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Theoretical and Methodological Approaches to the Analysis of the Spatial Distribution of Endemic Diseases of Geochemical Nature

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Abstract—Throughout millions of years of geological history (in the Phanerozoic), the coevolution of all living organisms took place in a fierce competition for resources and opportunities for the maximum reproduction. Due to the geochemical heterogeneity of the primary (pre-Quaternary) biosphere, this resulted in a self-regulating system of ecological niches, within which all local biocenoses and their animal and plant species were maximally adapted to the parameters of the habitat. However, with the emergence of reason, the situation changed fundamentally. Human beings became the dominant species and began the conscious development of new territories, including geochemically unfavorable ones, which led to the formation of zones of stable endemic diseases. Based on this premise, for all existing species, there should be areas with physiologically optimal habitat conditions, i.e., those under which the species has evolved to its present state. It follows that, by being able to record the geochemical parameters of the undisturbed biosphere, it is possible to obtain characteristics that are ecologically ideal for local animal and plant species. In theoretical terms, this allowed us to put forward the hypothesis that by fixing the difference between observed and ideal geochemical conditions, it is possible to build maps of risk of diseases of geochemical nature, including in areas subjected to anthropogenic pollution. The paper outlines the methodology and gives examples of construction of such maps. The obtained results can have an important practical value in organizing the system of sanitary–epidemiological service, in solving the problems of liquidation of the consequences of anthropogenic pollution, and in carrying out preventive measures to minimize the risk of diseases of geochemical nature.

Keywords: biogeochemistry, geochemical ecology, ecological and geochemical research, endemic diseases, human health

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INTRODUCTION

According to the basic tenets of biogeochemistry, the chemical structure of the biosphere at each stage of development is the result of evolutionary interaction between living organisms and their geochemical environment. In this case, man, as well as any species formed in the biosphere, according to the figurative expression of V.I. Vernadsky, cannot be free from the environment for a second. Based on the ideas of M.V. Lomonosov (Vernadsky, 1901, 1911), Vernadsky's teacher V.V. Dokuchaev (1899), and other scientists, Vernadsky outlined ways to study the chemical structure of the biosphere through quantitative assessment of the interaction of organisms with the environment through the exchange of chemical elements. He wrote that "... approaching geochemically and biogeochemically to the study of geological phenomena, we cover the nature surrounding us in the same atomic aspect. This distinguishes the 20th century from past centuries" (Vernadsky, 1980). This approach in studying material exchange between living and inert matter makes it possible to explore the peculiarities of biogenic migration in space and time at the level of individual chemical elements and compounds, on which the quality of life and the lifetime of any organism, population, and/or biocenosis depends. Because of this, practically all and any ecological and geochemical problem can have an appropriate solution only on the basis of the theory and methodology of biogeochemistry.

THEORETICAL APPROACHES AND THEIR ANALYSIS

On the History of Ecological Research in Biogeochemistry

The theoretical basis was laid by Vernadsky in his fundamental monograph *The Biosphere* (Vernadsky, 1926). Considering living matter as the totality of all

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living organisms allowed Vernadsky to study the phenomenon of life in the planetary aspect. According to Vernadsky, the fundamental problem of biogeochemistry is the knowledge of regularities that govern chemical interactions between living organisms and their habitats, and the main goal is to identify the quantitative parameters of the impact of living organisms on dispersion and concentration processes of the elements in the biosphere.

The targeted experimental study of the geochemical role of living matter was launched under Vernadsky's supervision in 1918 and continued at the Department of Living Matter (DLM), which he had organized at the Commission for Studying Natural Productive Forces in 1926, and then at the Biogeochemical Laboratory, which replaced the DLM in 1928. Before World War II, the staff of the laboratory studied the concentrations of I, Br, F, Ca, P, Sr, Ni, Co, Mo, and Pb in various living organisms and other components of the biosphere, with soil considered to be an inert material, a source of chemical elements, and a product of interactions between living matter and its habitat.

The biological approach per se in biogeochemical studies of the spatial structure of the biosphere was first clearly formulated by Vernadsky's disciple, colleague, and follower A.P. Vinogradov and applied to biogeochemical provinces related to biogeochemical endemies, diseases caused by a deficiency or excess of some elements in the soil, water, and/or air (Vinogradov, 1938).

These works were later continued under the supervision of V.V. Kovalsky, who had been invited by A.P. Vinogradov to the Vernadsky Institute of Geochemistry and Analytical Chemistry, Soviet Academy of Sciences, in 1954. At the junction of biogeochemistry and ecology, Kovalsky created a new science, geochemical ecology, among the problems of which the cognition of regularities in the geochemical heterogeneity of the biosphere, which is considered the environment of life, can be distinguished. When solving this problem, he paid attention to the different needs of living organisms for chemical elements and has determined for the territory of the Soviet Union the intervals of the content of some elements in soils and fodder physiologically necessary for animals. (Kovalsky, 1974; Kovalsky and Andrianova, 1970; Kovalsky et al., 1971). These values define the ranges within which the examined farm animals were able to maintain their homeostasis. Outside these ranges (at higher or lower values), the regulatory capabilities of the organisms were disturbed, and this inevitably resulted in pathological changes, which were interpreted as reactions of organisms to an excess or deficiency in biologically significant elements. Thereby, it was shown that obvious disturbances of regulatory mechanisms are often observed in only 5–20% of individuals in the studied populations. Kovalsky also elaborated the general principles of ecological and geochemical mapping, on the basis of which he created the first version of the map of biogeochemical zoning of the Soviet Union, taking into account the negative biological reactions identified in the studied plants, animals, and Human beings. This map has been revised several times based on newly acquired data, but has never been updated since 1984 when its author passed away. At the same time, medical–geographic maps of the Soviet Union and, then, of Russia constructed by other authors mostly displayed only how widespread infectious diseases are distributed over some territories, whereas the ecological and geochemical maps were designated for assessment of technogenic pollution levels against the global or regional geochemical background and the sanitary–hygienic standards or deviations from standards in concentrations of selected elements and compounds in tissues and fluids of organisms (e.g., Saet et al., 1990; Kist et al., 1998; Malkhazova, 2001; Gorbachev et al., 2007; Ermakov et al., 2018; Evstafeva et al., 2019; Rikhvanov et al., 2021). Among foreign publications, the most comprehensive geochemical cartographic documents are an atlas of the distribution of endemic diseases (Kashin–Beck, hypothyroidism, and fluorosis) in China; an ecological and geochemical atlas of China, which presented maps of concentrations of chemical elements in waters, bottom sediments, and, selectively, in soils (Xiang, 1989; Li and Wu, 1999); and soil–geochemical maps of Europe, Italy, Spain, Great Britain, Brazil, etc., which usually showed ecologically significant geochemical anomalies of natural and/or anthropogenic genesis (Davies et al., 2005; Thornton and Webb, 1979; Dissanayake and Chandrajith, 2009; Thornton, 2010; da Silva et al., 2010; Reimann and Caritat, 2012; Watts et al., 2020; Bineshpour et al., 2021).

