Development of ecosystem principles for optimising differentiated land use management

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Abstract. The article presents the results of the analysis of the main trends in the ecological and geochemical transformation of the environment of Southern Russia. The research on revealing the regularities of migration and distribution of elements in soils of landscapes testifies to the necessity of changing the basis of management. This includes introduction of ecosystem principles of management of nature use and environmental quality, timely adjustment of economic mechanisms and resource cycles. The methodology of the ecosystem ecological rationing of chemical elements in soils for optimisation of differentiated land use management has been developed. The system of measures to ensure environmental safety in the region is proposed. It includes identification of pollution and assessment of sources of environmental hazards, maintenance of environmental passports of land plots, measures to protect the environment in the process of economic activity, measures to prevent and eliminate natural and man-made emergencies associated with environmental pollution.

1 Introduction

Modern economics of nature use is based on the cost of natural resources, the value of which depends on the quality of the resource and the conditions of location. Careful control over the use of land, its condition and conservation are possible only if there are normative quality indicators, comparison with which allows us to judge its condition, the consequences of this or that land use or the scale of pollution. In the end, all this determines the value of land (lease) and related payments. Therefore, the selection and justification of land quality criteria is a key task in assessing the condition of land.

In terms of assessing the content of chemical elements in soils in the Russian Federation, there is only one criterion for the degree of soil contamination – the MPC. Moreover, it is approved only for 10 microelements and these values are unified for the whole territory of Russia. For 6 of them, as the most toxic trace elements, approximate permissible concentrations (APC) have been calculated, which have three values each, applied in different conditions in terms of pH and soil composition, with the lowest value (APC1) coinciding with the MAC. Some countries in the world use a similar approach, while others have different methods and criteria for identifying soil contamination, based on calculated values or coefficients using natural-functional zoning.

For example, the article [1] discusses the limitations of various "classical" approaches proposed to estimate the anthropogenic contribution compared to background, namely the pollution factor (CF), the enrichment factor (EF) and the geoaccumulation index (Igeo). Potentially toxic trace elements can be contributed by various pollution agents (physical, chemical and biological), and they can accumulate in soils or transit through dissolution, leaching, evaporation or denudation. When potentially toxic trace elements are in a bioavailable (i.e., relatively soluble) form, they can enter human and animal bodies [2]. Therefore, trace element contamination represents one of the most significant environmental potential health hazards, and assessment of soil contamination is one of the most important environmental issues.

Currently, most methods for assessing soil contamination with trace elements are based on chemical analysis of the gross content. When the total (gross) content of potentially toxic trace elements in soil exceeds the General Reference Level (GRL) (commonly referred to as the screening level), the soil is considered contaminated and hazardous. And investigations of the source and culprit of contamination are required, and extended soil analyses become mandatory [3].

However, the total content is not an existentially relevant value from a toxicological point of view, since trace elements in soils interact with other components and thus change their activity, availability to living

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organisms, mobility and pattern of occurrence forms in general. "Total" or pseudo-total (gross) contents of trace elements in soils, which are used by the EU as indicators of environmental policy, do not represent accurate information on the available amounts of these elements. Instead, they often represent the worst possible situation and overestimate the real risk. In addition, each country, region calculates its own GRL using different approaches, resulting in very different values. On the other hand, classical "risk analyses" may be ineffective in assessing trace element pollution due to landscape and geochemical peculiarities of a particular area, and the most commonly used programmes may give unreasonable results [4].

In our country, this problem is complicated by a large territory and natural diversity, so here official unambiguous standards based on the above criteria for identifying soil contamination with trace elements are not suitable. Justification of this is contained in many works; our arguments will be given below. Therefore, a new approach to land use management is proposed. A scientifically sound methodology should take into account geographical differentiation of the country, mobility of trace elements in soil and the share of bioavailable fraction of potentially toxic components. This involves information on natural levels of trace element concentrations in soils of different landscapes [5, 6] and technogenic factors of their transformation [7]. These data are extremely important for assessing the degree of produced pollution, predicting the potential danger to human health and the need for reclamation measures.

2 Materials and Methods

The scientific basis of our proposals is the conceptual provisions of landscape geochemistry, which establishes the relationship between the structure of the landscape and the content of chemical elements. The research methodology is based on biogeochemical and landscape-geochemical approaches. This is due to the fact that each landscape has a certain, radial and lateral structure and the nature of interaction between subsystems. Therefore, landscapes differing in vegetation cover and type of nature use, chemistry of soil solutions and intensity of aeral migration, relief features and geological structure (or at least one of these factors), naturally differ in concentrations and ratios of chemical elements in soils, their assimilation potential and response to external impact [7].

