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Current Approaches to Biogeochemical Regionalization in Ukraine

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Abstract The presented publication analyzes Ukrainian and foreign publications regarding the current principles of biogeochemical regionalization. Traditional domestic approaches to landscape zoning are described, namely according to Oleksandr Vinogradov and Victor Kovalskyi. With the traditional approach, biogeochemical regionalization is based on special biosphere taxa of various orders: biogeochemical regions of the biosphere (the first order taxa), biogeochemical subregions of the biosphere (the second order taxa), and biogeochemical provinces (the third order taxa). Within this frame, the article provides a detailed description of the concept of biogeochemical provinces. The main biogeochemical zones of Ukraine are described, which are currently carved out according to Ukrainian methods of biogeochemical regionalization: Forest-Marsh zone (occupies 19% of the territory), Forest-Steppe zone (occupies 34% of the territory), Northern and Southern Steppe zone (occupies 40% of the territory), and Forest-Meadow zone (occupies 7% of the territory). In a separate section, the author outlines the main approaches to biogeochemical regionalization, which are widely used in developed countries, particularly in the USA, China, and European countries. These approaches can be combined into three groups, each of which has its characteristics: pattern analysis (structural approach), spatially explicit analysis, and extrapolation method. In all these methods, special attention is paid to the choice of a priori discrete classification scheme. Two general types of field sampling designs are commonly used to capitalize on continuous variation in the controls over biogeochemical processes: in the first, one or more transects are arrayed along the major gradients, and sampling is conducted at regular or random intervals; the second type of design for sampling continuous variation is to utilize a grid sampling scheme that permits continuous variation in all independent and dependent variables. In the final part of the article, the author proposes ways to implement modern approaches in the field of biogeochemistry on a landscape (regional) scale to domestic methods, particularly the implementation of the principle of extrapolation using empirical modeling for hydrogeochemical data. The importance of using the experience and approaches of foreign scientists in connection with Ukraine's involvement in the European Union's LIFE environmental protection program was emphasized.

Keywords Biogeochemistry, Regionalization, Biosphere Taxa, Trace Elements, Endemic Diseases

1. Introduction

In recent decades, the number of scientific tools and approaches that allow specialists in environmental geochemistry to study biogeochemical processes at the regional level has increased. This kind of research is crucial for assessing the scale of interaction between different components of the environment, as well as human impact on the environment and global change. Studying biogeochemical processes on a large scale is a complicated task, as there is a risk of significant errors and uncertainties in the development of appropriate models. American researchers point out [1] that currently there is a great need for such studies, and the relatively young state of biogeochemistry at these scales and our limitations in taking into account such uncertainties serve as an incentive for future studies in the field of environmental geochemistry on a regional scale.

Landscape- or regional-scale biogeochemistry is a branch of biogeochemistry that focuses on the study of large-scale spatial changes in fluxes and distributions of elements. Applying ecosystem ecology principles to such large scales is no easy task because it is impossible to consider the entire spectrum of complex geochemical processes on these scales. Biogeochemical processes at this level are important determinants of geosystems regional and global dynamics, which best characterize the interaction of the atmosphere, biosphere, and economic processes associated with the production of food and other natural resources [1].

It is known that the normal development of the organism is possible only with a certain consumption of chemical elements, which is ensured due to the presence of regulatory mechanisms in organisms. All vital (essential) elements are consumed from the environment by organisms, regardless of their concentration, only at specific ratios. Instead, trace elements accumulate in organisms in proportion to their content in the environment. With a long-term violation of the ratio between microelements, various diseases appear, which are called endemic, and the phenomenon itself – is biogeochemical endemic [2]. In plants, endemic diseases manifest themselves in the chain: soil-plant; in animals – soil-plant-animal. A human has two options:

- soil-plant-human;
- soil-plant-animal-human.

Most commonly, biogeochemical endemics occur when there is a lack or excess of some threshold value of a trace element concentration or a violation of the ratio of other trace elements associated with it.

To identify endemic diseases, biogeochemical regionalization is performed. Biogeochemical regionalization is always based on the "reaction" of living matter to the character of the geochemical environment, which manifests itself in the form of endemics (this is its main difference from classical geochemical zoning) [2].

Understanding the basics of the theory of biogeochemical regionalization and biogeochemical provinces is necessary for studying the problems of many related disciplines, such as medical geology and medical geography, landscapes geochemistry, soil science, and environmental chemistry. The idea of the translation of anomalous distribution of chemical elements in the earth's crust, soil cover, and natural waters to the human body and animals is a practical basis for forecasting, diagnosing, and treating endemic diseases caused by an excess, deficiency, or imbalance in the content of chemical elements in the environment [3].