On the Origin of Biogeochemical Endemies

Human and animal diseases induced by living in geochemically unfavorable environments have been known since ancient times (endemic goiter, caries, fluorosis, scurvy, etc.), but their origin was scientifically explained and means for their treatment were developed relatively recently in the course of progress in medical diagnosis and mass chemical analysis. Zones with these diseases have covered millions of square kilometers, and these diseases have killed millions of persons around the world. The direct cause was, in this case, that the local geochemical conditions did not meet the physiological needs of the organisms, and the causes of this inconsistency are, thus, a very important scientific problem.

Having posed this problem, it should be pointed out that all endemic diseases have been found in human beings and in animals and plants introduced by human beings, whereas no native species of soil microorganisms, plants, and animals suffered from these diseases in experiments.

Proceeding from Vernadsky's theoretical principles that not only a habitat controls the composition of living matter in it but also the living matter itself profoundly modifies the geochemistry composition of its habitat, Vinogradov distinguished paleobiogeochemical provinces that were formed in the course of long-lasting geological processes, such as orogenesis, sea transgressions and regressions, volcanism, etc. He underlined that "... the chemical elementary composition, as thousands of analyses show us, is not a simple reflection, a repetition of the chemical composition of the environment, but is formed in the course of long development, by interaction of organisms simultaneously with all factors of evolution," and the main reason of the adaptation of living organisms to chemical features of the habitat is natural selection (Vinogradov, 1944, 1960). Hence, for each biological species, there are ideal parameters for the content of chemical elements it consumes from the habitat.

Comparison of all of these data with theoretical statements of biogeochemistry, made it possible to formulate the logically consistent hypothesis that stable endemic diseases of geochemical nature became possible only after the formation of *homo sapiens*, which is capable of surviving and providing the survival of domesticated and cultivated species under geochemical conditions significantly different from those under which these species had been formed; namely, at the noospheric stage of the evolution of the biosphere. In other words, no endemies stable in space and time could occur before the anthropogenic stage. Hence, any biogeochemical endemy is a product of anthropogenesis and is a direct consequence of the evolution of human civilization. Further work provided decisive arguments in support of this hypothesis. This is confirmed not only by the fact that no mass poisoning of wild animals are known, but also by the conclusion drawn by A.P. Buzhilova, who studied causes of death of ancient human beings and stated that "data on ancient hominids indicate that the level of physiological markers in the Pleistocene was at a minimum and approached a random distribution of the values" (Buzhilova, 2001). Similar evidence has also been recovered by D.G. Rokhlin and other researchers, who analyzed numerous bone relics of Paleolithic age and failed to find a single reliable piece of evidence of any endemic diseases (Osborn, 1910; Rokhlin, 1965).

Self-Organization of the Biosphere in the Pre-Anthropogenic Period of Time

The modern biosphere has been formed over billions of years, and at each stage has been a perfectly balanced self-regulating system characterized by the maximum possible biomass and maximum competition between organisms for resources and with the species with maximum competitive advantage with respect to maximum geochemical energy.

Vernadsky and Vinogradov have demonstrated, on the one hand, the leading role of organisms (living matter) in the formation of the biosphere and, on the other hand, the heterogeneity of its geochemical structure and the correspondence between geochemical parameters of the environment and the species of separate groups of organisms living in these conditions. As a result, in the primary biosphere, each of the existing species not only occupied an ecological niche ideally corresponding to it, but was also constantly in optimum ecological and geochemical conditions meeting its physiological requirements and stable reproduction. In an environment of steadily accelerating evolution and the progressive development of the nervous activity ("cephalization," according to Dana, 1864), the slightest weakening of a species meant its rapid death, while the slightest advantage, for example, the emergence of a Ni-containing enzyme capable of increasing nervous conduction, dramatically increased the chances for survival, often realized by one in thousands, sometimes millions, of individuals.

Indeed, it has been experimentally found that populations of the same species are obviously differentiated in terms of growth ability at different concentration levels of certain chemical elements in the environment (for example, in microbial strains extracted from soils from different biogeochemical provinces) (Letunova and Kovalsky, 1978; Letunova et al., 1986). Moreover, it has been experimentally demonstrated that, under extreme conditions, populations are able to rapidly form inheritable morphs that are able to normally live under conditions lethal for other individuals of the same species (Prat, 1934; Bradshaw, 1971, 1984). The time parameters needed for emergence of responses to rapid extremal conditions have also been analyzed. Initially, only 3 per 1000 seeds of *Agrostis tenuis* placed into a substrate with extremely high Pb concentration survived, but this number of seeds turned out to be sufficient to form a new stable morph (Bradshaw, 1952). It has, thus, been demonstrated that experience gained during the previous stages of evolution of a species is irretrievably lost, but it can be promptly implemented by means of activating defense mechanisms "written" in the genome, and this makes it possible to level off even obviously extremely severe geochemical impacts within one to three generations. This provides evidence of an inheritable mechanism for maintaining the survival of a species even under dramatic changes of geochemical conditions in the environment.

The organized character of ecological and geochemical niches caused by the evolutionary development of interactions between the organisms and the environment was vividly described by the famous biologist and ecologist Barry Commoner: "Everything in nature, from simple molecules to man, has undergone the fiercest competition for the right to exist. At present the planet is inhabited by only 1/1000 of the evolutionary proven plant and animal species." "The primary criterion for evolutionary selection is fit into the global biotic cycle and the filling of all ecological niches. Any substance produced by organisms must have a decomposing enzyme, and all decomposition products must be reintroduced into the biotic cycle (Commoner, 1971). The main planetary factor determining the specificity of natural biogeochemical processes on the Earth is climate. **Thus, it is reasonable to assume that the optimal geochemical environment for any of the existing species of animals and plants is only the one in which the particular species has been formed in its present quality in accordance to the existing structure of the natural zones.**

The aforesaid provides grounds to hypothesize that, if parameters of the undisturbed biosphere could have been fixed, it would be possible to obtain characteristics close to those ecologically and chemically ideal for most zonal species of plants and animals historically inhabiting this territory.