The study of distribution and migration of chemical elements was initially the subject of geochemistry, and in biocosm systems: biogeochemistry, landscape geochemistry. The results of numerous soil-geochemical studies show that different soils subjected to similar anthropogenic impact eventually differ in the degree of pollution or supply of trace elements, the structure of their forms, which significantly affects their productivity, ecological properties and the danger of pollution. Increasing anthropogenic pressure on the biosphere, attempts to squeeze the maximum out of soils in the struggle for agricultural productivity, lead to a significant biogeochemical imbalance in agricultural landscapes. On the one hand, it is formed by withdrawal of the most biophilic chemical elements with harvest, and on the other hand, by artificial compensation and additional chemicalisation.

Moreover, many chemical elements, for example, in the composition of mineral fertilisers, get into soils in concentrations ten times higher than those needed by plants and simply accumulate, forming pollution [8]. Therefore, the geochemical spectrum of soils is significantly changed, and their functions and characteristics important for our purposes are distorted. As a result, soils can not just reduce productivity, but become dangerous, toxic for the produced agricultural products and people as end users. In this regard, new methodological techniques are needed to assess soil condition, which are called ecosystem-based and rely on the determination of natural background and abnormal contents of chemical elements in soils of different landscapes.

The fact is that landscape and provincial fluctuations of trace element concentrations in soils are very large, which, as V.V. Dobrovolsky puts it, "creates insurmountable difficulties" for the use of unified standards for the whole of Russia to assess the condition of soils [9]. For a number of physiographic, palaeogeochemical and anthropogenic reasons, the problems of assessing the state of soils, provision with chemical elements, and ecological standardisation are particularly acute in the south of the East European Platform.

This was foreseen by A.P. Vinogradov [10], noting completely different conditions of chemical elements migration in chernozems, chestnut soils and grey soils in comparison with other zonal soils due to their saturation with colloids and calcium, high content of organic matter (in chernozems) and alkalinity of soil solutions.

Later, this was confirmed by studies led by V.A. Kovda and N.G. Zyrin [11]. Therefore, the use of the same MPC standards in the south of Russia to assess the condition of any soil as for the whole country leads to ignoring the natural regional and landscape differentiation of the geochemical background.

As a result, the quantitative assessment of soil condition becomes unreliable, and decisions on expenditures for their protection (restoration), agrochemical techniques or penalties for the "guilty" of pollution are unjustified. But until now we do not have objective background values and criteria of soil pollution developed in the south of Russia.

The main reasons for the incorrect application of environmental standards in the south of Russia are several. The first is that the level of differentiation of soils by the content of chemical elements is very high. Background concentrations of trace elements in soils of different landscapes of southern Russia differ from 1.6 (for Li) to 7.0 (for Cu) times [12]. With such high landscape-geochemical differentiation, the use of uniform environmental standards for soils of all landscapes is not only methodologically incorrect, but even harmful, since for some of them these values can significantly exceed the background and even minimal-anomalous values. And for others, they will be significantly lower than the normal concentration, as shown in Table 1, creating the appearance of pollution.

As a result, in the first case, focusing on MPC, it is possible not to pay attention to large-scale pollution or not to notice negative processes in nature management, and in the second case, we make claims to the subject of land use in the actual absence of the caused damage.

The second reason is the increased content of many chemical elements in the soils of southern Russia. This is due to the development here of highly humusified chernozems, non-leaching soil regime, loess character of soil-forming soils, history of the region's development and its position on the continent, the intensity of anthropogenic load [12]. As a result, soil-geochemical studies indicate that in Krasnodar Krai, from the point of view of ecological standardization, "clean" soils in terms of Ni, Zn, Cu and Sn content do not exist at all, as can be seen in Table 2

Table 1. Background (with 95 % probability) and minimal-anomalous concentrations of Cr, Mn and Ni ($n*10^{-3}$ %) in soils of landscapes of Krasnodar Krai.

Element, MPC	Type of nature use or vegetation cover	Composition and age of soil-forming rocks	Background concentration	Lower abnormality level
Cr, 10	Pastures on alpine meadows	Carb.-terrigenous I-K	8.9± 0.7	10.7
	Pastures on the steppes	Terrigenous N	10.8± 1.6	12.9
	Pastures on the steppes	Carb.-terrigenous I-K	12.9± 1.4	16.4
	Vineyards	Carb.-terrigenous K-Pg	11.1± 0.8	13.8
	Vineyards	Alluvial-marine Q	13.9± 1.5	17.1
Ni, 2.0	Tea plantations	Carb.-terrigenous K-Pg	3.46± 0.56	4.09
	Tea plantations	Terrigenous Pg-N	3.57± 0.39	4.11
	Pastures on alpine meadows	Carb.-terrigenous I-K	3.81± 0.22	4.46
	Deciduous forests	Carb.-terrigenous K-Pg	4.63± 0.19	5.82
	Pastures on the steppes	Carb.-terrigenous K-Pg	4.69± 0.28	5.77
	Deciduous forests	Terrigenous I	5.87± 0.70	8.65
	Rainfed arable land	Alluvial Q	5.92± 0.87	8.14
	Pastures on the steppes	Terrigenous N	8.33± 1.57	10.30
Mn, 150	Vineyards	Alluvial-marine Q	70.0± 4.7	80.3
	Pastures on the steppes	Terrigenous Pg-N	80.6± 12.1	105.3
	Deciduous forests	Terrigenous I	109.1± 20.2	124.5
	Fruit orchards	Alluvial Q	135.1± 22.4	187.5
	Deciduous forests	Terrigenous N	146.8± 51.7	283.8

