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# POSSIBILITIES OF REGIONAL MONITORING USING THE BASIN APPROACH

***Abstract.*** *The evolution of views on measures to protect the environment from the effects of human development of the subsoil and terrestrial natural environment is reflected in the tasks and methods of environmental control. The current nature of change, especially climate change, requires a shift to regional and global research and forecasting. However, the local and departmental differentiation of the monitoring network do not allow to make assessments of the regional level, and conclusions and forecasts – of the global. Water is the component of the environment that connects all spheres of the Earth, it is a universal solvent, transporter and accumulator of matter and energy. In order to ensure regional and global levels of monitoring, assessments should be carried out on a basin basis, and the subject of research should be the ways, processes and factors of migration of substances, which are based on the peculiarities of moisture balance formation. These principles are fully justified in the performance of various tasks: the definition of barrier functions of the environment in relation to different pollutants; determining the response of the pool hydraulic system to economic activity; assessment of the resistance of soil-plant complexes to the accumulation of toxic substances; assessment of the resistance of basins to hydrological and hydrogeological drought depending on landscape conditions, etc. The paper considers the general methodology and some results obtained through the application of landscape-basin approach to determining the barrier resistance of basins to radio strontium in the Chernobyl Exclusion Zone. For this purpose, the data of 20 years of observations on the removal of* $^{90}$*Sr from catchments were analyzed. It was possible to assess the degree of dependence of* $^{90}$*Sr removal and barrier stability on landscape factors, and to establish the time of active transition of* $^{90}$*Sr to mobile forms, the sequence of dominance of the processes of secondary pollution of surface waters and much more. The use of the obtained regression dependences helped to fulfil retrospective and prognostic tasks, as well as to model more favourable conditions in the catchments to reduce* $^{90}$*Sr removal by adjusting certain factors.*

***Key words:*** *monitoring, catchments, radionuclides, groundwater, landscape, the barrier stability of basins, radioecological assessment.*

**Introduction**

The imposition of different types of anthropogenic pressure leads to diversification and deepening of environmental reactions. These reactions are getting closer to irreversible. The growth of levels of environmental impact from local to regional and continental leads to the fact that the responses of the natural environment are combined in space and become global [8]. The main role in this is played by the most mobile sphere of the Earth - the atmosphere. Indeed, irreversible changes in the upper part of the earth's crust and the transformation of the noosphere into the technosphere with the disruption of the carbon cycle initially led to changes in circulation in the atmosphere, and then to climate change. Abnormal changes in the aquatic environment are already well visible, landscape and climatic zonation is disturbed. In this regard, approaches and methods of environmental monitoring are constantly being reviewed and improved as the main means of timely detection and response to various natural and man-made threats.

Departmental and territorial division, sometimes excessive locality of monitoring in Ukraine led to low scientific returns from the data obtained. Traditional methods of observation do not allow to establish regional patterns. According to the results of monitoring, it is possible to identify foci of a certain impact [12], but it is difficult to draw generalized conclusions about the effect of various factors on a particular component of the environment (groundwater or surface water, air, soil, vegetation). Sometimes, for example, it is difficult or impossible to establish the actual cause of quantitative and qualitative changes in the aquatic environment. However, approaches are being integrated in the world that can significantly increase the level of results and conclusions.

**Analysis of recent research and publications**

Thus, the Gravity Recovery and Climate Experiment (GRACE) mission has emerged as a valuable tool for monitoring global and regional water resource [14] changes, including groundwater data for data-scarce regions, where groundwater modeling has become a central issue [4,6,7].

Therefore, it is necessary to look for a unifying paradigm that can combine observations of the state of the related components of the environment and provide an opportunity to draw regional and global conclusions. To get a complete picture of the state of water resources, trends in its changes and make a correct forecast, it is necessary to take into account not only hydrological changes but also climate change, water exchange between surface and groundwater, hydraulic design, water extraction and human systems in a single integrated structure [13].