In the theoretical aspect, the validation of this hypothesis means the principal solution of the problem of the physiologically optimal geochemical background for all species of living organisms, human beings inclusive. Inasmuch as the earliest *homo sapiens* were rigidly incorporated into an ecological niche ideally corresponding to their needs, any diseases induced by a deficiency or excess in any chemical element (or elements) could not significantly show themselves at the population level, although the probability of some individual cases cannot be excluded.

Evolutionary Stages of Endemic Diseases in the Noosphere

The amount of individual competitive advantages accumulated in the course of evolution should have been inevitably transformed into a new quality, and this brought about the species *homo sapiens*, which has extremely quickly (compared to natural evolutionary processes) acquired the ability not only to uncontrollably increase the population but also, eventually, to consciously and purposefully modify the habitat. Evidently, such transformations induced by a single species rapidly brought about disturbances in the preexisting mechanisms of the self-regulation and self-organization of most of the systems of the primary biosphere. As a result, a qualitatively new system was instantaneously, geologically speaking, formed. This system was named the “noosphere” by Vernadsky, a term coined by Pierre Teilhard de Chardin and Édouard Louis Emmanuel Julien Le Roy under the influence of Vernadsky’s geochemical concept of the biosphere, which Vernadsky had presented in his lectures at the Sorbonne in the early 1920s. The principal distinguishing features of the modern noosphere are (1) notable transformations in self-regulation mechanisms and (2) that any significant change entails a deterioration of the ecological conditions. The growth of the human population and its competing for resources gave an impetus to the migration of peoples and spread of human beings over the then-reachable parts of continents. An inevitable consequence of this was the situation in which the modern world faces serious ecological–geochemical problems.

Humanity paid a price to become the “master” of the planet: several endemic diseases of geochemical nature have emerged. First, these were diseases of natural origin, such as scurvy, goiter, and/or Kashin–Beck (Urov) disease. D.G. Rokhlin (1965) wrote about the latter disease that “... the ancient nature and distribution of the latter provokes keen interest. Evidence of these diseases was found in 14 of 87 skeletons found in the course of archeological excavations. This systemic disease was found in the remnants of people that liven in the Bronze Age and in the 8–10th centuries. The colonization of new territories and the consciously adopted sedentary life style under unaccustomed geochemical conditions provoked persistent biogeochemical endemies of type I, which are characterized (1) by a natural origin and (2) by that fact that they impact only human beings and plant and animal species introduced by human beings.

The true causes of these diseases were not been elucidated until the 20th century, and this enabled searches for simple and efficient (geochemical) means of treatment. For example, it has been found out that scurvy results from a deficit in vitamin C, widespread goiter is prevented by iodine-bearing medicines, etc. Thus, the whole classes of diseases can be eliminated by corrections of misbalances between conditions in the habitats and the requirements of the physiological optimum.

Following the above logics, it is reasonable to hypothesize that, would have an endemic (spatially deterministic) character of some other human diseases, such as asthma, diabetes, and/or cancer (e.g., Romanov et al., 2022) been proved, then approaches to their prevention would also be based on the identification of inconsistencies between the composition of the food ingested by the local human populations and the biological parameters of the physiological optimum, which is determined for at least some of the sex and age groups of the population.

During the current evolutionary stage of human society, the ecological state can be significantly changed by industrial contaminations, which have been proved to be the causes of some previously unknown endemic diseases. The latter mark the beginning of a new, qualitatively different evolutionary stage of such diseases. Anthropogenic (industrial) contaminations manifest themselves as a relatively thin specifically organized layer of elements and compounds overprinted on the originally heterogeneous natural background. Given the fact that contaminations of this type spread from spot (or more rarely, linear) sources and always result in monocentric anomalies, it is logical to suggest that the overall situation