Table 2. Assessment of compliance of soils of geochemical landscapes of Krasnodar Krai with environmental standards (by total content)

Element	Landscape type	Number of landscapes					
		compliant with environmental regulations			inappropriate environmental regulations		
		MPC/ ODK 1	ODK 2	ODK 3	MPC/ ODK 1	ODK 2	ODK 3
Ni	Natural	-	-	16	16	16	-
	Anthropogenic	-	4	42	43	42	1
Zn	Natural	-	-	16	16	16	-
	Anthropogenic	-	10	43	43	33	-
Cu	Natural	-	16	16	16	-	-
	Anthropogenic	-	28	39	43	15	4
Sn	Natural	-			17		
	Anthropogenic	-			43		
Cr	Natural	1			15		
	Anthropogenic	3			40		
Pb	Natural	-	16	16	16	-	-
	Anthropogenic	38	43	43	5	-	-
V	Natural	11			5		
	Anthropogenic	38			5		
Mn	Natural	15			2		
	Anthropogenic	42			1		

Soils of only a few landscapes meet the requirements of MPC for Cr content. And only for Co, Cd, As, "polluted" landscapes are completely absent. Obviously, this situation is not normal and is the result not only of technogenic transformation of the biosphere, but also of natural peculiarities of landscapes of the region, imperfection of methods of assessment of soil condition and should be corrected as in the conditions of the south of Russia, the available indicators of ecological standardisation do not "work". Similar conclusions about the non-compliance of soils of the North Caucasus and southern Russia as a whole with generally accepted environmental standards were made earlier [6, 7, 12].The third factor forcing the elaboration of new proposals on ecological standardisation of soils is a limited (only 10) list of chemical elements standardised on gross content in soils (8 according to MAC and 6 according to EPC). Taking into account that humankind uses practically the whole table of Mendeleev, it turns out that geo-ecological control over the majority of chemical elements is absent or biased. In this regard, it is necessary to develop at the regional level landscape-differentiated indicators, defined taking into account natural and anthropogenic features of territories. For the south of Russia, it is especially relevant due to the huge variety of physical and geographical conditions (plains, low, middle and high mountains, deserts, steppes, meadows, deciduous, mixed, coniferous forests, subalpine and alpine meadows) and geochemical specificity. Practically all types of anthropogenic transformation of natural landscapes found in Russia are present here. Therefore, geographically differentiated indicators for soils and the development of an economic mechanism for using geo-ecological information for objective assessment of soil quality and land use, establishing the degree of environmental pollution in order to adjust the cost of land plots (lease) or develop penalties corresponding to the degree of soil degradation are necessary.

3 Results and Discussion

Such indicators can be developed only on the basis of the landscape-geochemical mapping of territories. Landscapes differ in migration conditions, geochemical barriers, the structure of forms of location, concentrations and ratios of chemical elements in soils and plants, as well as assimilation potential and response to external impacts [7]. All this puts the methodology of landscape geochemistry at the core of biosphere studies and leads to the need to study and systematise landscapes for state assessment, natural-functional zoning and mapping of regions, based on the factors of landscape formation that determine the migration of chemical elements.

The principles of landscape geochemical mapping and environmental assessment allow one to take into account and visualise the peculiarities of anthropogenic and natural substance flows and to develop the ecological and geochemical zoning of territories. In fact, landscape geochemistry allows making qualitative and quantitative account of the specificity of biogeochemical cycles of different territories, and thus can be the basis for the development of a strategy to create optimal ratios and concentrations of chemical elements as a result of their (biogeochemical cycles) correction.

Landscape-differentiated indicators of soil condition can be used not only for ecological assessment of the quality of a certain territory, but also for prioritization, for example, for remediation, reduction of emission limits, adjustment of land value (lease). These values can be set as criteria for the protection of water sources, protection of plant and animal populations, specially protected natural areas, preservation of proper food quality and, ultimately, for the protection of health.