2. Materials and Methods

The presented work is a generalized review of Ukrainian and foreign literature on the problem under consideration. The research uses a structural-genetic analysis and a systemic approach, as well as an inductive method of cognition.

Since the structural-genetic analysis is used when considering the history of the object of research, in which cause-and-effect relationships are studied in depth, the author used this method to highlight individual elements or links (in this case – biosphere taxa of various orders) and to determine through them the key parameters that decisively affect the state of the biosphere and related geospheres (natural chemical composition of the environment, elemental anomalies and specific biological reactions – endemic diseases). The main principles of the system approach were also used in the work, namely, the principle of multidimensionality (in this instance, the biosphere as a complex object is characterized by a large set of properties (centralization, openness, homeostasis, diversity, mechanisms of the chemical substances circulation etc.), which are combined into clusters (biogeochemical provinces), each of which describes one or another of its features (specifics of biogeochemical cycles, geochemical anomalies, etc.); and the principle of hierarchy (the study of the biosphere and related geospheres is based on the idea of the hierarchy of its structure from the highest level to the lowest, in this case from first order taxa to third order taxa, both primary and secondary). The application of the described approaches was reflected in the schemes drawn up by the author and presented in this article. The inductive method of knowledge, which provides for the possibility of obtaining a general conclusion based on individual facts, echoes the extrapolation method widely used in foreign countries in the field of landscape biogeochemistry. The author considers this approach the most suitable for use in Ukraine, therefore the justification of the prospects for further research is related to this method of scientific knowledge.

3. Current State of the Problem

3.1. Approaches Used in Ukraine

Two main approaches to biogeochemical regionalization are traditionally used in Ukraine (Figure 1):

- by Oleksandr Vinogradov [4] (the basis of the biosphere division is the biogeochemical province; zonal and intrazonal biogeochemical provinces are carved out);
- by Victor Kovalskyi [5] (not just the excess or lack of an element is taken into account, but its threshold concentration interval at which the normal development of the organism is ensured; at the same

time, the biosphere is divided into regions and subregions).

Thus, with the traditional approach, biogeochemical regionalization is based on special biosphere taxa of various orders [3]:

- *Biogeochemical regions of the biosphere* (the first order taxa);
- *Biogeochemical subregions of the biosphere* (the second order taxa);
- *Biogeochemical provinces* (the third order taxa).

The main features of the biosphere taxa are characteristics of biogeochemical food chains (Figure 2). Starting with the chemical composition of igneous and sedimentary rocks, geochemical anomalies in the distribution of chemical elements are transmitted through soils, water, air, soil microflora, and the chemical composition of plants, fodder, food products, and human and animal diets. However, these anomalies play a decisive role not by themselves, taken separately, but in the functioning of biogeochemical cycles of chemical elements and their migration forms.

Hence, each region of the biosphere is divided into subregions – smaller areas, which, in turn, include a few biogeochemical provinces. A distinction is made between subregions in which the features of the region are combined with concentrations that reach threshold values, ratios of chemical elements and the possible manifestation of specific biological reactions, and subregions whose features do not correspond to the general characteristics of the region. As a rule, they are formed above ore bodies during the dispersion of chemical elements concentrated in them, in regions without drains, in areas of volcanism, during man-made pollution, etc. In extreme conditions of the subregions, there are clearly expressed signs of biological reactions of organisms caused by an excess or lack of elements.

In other words, biogeochemical provinces are areas on the Earth's surface in which some biological reactions occur in living organisms in response to geochemical factors (lack or excess of certain chemical elements in the environment).

Currently, biogeochemical provinces with the anomalous distribution of more than 30 chemical elements (Se, P, B, F, C, N, Si, Li, Mg, Ca, Al, Hg, As, Pb, Cu, Zn, Fe, etc.) have been described.

It is worth noting that in natural conditions, biogeochemical processes that lead to qualitative changes in the environment proceed slowly, and therefore the human body, often showing a selective ability to certain chemical elements or substances, manages to adapt. However, in our time, when the biogeochemical environment is changing at rates that have never been observed before during the evolution of living matter, organisms cannot always adapt and eventually react in form of lesions.

Biogeochemical regions, subregions and provinces characterized by a deficiency of essential microelements are most vulnerable to anthropogenic heavy metal pollution.