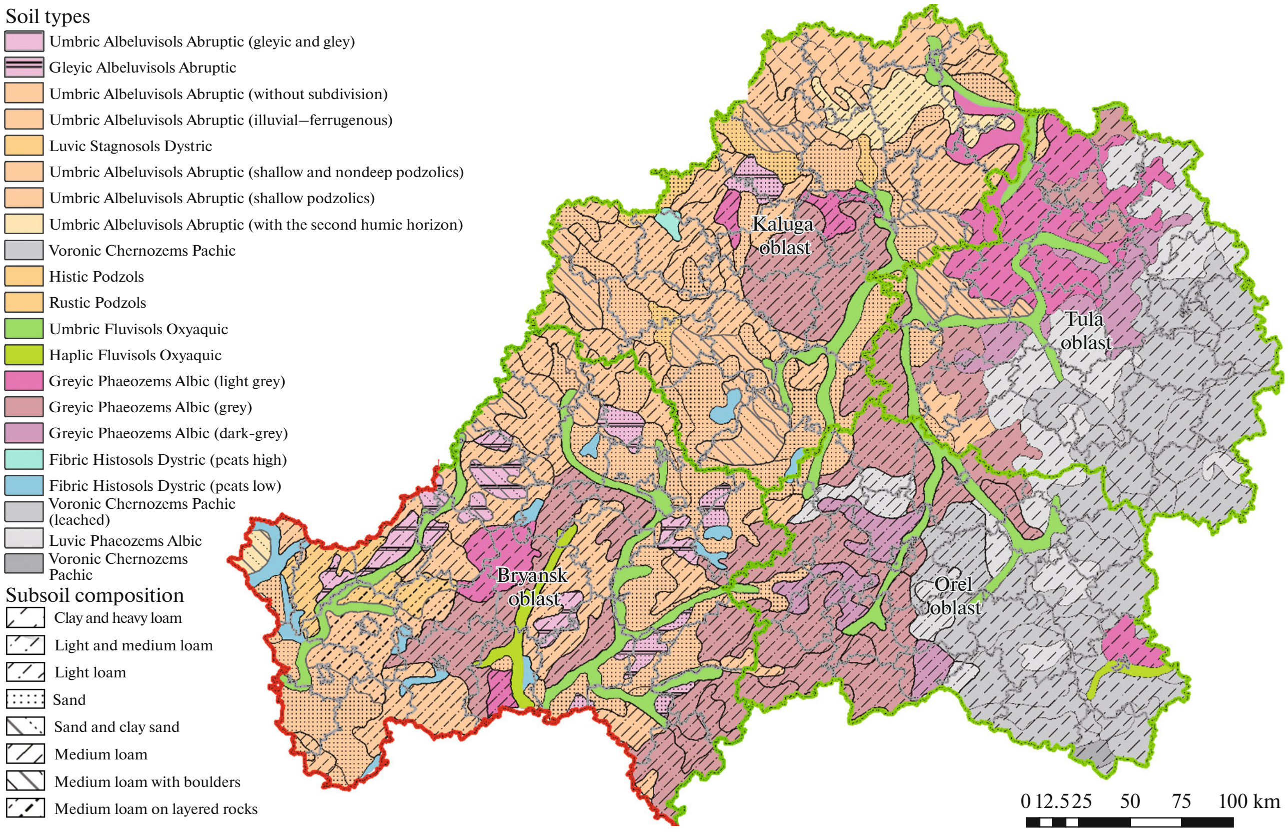

Fig. 1. Numerical soil map of the four administrative regions in the Russian Federation most significantly contaminated with radionuclides as a result of the accident at the Chernobyl Nuclear Power Plant.

produced by the interference of natural and anthropogenic fields can be reproduced in the form of maps and analyzed in much detail.

A METHODOLOGICAL APPROACH TO SPATIAL PATTERNS IN THE DISTRIBUTION OF ENDEMIC DISEASES

This problem is easy to formulate, but difficult to solve. Its solution should be based on, first, the knowledge of the optimal geochemical parameters for each of the biological species and, second, on as much as possible accurate and precise data on the ecological–geochemical features of the territory in question. Therewith, the problem of finding an optimum can be resolved in two ways: (i) by studying the geochemical environments in territories from the species of interest originate and (ii) by finding an extreme point on the so-called "Kovalsky curve" with reference to the same species or biocenoses as a whole.

The aforementioned facts and considerations make it possible to formulate in general terms a methodological approach for solving the problem of endemic diseases of geochemical nature. In contrast to the absolute majority of attempts undertaken by both national and foreign researchers, here we mean a deductive (i.e., proceeding from the general to specific) method of solution. This approach involves, first, the separate mapping of the geochemical background (separately the natural and industrially modified ones), after which a complex synthetic map is created to display the integral effect of both studied factors. It is important that this approach theoretically enables obtaining a general solution for the problem of biogeochemical zoning of the modern noosphere and can be implemented within the framework of a certain methodical procedure that enables one to quantitatively characterize the direction, tempo, and sometimes even the results not only of the past but also of the potentially possible ecological–geochemical transformations (Korobova, 2019).

The proposed approach has been tested by creating maps for the risk of thyroid gland diseases in the Russian part of the zone impacted by the accident at the Chernobyl Nuclear Power Plant in 1986. It was assumed that the growth by many times in the incidence rate of thyroid carcinoma (TC) was triggered by a combination of the "iodine impact" and natural iodine deficit. The risk map showing the level of the integral effect of these two factors should have outlined territories with both the maximum and the minimum incidence rates.

Our work aimed at elucidating the genesis and evolution of the physicochemical parameters of the modern soil covering unambiguously indicates that the geochemical characteristics of most of the undisturbed soil aureoles can serve as an uniform marker of ecological–geochemical conditions that are optimal for local biogeocenoses. Thus, the most rational and fast means of solving the problem of natural background for them is to use currently available soil maps, which make it possible to reasonably accurately and in reasonably much detail study the structural organization of the noosphere at various levels. However, the problem is that both Human beings and most accompanying animal and plant species are introduced into most natural habitats, and these habitats are most commonly not optimal for the Human beings and these species.

Example of Constructing a Risk Map

The map was constructed using the QGIS program package. The natural geochemical background was assumed to be a 1 : 2500000 soil map of the territories of four administrative units: Bryansk, Orel, Kaluga, and Tula oblasts (Fig. 1) (Alyabina et al., 2014). With regard to the threshold iodine concentrations in the soils (determined by Kovalsky) and iodine availability for the soils of different type, the studied territory was subdivided into six grades according to iodine concentration, from 1 (maximum iodine concentrations in the soils and the minimum iodine deficiency) to 6 (minimum iodine concentrations in the soils and the maximum iodine deficiency) (Fig. 2).

The level of the iodine deficit for each rural population center was evaluated by the formula

$$I = \sum_{i=1}^{n} I_i A_i, \quad (1)$$

where I is the mean iodine concentration in the area, I_i is the iodine concentration in soil of type i with regard to the soil-forming rock, A_i is the fraction of the soil contour of the total surface area of the region, and n is the number of soil contours in the region.

The iodine-deficit map is shown in Fig. 2.

The intensity of the "iodine impact", i.e., the level of contamination of the study area with the radioisotope ^{131}I was calculated by the formula of (Zvonova et al., 2010) using data on the contamination density with ^{137}Cs. Based on these data, a digital map was constructed in the same projection, in which the study area of the four regions was also subdivided into six zones according to the levels of contamination with ^{131}I (Fig. 3).

Regression analysis of the contributions of natural and anthropogenic factors (natural iodine deficit and contamination with iodine radioisotopes) and the risk of thyroid carcinoma (TC) for the rural population of the four regions (by the district level) was carried out using the TIBCO STATISTICA 13 program package. Therewith, the weighted mean iodine availability for the soil covering and the weighted mean contamination with ^{131}I within 5 km from each of the 2.5 thousand settlements were calculated analogously to the approach in (Korobova and Kuvylin, 2004). The calculated results are presented in Table 1.