The world is beginning to realize that surface water resources in the context of global warming and wide use are becoming vulnerable to depletion [2,3]. In addition, open water sources suffer from various types of pollution, depleting their quality.

In our opinion, water and water resources of Earth are the base component and object of ecological monitoring research, which combines all layers of the biosphere and embodies integrated indicators of its state.

In developed countries, global environmental approaches to the state of the environment are beginning to evolve rapidly. Because the automation of production is so high that it does not require a significant amount of labour, large enterprises, thermal power plants, nuclear power plants are located far outside the city. That is, it is obvious that a safer way for a person is to find ways to localize and dispose of pollution near its sources and if possible, to prevent emissions. The tasks of environmental monitoring are narrowed to *local* ones.

Re-equipping old observation posts with more modern means of observation, while all research remains within the framework of regulations developed in the last century, does not give us an explanation of the complex and very dynamic phenomena that have occurred over the past two decades.

**The aim of the study:** to create a conceptual framework for modern integrated environmental monitoring, expanding its powers in terms of scientific processing and presentation of information, which will enable it to perform regional and global generalizations.

**Research methods**

Analysis of modern monitoring systems and the effectiveness of the information received. Substantiation of the methodology of regional monitoring on the example of radioecological monitoring of catchment basins of the exclusion zone.

**Presentation of the main material of the study**

To localize the bulk of pollutants in uninhabited areas near enterprises, it is advisable to assess in advance the acceptability of the location of these enterprises according to geochemical criteria. If it is possible to change the location of the object, it should be moved to an area that has a geochemical background that is least conducive to the migration of pollutants. In other words, the terrain must have high barrier capabilities that ensure the deposition of pollutants. It is clear that in order to make an informed decision, it is necessary to conduct not one-time research, but long-term monitoring, or rely on observations made in similar biogeochemical areas. Therefore, a monitoring program should include the study of regional geochemical patterns of pollutant migration [11].

The main way or mechanism of migration of pollutants, including radionuclides, is water migration. Therefore, the barrier capacity of the environment is assessed by its ability to reduce water removal of pollutants.

At the regional level, the choice between geoecosystem approaches: basin and aquatic is strategically important in terms of the significance and representation of the results obtained. The choice of basins as the main objects of radiohydrogeochemical assessment (Fig. 1) allows to functionally combine a much wider range of components and thus close the migration cycle of the pollutant. It also allows you to take into account economic or environmental activities in the catchment and its impact on the flow of matter due to changes in the state of natural landscapes.

The concentration of certain, migratory active components of the chemical composition of open streams reflects the result of a wide range of hydrogeochemical and biogeochemical processes that occur with the distribution of these substances unevenly on catchment. Estimation of the potential for water removal of radionuclides from their contaminated area can be performed by rigorous quantitative description (digitization in GIS) of typical landscape features for watersheds, the set of which may differ for each of the radionuclides [10].

The catchment surface of small rivers is flat and low-gradient, which determines the dominant role of precipitation infiltration over planar surface runoff, and hence the decisive role of groundwater among other sources of secondary inflow of radionuclides to rivers. It is obvious that the landscape-geochemical characteristics of the catchment area, where groundwater is fed and discharged, determine the degree of involvement of radionuclides in water migration and their general removal to water intakes (or retention in the geological environment). Comparing the prevalence of landscape features and the values of annual water removal of radionuclides between different basins over a long period of time allows to differentiate catchments by barrier capacity – the main criterion for radioecological assessment of areas around radiation-hazardous objects [9].

According to the results of statistical analysis and comparison of long-term dynamics of water removal of $^{90}$Sr from different basins of the ChEZ, it follows that natural landscape and geochemical characteristics, not water protection measures and structures, are responsible for the formation of stable barrier functions. Various man-made facilities mostly only worsen the barrier capacity of the catchment in the long term, for example, the additional artificial drainage network due to the possibility of its regulation helps to reduce the removal of radionuclides in low-water years, but in high-water – significantly weakens the barrier functions. The constructed water protection dams also have an ambiguous effect: protecting the floodplains from flooding the contaminated areas, they create backwater of groundwater and surface water coming from the catchment area.