Comparison of maps of microelement content in soils with data on microelement disease distribution does not always characterize the degree of the particular district welfare. In most cases, such discrepancies can be explained by antagonistic or synergistic effects.

Concepts of biogeochemical provinces have been transformed now. According to modern views, they are the biosphere taxa, constituent parts of subregions; therefore, not geographically isolated biogeochemical provinces are considered, but typical primary and secondary ones in connection with potential and background ones. In this way within the biosphere subregions, regionalization is carried out according to the principle of geographical continuity.

Following this principle, the integration of the biosphere subregions in the region gives more specific information about biogeochemical heterogeneity, the mosaicity of the biosphere. This phenomenon is well illustrated by maps and schemes of biogeochemical regions, which show the differences between the biosphere subregions, distinctions of the characteristics of typical biogeochemical provinces, primary and secondary, as well as potential and background. So, within the boundaries of the biosphere subregion, there can be more than one typical province, both potential and background [3].

Moreover, during biogeochemical regionalization, geochemical ecology data are used, which are based on the ideas about the unity of the medium and life. This concept is the main methodological requirement for the analysis of the biosphere systemic organization at all levels of its evolution.

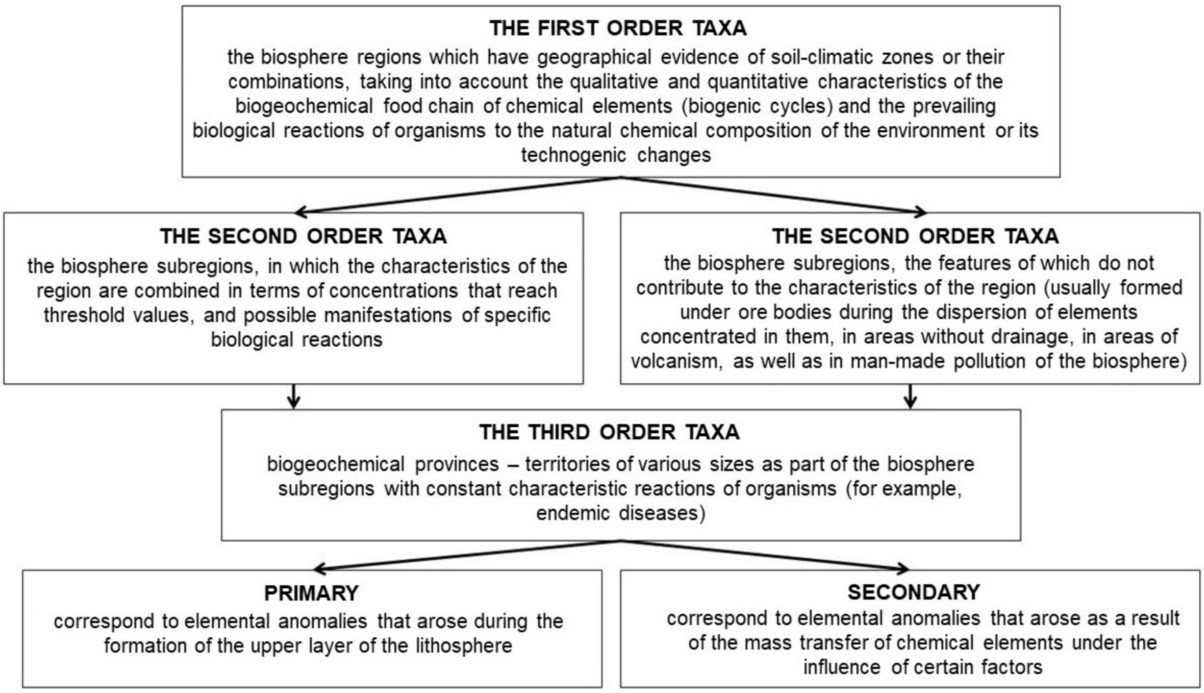

Figure 1. The author's scheme of biosphere taxa of various orders, compiled by [4,5]