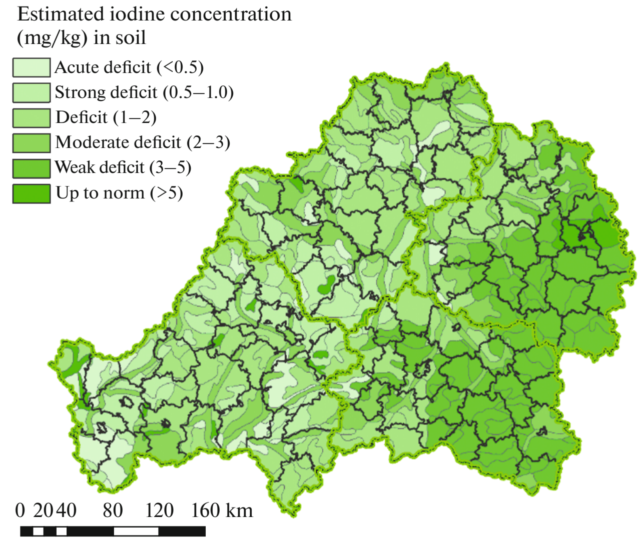

Fig. 2. Estimated iodine deficit levels in the four administrative regions of the Russian Federation.

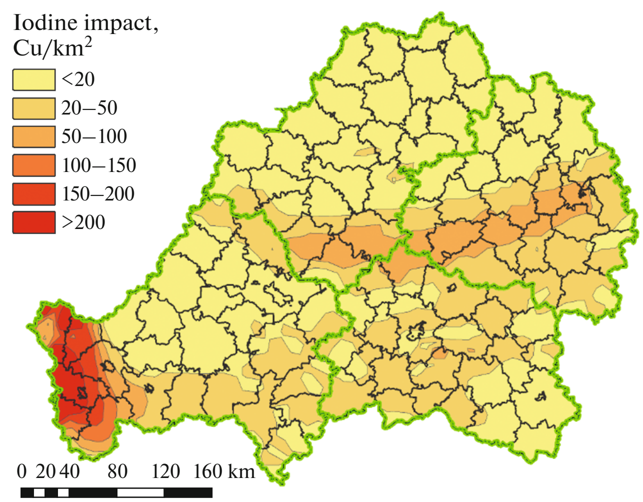

Fig. 3. Estimated iodine impact in the four administrative regions of the Russian Federation.

The parameters thus obtained led us to derive the following formula for evaluating the contributions of each factor to the integral natural–anthropogenic risk:

$$R = 0.72F + 0.28S, \quad (2)$$

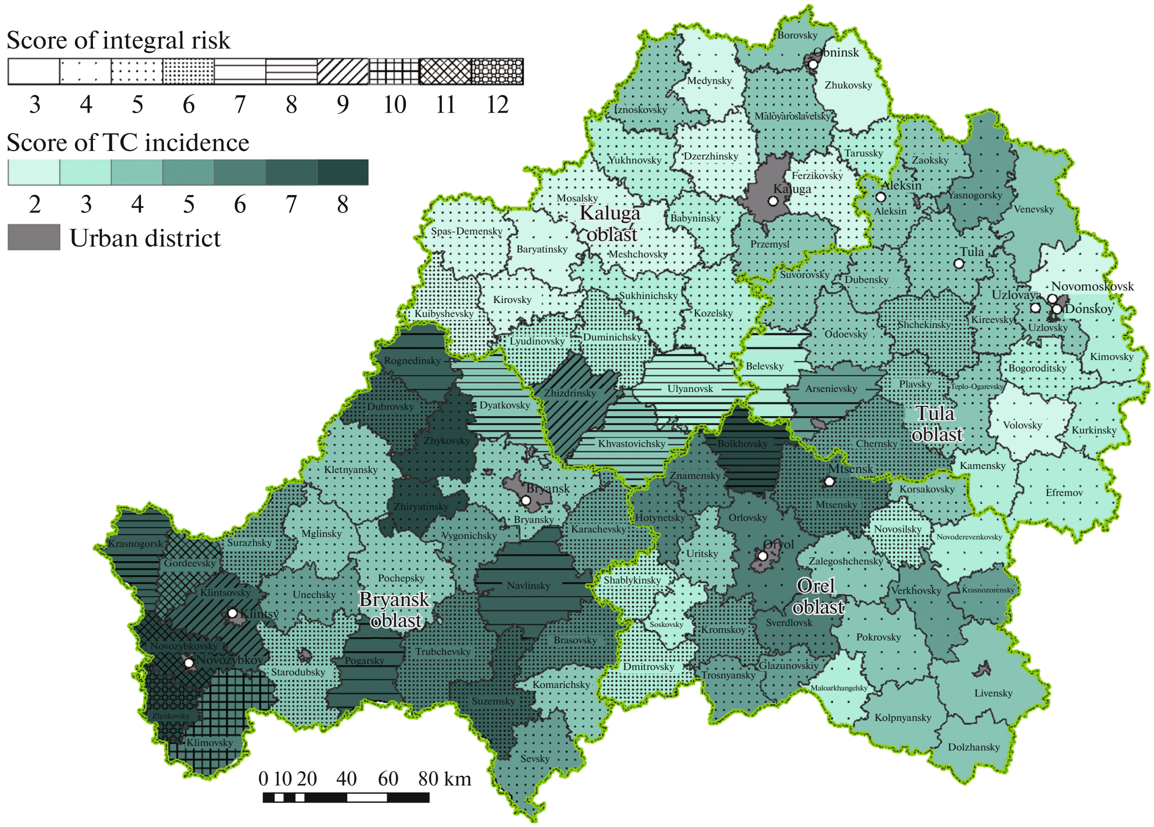

Fig. 4. Comparison of combinations of natural–anthropogenic risk and TC incidence in the administrative units of the four administrative regions of the Russian Federation.

where R is the integral risk, F is the intensity of "iodine impact" (ranked from 1 through 6), and S is the estimated natural iodine deficit (ranked from 1 through 6).

During the next stage, the estimated contributions of the geochemical factor were compared in maps with data on the TC incidence for the rural population of 95 administrative districts (Ivanov et al., 2005) (Fig. 4).

In spite of the significant variations of the standardized incidence rate between the administrative units attributed to the same risk class (which is inevitable because of the geochemical heterogeneity of the administrative units and the different contributions of local foodstuff to the daily rations), the integral risk coefficient (which was calculated with regard to both natural and anthropogenic factors) shows a tends to positively correlate with the actual TC incidence: $n = 93$ (Fig. 5).

The result is consistent with data previously obtained for the Bryansk region and demonstrate the principal possibility of combined cartographic analysis of geochemical and medical information at the level of administrative units. At the same time, our experience indicates that it is much more reasonable to compare geochemical and medical information at the level of population centers, because this makes it possible to avoid averaging errors when integrating the effects of small anomalies and, on the other hand, to more accurately account for the contributions of foodstuff and water to the rations of the local human population.