*The aim of radioecological assessment* of river catchments is to determine their barrier stability by landscape and geochemical characteristics. The barrier stability index, which characterizes the retention of radionuclides in catchments, expresses the ability of the catchment, as a hydrodynamically isolated part of the geological environment, to resist water removal of radionuclides due to the predominance of landscape-geochemical features (elements) with holding capacity. The high barrier resistance will also be evidenced by the minimum, compared to other catchments with a similar density of pollution, amount of radionuclides removed during high floods, without taking into account the consequences for the ecosystem-holder. The values of annual water removal of radionuclides from the catchment for decades, including cycles of different water content and stages of different ratios of migratory, active and passive forms of radionuclides, integrally reflect the action of various landscape-geochemical factors and barrier features of water catchment under different hydrometeorological conditions. The generalized set of landscape characteristics that have the greatest impact on the migration and removal of man-made radionuclides with water determines the ultimate required indicators of barrier stability and groundwater protection. In accordance with these indicators, the choice of the site for the location of a nuclear facility – a potential source of radioactive contamination should be justified.

The procedure for selecting factors influencing the mobilization (or remobilization) and removal of $^{90}Sr$ with water is basic in the methodological approach to forecasting the concentrations and water removal of radionuclides. It is based on the use of stable landscape-geochemical and dynamic hydrometeorological factors.

The direct indicator of pollution, namely – radionuclide reserves in the catchment, in 10-15 years after precipitation, has no decisive effect on removal volumes [10], which indicates the emergence of dominant natural factors, among which are important geochemical features of the catchment area.