The basis for the development of regionally and landscape-differentiated indicators is soil sampling and analyses. They are grouped into samples of different landscapes, in which the calculation of variation-statistical parameters of the background and anomalous distribution of the gross content of the most technophilic chemical elements (if possible, and in mobile form, determining the degree of toxicity) occur. On the basis of calculation results, normative indicators and procedures are formed. Detection of their increased (or decreased) concentrations in soils (relative to calculated values) indicates environmental pollution or negative phenomena in land use (except for ore mines or deposits). Depending on the degree of deviation of the detected concentrations from the background characteristics, a certain procedure for further actions on land survey and a system of penalties will be developed. Hence, a geographically adequate ecological and economic system will be created to monitor land of different purposes, determine the quality of land use, the degree of soil contamination to establish reasonable payments, calculate penalties for irrational use of natural resources and assess the cadastral value of land plots, and introduce their ecological component into widespread practice.

For integral assessment of the degree of deviation from the regional background, it is advisable to use a new indicator: the coefficient of individuality (Ki) of landscapes [12]. It is calculated for each landscape (land plot), relative to the regional background and is equal to the sum of the concentration and dispersion coefficients of the considered chemical elements, minus their quantity. The most widely used indicators in ecological studies (CC, CR, Ks, Zs) are aimed at identifying increased or decreased concentrations. However, from the point of view of ecology, agriculture and medicine, deviations from the background in both directions are equally important, since anthropogenic transformation of the biosphere leads not only to increased but also to decreased concentrations of many chemical elements, which can be equally dangerous.

A landscape-geochemical approach to determination of regional normative indicators allows detecting even weak-contrast soil contamination at an early stage, determining more accurately the damage caused, considerably expanding the list of controlled elements in a short time, assessing the dynamics of their concentrations in different conditions.

The introduction of regional and landscape-differentiated (ecosystem) principles of rationing, monitoring and assessing soil condition into the economy of nature management and environmental protection activities will make it possible to objectively determine the overall level of pollution and the degree of toxicity of soils for a wide range of chemical elements. At the federal level, their list is very limited, and the application of the existing ones revealed a lot of shortcomings in the soil survey of southern Russia substantiated above [6, 12, 13].

Ignoring the natural regional and landscape differentiation of soil geochemical background leads to the fact that the quantitative assessment of their condition becomes unreliable, and decisions on the costs of protection (restoration) or penalties to the perpetrators of pollution are unjustified. In fact, each landscape is a statistical model of the spatial distribution of chemical elements under different combinations of landscape-forming factors [14, 15], the degree of differentiation of the territory and the history of its development. From the point of view of environmental protection and rational nature management, this allows considering landscapes as adequate models of chemical differentiation of the territory to assess the degree of accumulation of pollutants within its boundaries, the consequences of different types of nature management under certain combinations of landscape-geochemical factors.

The methodological basis for using the proposed indicators is the identification of landscape and geochemical features of the site under consideration with its regional analogues and comparison with the calculated indicators of its ecological state with normalised characteristics. In case of parameters deviation from the background value, further procedure and adjustment of the land plot value depend on the degree of deviation from the norm [16]. For this purpose, it is proposed to use three levels of abnormality, determined by means of the variation-statistical processing of the results of sampling and cartographic modelling.

On their basis, it is necessary to develop procedures for land surveys and conduct them not only in emergency situations, but also whenever there is a change of landowner or land user, and record the results in the environmental passport of the land plot. As a result, at the expense of land users, the state of land will be recorded, the cadastre will be replenished, the quality of land use will be determined and soil monitoring will be carried out, which will significantly increase the measure of responsibility in the exploitation of natural resources.

It is also necessary to take into account that the degree of deviation of the land plot may depend on gas-dust emission from ship power plants [17–21] in the Novorossiysk Bay characterised by intensive shipping traffic (more than 6000 ship calls per year).

4 Conclusion

Geographically differentiated indicators are necessary for regional and municipal levels of executive power to optimise environmental management and ensure a favourable level of environmental conditions [22]. Their use will make it possible to objectively assess the damage caused to soils, identify the culprit of pollution and apply penalties, strengthen regulatory and legal positions in this matter, and adjust the value of land plots depending on the environmental condition [23]. As a result, it is possible to seriously replenish municipal and regional budgets, improve the quality of the environment, the investment attractiveness of the region and, especially, the recreational potential. Therefore, an economically and geographically sound mechanism for controlling the condition and management of the quality of land resources and the environment will be created, which has both applied and fundamental importance for the economy of nature management in the regions of Russia [24, 25]. The adoption of regional environmental standards is stipulated by the Law "On Environmental Protection" and the "Town Planning Code". However, in practice this possibility is very rarely used.

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