Table 1. Integral contributions of iodine deficit and fallouts of radioactive ^{131}I

Factor	β*	Standard deviation	p value
Anthropogenic contamination with ^{131}I	0.45	0.09	0.000003
Natural deficit in ^{127}I	0.19	0.09	0.03
Absolute term	–	–	0.12

* β is the coefficient B in the regression for the standardized variables, which makes it possible to evaluate the relative contributions of each of the independent variables to the prediction of the value of the dependent variable.

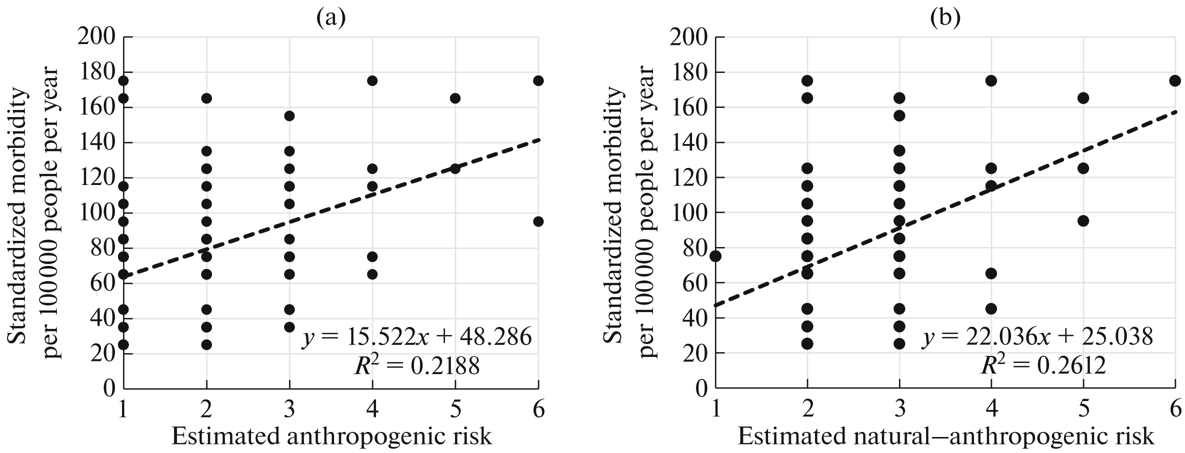

Fig. 5. Comparison of the estimated geochemical risk and actual TC incidence in the administrative units of the four administrative regions of the Russian Federation.

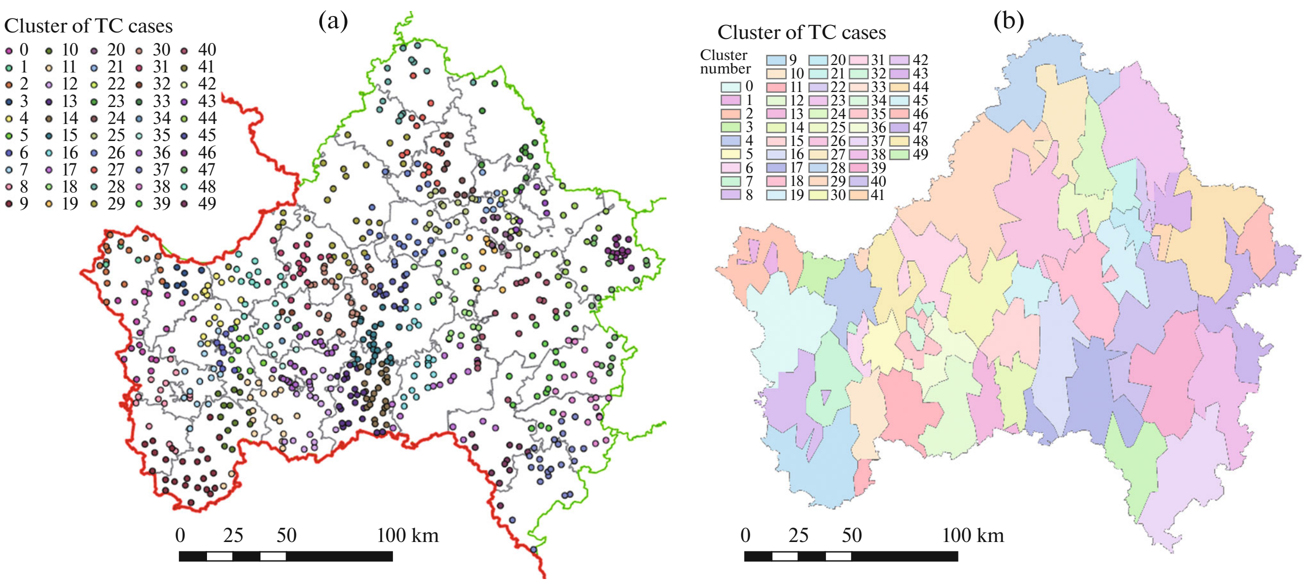

Fig. 6. Spatial clusterization of registered thyroid carcinoma (TC) by the administrative units of the four administrative regions of the Russian Federation.

During the next stage, the effects of local features were more accurately estimated with the use of individual geochemical and medical data on rural settlements in Bryansk oblast.

The geochemical parameters were estimated using the original databases on iodine concentrations in soil, drinking-water, and milk samples collected in the course of the 2007–2021 fieldwork (Korobova et al., 2017, 2020) and literature data on the radioactive contamination of the Bryansk region. Because the drinking waters used by the rural population were dominated by water from the central water-supply systems (public water-supply systems and public standposts), further evaluations were carried out using water from these sources. The anthropogenic factor (fallouts of ^{131}I as a consequence of the Chernobyl accident) was calculated for each settlement by recalculating data on the contamination of this settlement with ^{137}Cs (Pitkevich et al., 1993) according to (Zvonova et al., 2010).

The TC incidence was evaluated using a medical relational database that contained depersonalized information on TC cases in specified settlements. The analysis was carried out using only cases registered at the rural settlements (settlements without an urban status: villages, hamlets, and khutors) (*Law ...,* 2004).