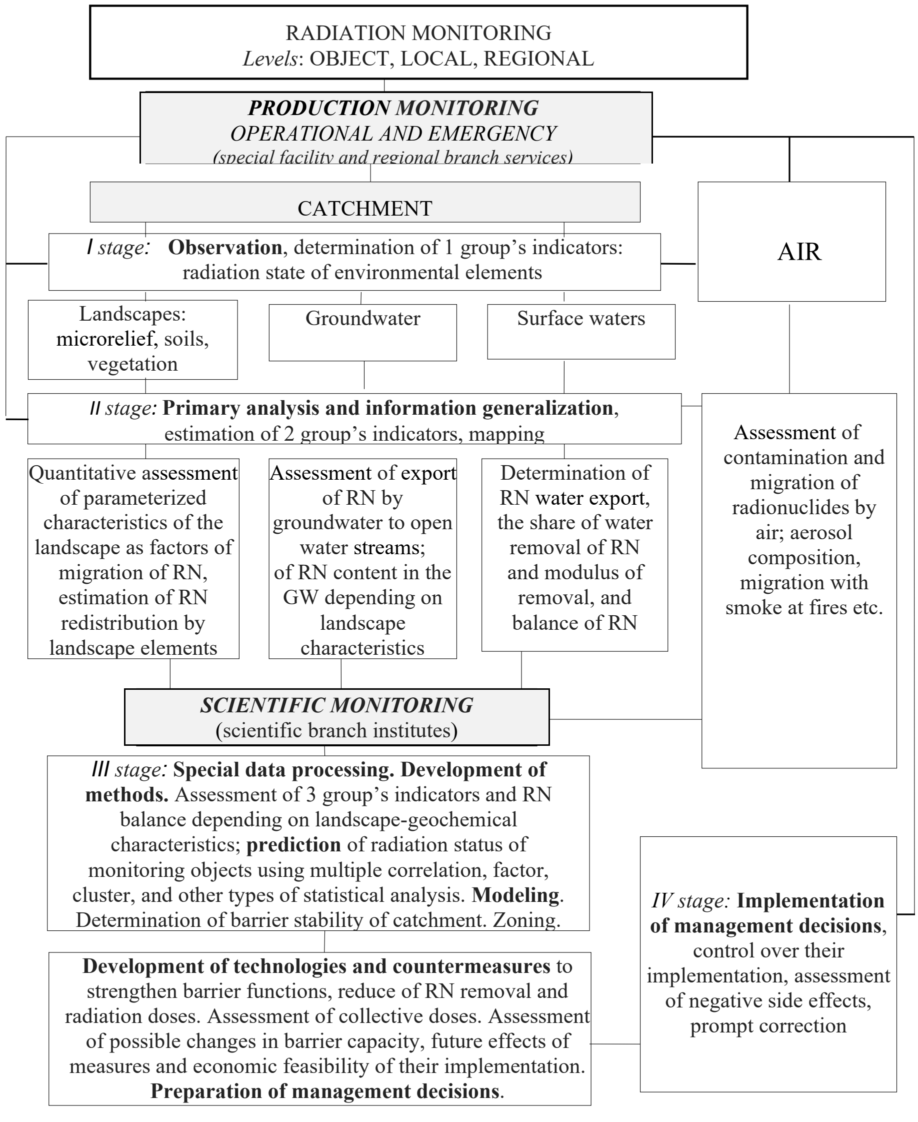


**Fig. 1.** Radioecological monitoring (RM) structure at object, local and regional levels (RAW, NPP, Chornobyl Exclusion Zone, etc.) with the selection of objects and tasks of production and scientific monitoring

In the first years after the Chornobyl disaster (until 1989), solid-phase, weak-moving forms of $^{90}Sr$ predominated. At that time, the most important role in the formation of $^{90}Sr$ and $^{137}Cs$ removal from water catchment was played by the water level in canals and rivers (direct dependence) and the share of unpolluted groundwater in the total runoff (inverse dependence). The following stable landscape features contributed most to the increase in water removal of $^{90}Sr$: the area of acid soils (pH <6), the density of the hydro network, the relative area of the leading depressions. At the same time, the number of dry depressions and the relative area of waterlogged depressions and organogenic soils in the watershed contributed to the reduction of $^{90}Sr$ removal. For the period 1991-1995, there was an inverse relationship between the flow rate (at low levels) and the concentration of $^{90}Sr$ in surface waters, as well as between the relative area of depressions on the catchment and the removal of $^{90}Sr$. During the high-water cycle of 1997-2001, elevated concentrations of $^{90}Sr$ coincided with high values of permanganate oxidation and water levels in canals and rivers. In contrast, the inverse relationship between the concentration and removal of $^{90}Sr$ was observed with the share of groundwater in the total runoff. Among the negative landscape factors, that reduced the barrier resistance of watersheds to the removal of $^{90}Sr$, were the density of the hydro network and general drainage, the number of wetlands, the area of conductive and the density of all depressions. In 2002-2010, the concentration of $^{90}Sr$ in river water was positively affected by flow rate and water pH, and the increase in oxidation coincided with an increase in the concentration of $^{90}Sr$. At this time, the share of groundwater inflow shifted to factors that had a positive correlation with $^{90}Sr$ removal, as well as the density of the hydro network, depressions and overall drainage of the area. However, if the relative area of drainage systems in the regulated state did not exceed 20%, this contributed to the strengthening of barrier capacity. Since 2004, large areas of forest have been one of the main obstacles to strontium removal. The growing role of these factors is well coordinated with the release of $^{90}Sr$ from the solid-phase matrix of radioactive fallout and the beginning of the dominance of mobile forms of $^{90}Sr$. Since 2015, the negative role of the high share of groundwater inflow in the formation of $^{90}Sr$ concentration and removal has only intensified (Fig. 2).

The contribution of the main sources and processes to the secondary pollution of water courses (Fig. 2) is determined by solving empirical balance equations, systems of equations and compartment models. At different stages after the initial pollution, different sources of secondary pollution of the ChEZ water courses prevailed: 1987-1994 – leaching by surface planar runoff and desorption from bottom sediments; 1995-1996 – desorption from bottom sediments and flooded contaminated slopes of the regulated drainage network; 1997-1998 – leaching from flooded slopes, to a lesser extent – from bottom sediments and so on.