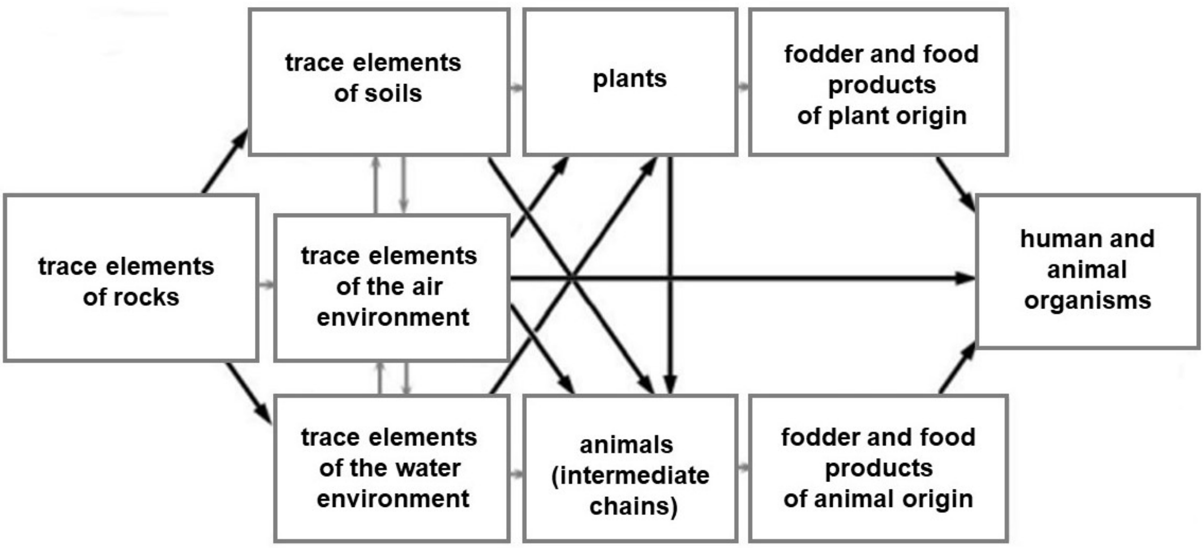

Figure 2. Biogeochemical food chains according to Victor Kovalskyi [5]

According to the genesis, two types of biogeochemical provinces are carved out – *zonal* and *azonal* [3]:

Zonal provinces correlate with certain zones in the form of separate habitats or areas of soil cover. This type occurs due to the deficiency of a certain element compared to its average content in the lithosphere. Thus, zones of sod-podzolic and podzolic soils, which is a strip stretched across almost all of Eurasia, are congruent with biogeochemical provinces with insufficient content of I, Cu, Co, Ca, etc. Similar biogeochemical provinces with characteristic endemics are absent in the adjacent black soil zone. This is a consequence of the high migration mobility of ions I, Ca, Co, Cu, etc., which are easily washed out of podzolic soils. Similar provinces are observed in the area where analogical soils occur in the Southern Hemisphere.

Azonal biogeochemical provinces and associated endemic areas occur in all zones; they arise against the background of primary or secondary areas of dispersion of ore minerals deposits, salt deposits, volcanic rocks, etc. Examples are:

- Boron biogeochemical provinces and endemics of animals and plants in waterless areas;
- Fluorine biogeochemical provinces and endemics of people and animals in areas of volcanic activity,

fluorapatite deposits $Ca_{10}(PO_4)_6F_2$ and fluorite deposits CaF_2;
- Molybdenum biogeochemical provinces and endemics (molybdenosis) – in the areas of molybdenum deposits, etc.

This type of provinces mainly correlates with an excess of chemical elements in the environment [3]:

By origin, biogeochemical provinces are divided into *primary* and *secondary*. Primary ones corresponds to elemental anomalies that arose during the formation of the upper layer of the lithosphere; secondary – as a result of the mass transfer of chemical elements under the influence of some factors.

Biogeochemical provinces are also divided into *natural* and *man-made*. In the first case, they are due to the mosaic distribution of chemical elements in the ecosystem components, and in the second – the results of anthropogenic activity.

According to the expression degree, biogeochemical provinces are divided into:

- *Typical;*
- *Potential (hidden);*
- *Expected;*
- *Background.*

Such gradations are related to the content of an abnormally distributed chemical element in the natural objects of the biogeochemical province, the direction, and intensity of the processes of its concentration in the environment, or the reduction of its content. It should be noted that the specified classification is quite conditional. There are such subregions of the biosphere, which include all the above-listed varieties of biogeochemical provinces according to the degree of expression [3].