Based on these data, Voronoi polygons (Voronoi, 1908) were constructed around each settlement, after which a redistricting algorithm was applied to com-

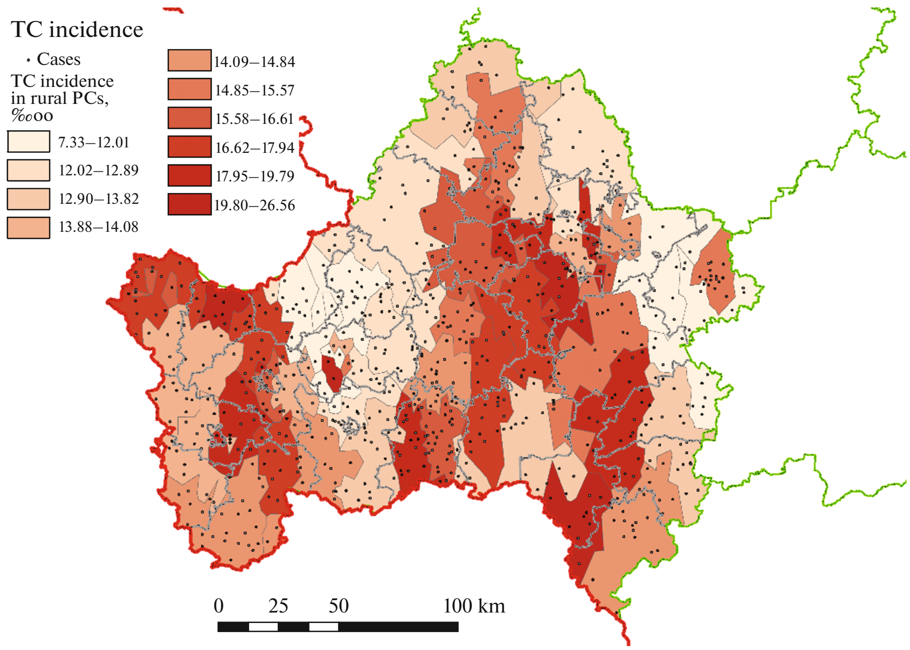

Fig. 7. Zones of TC cases of the residents of Bryansk oblast in 1990 through 2020, obtained by redistricting Voronoi polygons (based on data from the Bryansk Clinical and Diagnostic Center).

bine them into larger divisions (Levin and Friedler, 2019). This led us to form maximally compact clusters with equal numbers of indentified oncological disease cases in each cluster (Fig. 6).

This method is advantageous because, first, it enables one to proceed from spot objects (individual population centers) to polygonal ones and, second, it makes it possible to apply GIS technologies for the later statistical evaluations of the contributions of geochemical factors spatially conjugated with data on the incidence levels in the local human population.

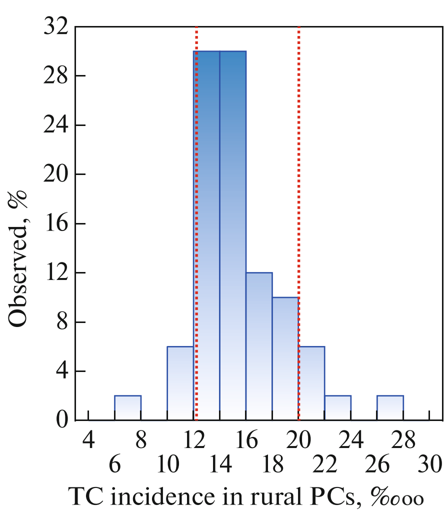

Fig. 8. Distribution of normalized TC incidence indicators of the rural population in the zones.

Using the method described above, we subdivided the territory of Bryansk oblast into 50 areas (clusters) with roughly equal TC incidence among the rural population (Fig. 7).

To statistically evaluate the significance of the contributions of the studied geochemical factors, the clusters were quantitatively stratified into five groups with roughly equal TC incidence (ten clusters in each), which allowed us to differentially analyze the dataset. Thus, at least 300 TC cases were registered in each of the groups (Figs. 7, 8).

Because practically all of the studied geochemical parameters are characterized by distributions different from normal ones (Figs. 9a, 9b), statistically significantly differences were identified using the Mann–Whitney rank *U*-test (Mann and Whitney, 1947) for sets with contrasting (minimal and maximal) TC incidence (Fig. 8).

According to our data, divisions with the maximal TC incidence statistically significantly differ from those with the minimal incidence in higher fallout levels of ^{131}I ($Z = 12.10$, $p < 0.001$) and lower concentrations of Mg ($Z = -1.72$; $p = 0.086$) and K ($Z = -2.59$; $p = 0.010$) in drinking water and stable I concentrations in water ($Z = -1.87$; $p = 0.062$) and soil ($Z = -3.009$: $p = 0.003$) (Table 2).

Thus, a statistically significantly spatial heterogeneity of TC incidence in the rural population of the Bryansk region was estimated by the cartographic technique, and a statistically significantly difference was identified between the zones with the maximal and minimal incidence. Statistical analysis allowed us