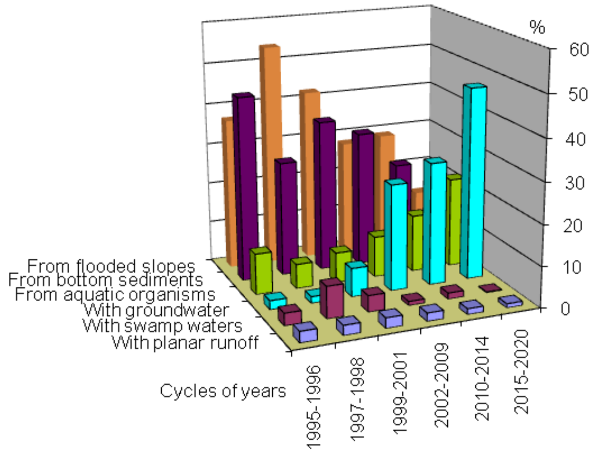


**Fig. 2**. Gradual change of the dominant sources of secondary pollution of watercourses with strontium-90.

The current stage of radioecological monitoring is marked by the deepening impact of global warming on the surface and underground hydrosphere. Groundwater levels (GWL) that have not recovered in 2021-2022 after abnormally low rainfall in 2019 and a fall in GWL may move into a protracted phase of hydrogeological drought. During this phase, precipitation restores only soil moisture in the aeration zone, but practically does not enter groundwater. Signs of this can be seen in the reduction and stabilization of radionuclide concentrations. Drought in this case, contributing to the increase in the thickness of the protective zone of incomplete saturation, becomes a factor in the self-rehabilitation of groundwater and strengthening the barrier capacity of watersheds. Thus, due to its landscape characteristics, the drainage area not only determines relatively stable barrier functions over time, but also affects the course of dynamic processes generated by climate change.

The presented principles and methods of assessing the barrier capacity of landscape complexes in watersheds in relation to water removal of radionuclides and other pollutants can also be used to assess the barrier stability of soil and plant communities in relation to the transition of radionuclides into crops, forests and berries, animals, etc. According to the same principles, but with the use of completely different indicators, it is possible to assess the resistance of basins to hydrological and hydrogeological drought, etc.

One of the most pressing modern radioecological problems is the accumulation of americium-241 in the natural environment and its dosage. Currently, the content of this radionuclide outside the emergency power unit is almost equal to $^{90}Sr$ and will continue to increase until the middle of this century. At the same time, its radiobiological efficiency significantly exceeds gamma and beta radiation of dose-forming $^{137}Cs$ and $^{90}Sr$.

Nowadays, the isotopes Am and Pu play an increasingly important role among radioactive migrants in the Chernobyl Exclusion Zone (ChEZ). The ratio of $^{241}Am/^{239+240}Pu$ activities increases every year. If in 1986 it was 0.13 ± 0.03, then over the next 70 years it will increase 20 times due to the radioactive decay of $^{241}Pu$ and the accumulation of $^{241}Am$. According to estimates [5] the maximum level of $^{241}Am$ pollution will be set at 2060 and will exceed $^{239+240}Pu$ by 2.7 times. At the same time, areas with a pollution level of $^{238+239+240}Pu$ + $^{241}Am$ up to 1000 Bq/m$^2$, may even go beyond the 30-km zone. Currently, the maximum levels of pollution in the $^{241}Am$ exclusion zone reach 37 GBq/km$^2$. It is therefore necessary to continue the ongoing work to assess the barrier capacity of catchments, but now in relation to $^{241}Am$.

