization to air, Dali/kg, Lg scale

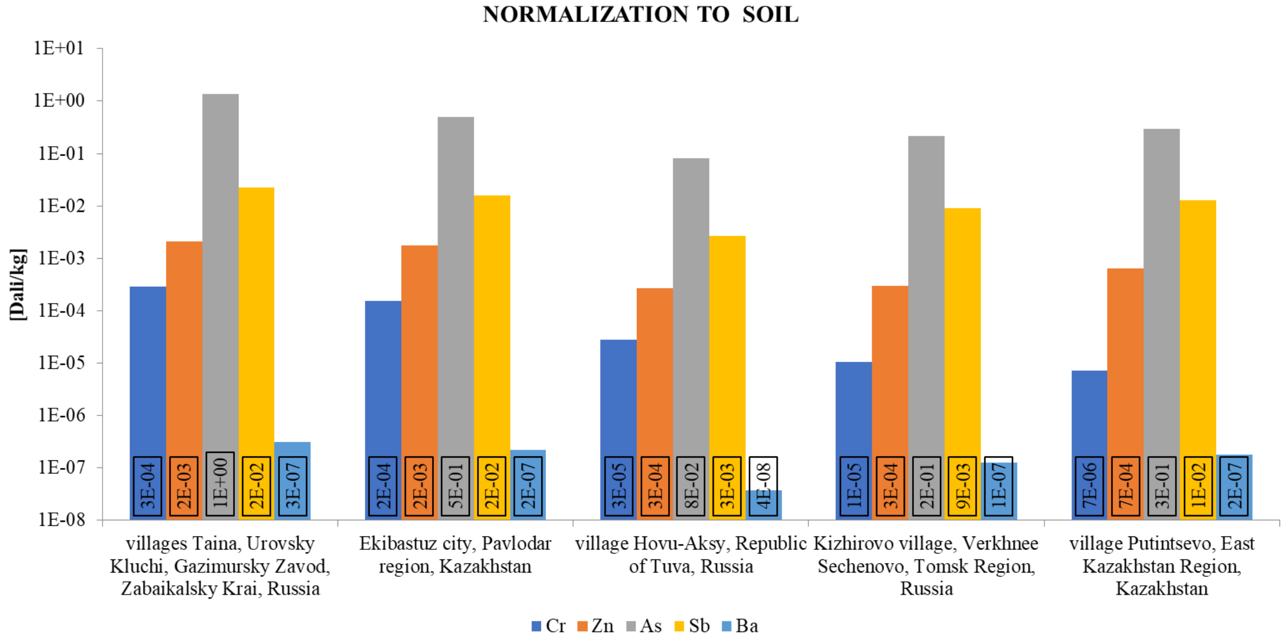


Figure 93. The characteristic coefficient calculated for Cr, Zn, As, Sb, Ba for the studied territories, normalization to the soil, Dali/kg, Lg scale

The characteristic toxicity coefficient calculated using the modified exposure coefficient reflects the potential hazard of substances to public health, considering the environmental characteristics of each region. According to the calculations, most of the elements have the highest levels of toxicity in the villages of the Zabaikalsky Krai, both via normalization to air and soil. It can be noted that, except for chromium, the minimum toxicity coefficient for human health of the selected elements is found among residents of the village of Hovu-Aksy of the Republic of Tuva.

For most elements, the ranking of the toxicity index for entry from the territory through the soil is as follows: Zabailkasky Krai> Palodar Region> East Kazakhstan Region> Tomsk Region> Tyva. For chromium, the sequence changes, the Republic of Tuva takes the third place in terms of danger for absorption, and the East Kazakhstan region last.

The risks to human health calculated with the normalization for air have a different order. In last place in terms of all the characteristic coefficients is the village of Putintsevo, East Kazakhstan region. In third place, in terms of the characteristic coefficients for zinc and arsenic, are the villages of Kizhirovo and Verkhnyaya Sechenovo of the Tomsk Region, and for chromium, antimony, and barium, the village of Hovu-Aksy of the Republic of Tyva. The main contribution to the characteristic coefficients for the studied regions is made by arsenic, and barium has a minimal effect. For all the studied territories, except the village of Putnitsevo of the East Kazakhstan region, the elements in terms of toxicity are arranged as follows: As> Cr> Sb> Zn> Ba. For the East Kazakhstan region, Zn takes third place in toxicity, and Ba takes the fourth place.

Thus, the results of assessing the toxicity of elements in different studied territories are consistent with studies conducted earlier, and show the potential toxicity of elements not only depends on the concentration of elements in biomaterials, but also the size of the territory and population density.

CONCLUSIONS

The studies conducted allowed us to draw the following conclusions:

1. In the conditions of the local territories of Russia and Kazakhstan, various specific chemical elements arise, and their correlations change, which can be used as indicators of the geoecological situation in the region. The organism of domestic pigs, selected in the city of Ekibastuz, Pavlodar region, is characterized by the concentration of such elements as Na, Zn, Rb, Ag, Sm, Lu, with their predominant accumulation in the organs of the digestive and musculoskeletal system. Tomsk region is characterized by a concentration of respiratory organs and the circulatory system.

2. Regardless of the region, stable correlation bonds of elements with chromium are formed in the mammalian organism. Technological environmental conditions form various associations of this element, for the city of Ekibastuz, Pavlodar region of the Republic of Kazakhstan and the settlements of the Tomsk region of Russia - positive, for the settlements of the Zabaikalsky Krai - negative.

3. Under conditions of increased anthropogenic impact, the work of barrier organs is disrupted. The accumulation of chemical elements in the brain, placental tissue and mammalian embryos begins.

4. The modified reporting toxicity coefficient allows ranking the local territories of Russia and Kazakhstan by the degree of toxicity of individual elements for human health. In general, this indicator is characteristic for the settlement of the Zabaikalsky Krai, as the zone of the most intense load for humans.

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