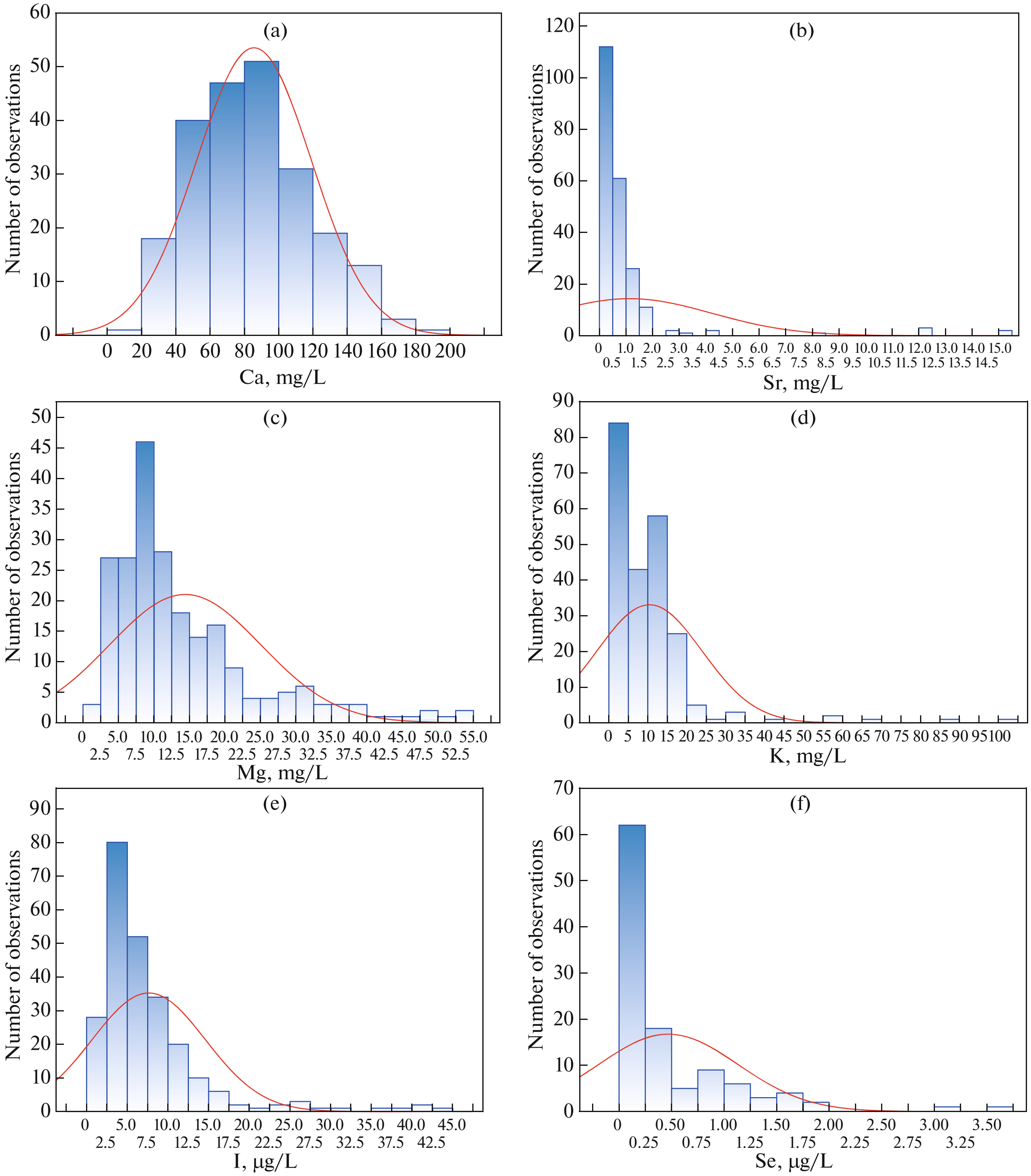

Fig. 9. Histograms of the distribution of some geochemical parameters of the drinking water from the centralized water-supply system of Bryansk oblast (Korobova et al., 2017). (a) Ca, (b) Sr, (c) Mg, and (d) K are in mg/L and (e) I and (f) Se are in µg/L (red lines always show normal distributions).

to identify correlations between the incidence, level of contamination with radioactive iodine, and iodine concentrations in the drinking waters and soils, as well as the availability of Mg and Ca for drinking waters, a fact that obviously deserves further study.

CONCLUSIONS

The aforementioned theoretical and methodological approaches to the elimination of endemic diseases of geochemical nature are obviously of great applied importance. This is particularly so because

Table 2. Statistical significance of differences in individual geochemical parameters in the zones of the minimal and maximal TC incidence in the rural population of Bryansk oblast

Geochemical parameter	*U*	*Z*	*p*	*Nmin*	*Nmax*
Concentration in drinking water from the centralized water-supply system					
Ca, mg/L	526	–1.107	0.268	25	50
Sr, mg/L	577	–0.534	0.593	25	50
Mg, mg/L	**472**	**–1.720**	**0.086**	**25**	**50**
K, mg/L	**394**	**–2.591**	**0.010**	**25**	**50**
Na, mg/L	493	–1.478	0.139	25	50
Mn, mg/L	497	1.076	0.282	24	49
Zn, mg/L	**46**	**–2.286**	**0.022**	**9**	**22**
Fe, mg/L	528	0.429	0.668	23	49
Si, mg/L	73	2.740	0.006	14	23
Ba, mg/L	53	–2.757	0.006	14	18
S, mg/L	51	1.083	0.279	10	14
HCO_3^-, mg/L	446	–1.532	0.126	26	44
F^-, mg/L	424	0.960	0.337	26	38
Cl^-, mg/L	531	–0.183	0.855	26	42
SO_4^{2-}, mg/L	515	0.437	0.662	25	44
NO_3^-, mg/L	525	–0.571	0.568	26	44
PO_4^{3-}, mg/L	298	–1.738	0.082	24	34
Hardness, mg/equiv	111	0.101	0.919	12	19
pH	**256**	**–3.022**	**0.003**	**26**	**36**
TDS, mg/L	399	0.008	0.994	21	38
I^-, μg/L	**521**	**–1.866**	**0.062**	**27**	**52**
Se, μg/L	59	–1.464	0.143	9	20
I-131 fallout as of May 10, 1986, Cu/km^2	**27815**	**12.099**	**0.000**	**588**	**214**
I in potatoes, μg/kg	2882	–0.811	0.417	63	99
I in household farm soil (0–10 cm), μg/kg	**198**	**–3.009**	**0.003**	**29**	**26**
I in household farm soil (10–20 cm), μg/kg	575	–1.447	0.148	34	42
I in milk, μg/kg	1465	–1.517	0.129	50	70

Z is the *U*-test recalculated to normal distribution, *p* is the confidence level; *Nmin* is the number of samples in minimum incidence zones; *Nmax* is the number of samples in maximum incidence zones. Bold text is parameters with $p \leq 0.100$.

the approach is universal and opens the possibilities of constructing maps of the probability of the risk of practically any endemic disease. In this context, it seems to be promising to explore the possible endemic character (spatial constraints) of such widespread diseases as diabetes, asthma, arthrosis, etc.

When this line of research is pursued, a problem of no lesser importance (and which is still unresolved) lies in constructing detailed incidence maps that would have made it possible to outline divisions with statistically significantly different risks of one or another disease. Therewith, difficulties involve not only the problems in acquiring medical information but also devising approaches to make up cartographic representations of the probabilities of the rare events. In this context, our experience indicates that, in spite of the obvious difficulties, all of the problems listed above are of technical nature and, hence, should be definitely solvable. We thereby cannot rule out that a successive implementation of the elaborated approaches may (as in the case with scurvy) facilitate the complete elimination of the whole classes of "human" diseases and not only in Russia, but also worldwide.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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