The geochemical concept of basin-based (regional) environmental monitoring demonstrates the wide possibilities of scientific data analysis and the importance of the results obtained. The methods of analysis proposed by us are not a dogma, obviously, the other, better mathematical tools [1,4,6,15] can be used to find more accurate solutions. The main thing is to take into account all the main factors that affect water migration and the retention of pollutants (or related to moisture balance) in the landscape or geological environment.

**Conclusions**

The effectiveness of monitoring studies increases significantly if observations are conducted on catchments at a regional scale. Based on almost 20 years of monitoring observations of $^{90}Sr$ removal from the catchments of the exclusion zone, it was possible to assess the barrier stability of basins, the degree of dependence of $^{90}Sr$ removal and barrier resistance on landscape factors, the time of active transition of $^{90}Sr$ to mobile forms (1999-2001), the sequence of dominance of the processes of secondary pollution of surface waters, etc. At the present stage, secondary pollution of watercourses occurs mainly due to groundwater, decomposition of aquatic organisms and linear erosion during heavy rains. Forecasts of water removal of radionuclides from catchments can be performed based on the dependences of removal only on landscape-geochemical characteristics. The presented monitoring methodology allows to separate the influence of anthropogenic and natural factors on the required indicators. In the long run, such monitoring can be used to highlight the impact of global warming on changes in regions' water resources and to make decisions about their more rational use.

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**МОЖЛИВОСТІ РЕГІОНАЛЬНОГО МОНІТОРИНГУ ПРИ ВИКОРИСТАННІ БАСЕЙНОВОГО ПІДХОДУ**

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***Анотація.*** *Сучасний характер змін, особливо зміни клімату, вимагає переходу до регіональних і глобальних досліджень і прогнозування. Проте локальна та відомча диференціація мережі моніторингу не дає змоги робити оцінки регіонального рівня, а висновки та прогнози – глобального. Вода є складовою довкілля, що пов'язує всі сфери Землі, є універсальним розчинником, переносником і накопичувачем речовини та енергії. Для того, щоб забезпечити регіональний та глобальний рівні оцінок спостереження слід проводити за басейновим принципом, а предметом досліджень повинні бути шляхи, процеси та чинники міграції речовин, в основі яких лежать особливості формування балансу вологи. Такі принципи цілком виправдовують себе під час виконання різноманітних завдань: визначення бар'єрних функцій середовища* *по відношенню до різних полютантів; визначення реакції гідросистеми басейну на господарську діяльність; оцінка стійкості ґрунтово-рослинних комплексів до накопичення токсичних речовин; оцінка стійкості басейнів до гідрологічної та гідрогеологічної посухи в залежності від ландшафтних умов тощо. В роботі розглянуто загальну методологію та окремі результати, отримані завдяки застосуванню ландшафтно-басейнового підходу до визначення бар'єрної стійкості басейнів до радіостронцію у Чорнобильській зоні відчуження. Для цього було проаналізовано дані моніторингових спостережень за 20 років. Виділено природні та техногенні чинники, що впливають на бар'єрну стійкість басейнів по відношенню до стронцію. Потенціал водного винесення радіонуклідів з водозбору та рівень бар'єрної стійкості визначено шляхом оцифрування типових для водозборів ландшафтних ознак та кореляційного аналізу. Показник бар'єрної стійкості виражає здатність водозбірного басейну протистояти водному винесенню радіонуклідів завдяки переважанню ландшафтно-геохімічних ознак (елементів) з утримуючими здатностями. У 2002-2010 рр. позитивно на концентрацію $^{90}Sr$ у воді річок впливали швидкість потоку і pH води, а зростання окиснюваності співпадало із збільшенням концентрації $^{90}Sr$. У цей час частка притоку ґрунтових вод перейшла до чинників, що мали позитивну кореляцію із винесенням $^{90}Sr$, як і щільність гідромережі, западин та загальна дренованість площі.*

***Ключові слова:*** *моніторинг, водозбори, радіонукліди, підземні води, ландшафт, бар'єрна стійкість басейнів, радіоекологічне оцінювання.*