Based on the above-mentioned approaches, the following biogeochemical zones are currently carved out within the borders of Ukraine (Figure 3):

- *Forest-Marsh zone* – occupies 19% of the territory, includ es the territory of Polissia (sod-podzolic soils);
- *Forest-Steppe zone* – occupies 34% of the territory, includ es Ternopil, Rivne, Vinnytsia, Chernivtsi, Lviv, and Khmelnytskyi regions – characterized by gray forest soils and black soils;
- *Northern and Southern Steppe zone* – occupies 40% of the territory, includ es Kherson, Mykolaiv, Odessa, Dnipropetrovsk, Donetsk, and Kropyvnytskyi regions (black soil).
- *Forest-Meadow zone* – occupies 7% of the territory, includes Transcarpathia and mountainous Crimea.

An endemic disease – endemic goiter – is characteristic of the Forest-Marsh and Forest-Steppe zones.

There are also two intrazonal provinces in Ukraine: Kryvyi Rih province and Azov-Black Sea province; their borders are connected with iron ore deposits [2].

The ideas of O. P. Vinogradov and V. V. Kovalskyi found their development in the works of Ukrainian scientists [6-8]. In particular, Natalia Kryuchenko and co-authors [8] studied the content of fluorine, iodine, cobalt, and copper in surface and underground waters, as well as in the soils of Transcarpathia region. Based on endemic goiter and caries data, the researchers established biogeochemical provinces for this region.

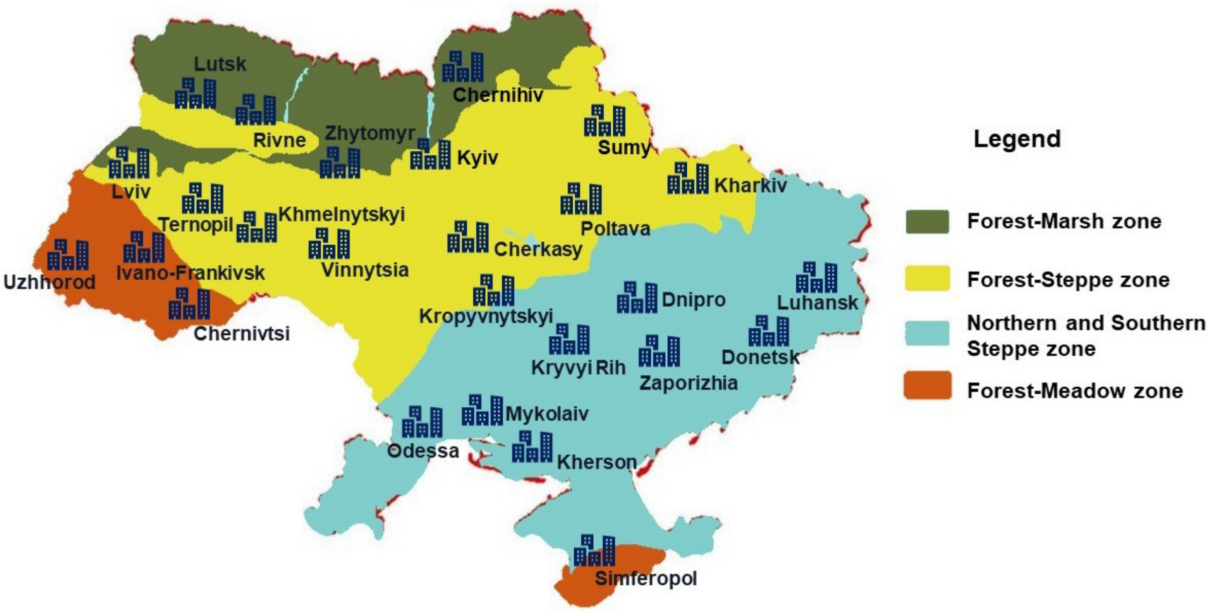

Figure 3. Schematic map of Ukraine with the main biogeochemical zones

3.2. Approaches Used in the World

Today, in many countries of the world, in particular in the USA, China, and European countries, three main approaches are the most common in the field of landscape (regional) biogeochemistry [1,9-11]:

- *Pattern analysis or structural approach.* Research is aimed at identifying patterns in the distribution and flux of elements in currently existing landscapes or regions. To study biogeochemical processes, this type of research often uses the concept of spatial and temporal variability, which is observed on a large scale. For instance, a landscape or region may have strong variations in soil water availability, soil temperature, soil texture, and land use, all of which are important controls over net primary productivity, decomposition, soil organic matter, and trace gas flux. The landscape provides an experimental framework in which scientists can ask how these controls interact to influence the flux and distribution of elements. This experimental framework is simpler than conducting a manipulative analysis. However, when applying this approach, there are significant difficulties – the high variability of biogeochemical processes (related to the microclimate and types of soil deposits) is significantly manifested within the entire landscape, and this, in turn, makes it difficult to single out any one key influencing factor.
- *Spatially explicit analysis.* In this type of analysis, scientists address the biogeochemical connections among components of the landscape. In this case, components of the landscape are spatially dependent; changes in one place influence the flux and distribution of elements in another. Water is most often the important vector for transporting elements among landscape components, so this type of study often addresses the terrestrial-aquatic interface. Wind may also be an important vector, particularly for soil erosion. This type of study is fundamentally different from the pattern analysis (structural approach) described above because the biogeochemical processes studied are so-called "spatially explicit," or represent spatial redistribution within or among landscapes and regions.
- *Extrapolation method.* During this type of research, scientists attempt to extrapolate our understanding of the controls over biogeochemical pools and fluxes over a large scale. Landscapes and regions correspond with the scales on which many important processes and perturbations occur, including land-use management, fires, flooding, and some severe weather events. Simple empirical modeling or simulation analysis is used to assess the current processes occurring at these scales, and the potential sensitivity of biogeochemical pools and fluxes to these types of perturbations.

4. Discussion and Conclusions

In the author's opinion, the implementation of foreign approaches to landscape biogeochemical regionalization to traditional Ukrainian methods is promising, since the above principles make it possible to interpret limited geochemical information on a regional scale, taking into account possible errors and uncertainties. In particular, when establishing biogeochemical provinces, based on determining a relationship between the trace element composition of potable groundwater and the morbidity of the population, it is possible to apply the principle of extrapolation using empirical modeling, because, as a rule, in practice, a large area (corresponding to the first order aquifer system) should be tested with an accurate observation network, which is a technically difficult task. Actually, such an approach will correspond to the inductive method of scientific knowledge, when based on knowledge about the particular, a conclusion is made about the general, and the validity of the proposed assumption or hypothesis is established.

It is also worth noting that, having acquired the status of a candidate for membership in the European Union on June 23, 2022, Ukraine became a participant in the LIFE environmental protection program (the main goal of which is the preservation of nature and climate), which provides for the receipt of money and other resources to eliminate the long-term consequences of Russian aggression and environmental protection in general. In this connection, the use of the experience and approaches of developed countries becomes especially relevant for Ukraine.

In further research, the author intends to use the Korostyshiv district of Zhytomyr region as a Ukrainian pilot area for biogeochemical regionalization. This region, along with Kherson and Chernihiv regions, is characterized by the maximum growth rate of cardiovascular diseases in Ukraine. Also, this area has high dynamics of malignant neoplasms spread. In general, according to the scoring of trends in the dynamics of various population diseases, Zhytomyr region, along with Kirovograd, Mykolaiv, Kharkiv and Kherson regions, belongs to the regions with a predominance of negative characteristics of morbidity dynamics. These areas are characterized by an increase in the number of malignant neoplasms cases, cardiovascular and respiratory diseases [12]. The author already has experience in this direction. In particular, the study of microelement composition of potable groundwater in Korostyshiv district of Zhytomyr region in terms of potential threats to human health was conducted. The study was conducted as part of general monitoring studies set of groundwater quality in the region in July 2020 – August 2021. Microelement analysis of water samples was performed by use of modern highly sensitive method of mass spectrometry with inductively coupled plasma (ICP-MS). Comparison of biologically significant concentrations (BSC) of the main groundwater trace elements with the content of microelements determined during the study, allowed to identify features: in the studied waters there is an excess of such elements as Sr and Ba. Cr is present in sufficient quantity. Instead, insufficient elements such as Li, V, Mn, Co, Ni, Cu, Zn, As, Cd and Pb were detected. The established features of groundwater microelement composition allowed outlining the range of probable negative consequences for public health [13]. In particular, detected excessive concentrations of Sr and Ba can cause the so-called Urov (Kashin-Beck) disease, which is manifested by severe lesions of the musculoskeletal system – bones curvature, their fragility, joint pain. In the future, the author intends to investigate the forms of migration of the studied elements in water using the method of thermodynamic modeling (with the help of the specialized GEMS software). After that, during the next stage of the research, it is planned to use the extrapolation method and, in part, spatial explicit analysis, to extrapolate the obtained data (depending on the obtained correlations): or to the entire administrative region (Zhytomyr region), or on the first-order hydrogeological zone (region of distribution of the aquifer system of Ukrainian Shield), or on a regional-scale natural or man-made geochemical anomaly (if it will be detected).

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