CONCEPTUAL MODELING OF INVESTMENT RISK IN HEAVY METAL CONTAMINATION OF AGRICULTURAL LAND SOILS IN RYAZAN REGION

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Abstract. The main cause of polyelement pollution of farm lands is related to the long-distance transport of pollutants from sources of heavy metal emissions into the atmosphere. There are different conditions for polyelement contamination of land in the differentiated wind field of the Ryazan region. This depends on the intensity and direction of the air-technogenic flow of pollutants. Therefore, it is possible to establish the risk categories of polyelement contamination of agricultural land. Basically, the land farms of the Ryazan region can be classified as a high risk of polyelement pollution priority pollutants – zinc, lead, copper. Soil genetic features of chernozems, gray forest soils, sod-podzolic soils, alluvial soils do not affect the risk of polyelement contamination, which is more dependent on the wind flow of pollutants. Agricultural land is contaminated with cadmium, which should also be taken into account to assess the risk. It is possible to use the methodology of "applied information economy" for creating a conceptual model of accounting for the risk of multi-element contamination of agricultural land. This allows to quantify non-economic factors in the presence of risks and uncertainties. The following non-economic risk factors were identified: 1 – changes in the content of priority pollutants in soils, such as zinc, copper, lead; 2 – changes in the content of accompanying pollutants in soils, for example, cadmium; 3 – changes in the quality of land due to pollution; 4 – changes in the soil quality due to pollution. Under the influence of these environmental factors there is a loss of land value. Further, the Fermi method and the Monte Carlo method should be used in analytical modelling of investment risk due to contamination of agricultural land with heavy metals. After a set of sufficient statistics probabilistic distribution for the indicator of land value, which allows to establish the most likely change in the value of the land with polyelement soil pollution, is calculated.

Keywords: soil contamination, risk, land assessment.

Introduction

Soil contamination by inorganic and organic toxicants continues to increase widely as a result of different reasons, including pollutant emissions into the atmosphere [1-4]. There is an understanding of the risk of soil pollution by heavy metals and its effects on humans, living organisms and the environment [5-7]. The global environmental problem is the pollution of soils with heavy metals, which necessitates the application of significant means for remediation of contaminated soils to prevent pollutants from entering food [8-9]. The high biological availability of metals entering the soil due to industrial activities is a potential hazard to the existence of living organisms [10].

A topical issue of the regional economy is the expansion of the real estate market by increasing the turnover of land and attracting investment. Assessment of the market or investment value of real estate objects assumes that the participants of the transaction are well aware of the subject of the transaction.

Agricultural land is an important part of the real estate fund in the Ryazan region. Many agricultural lands are influenced by long-distance atmospheric transport of pollutants, including heavy metals-zinc (Zn), cadmium (Cd), lead (Pb), copper (Cu) - which have toxic and carcinogenic effects. Pollution due to thermal power plants, metallurgy enterprises, machine-building, oil refinery, road.

State regulation measures are applied to substances that pollute the environment [11].

The parties to the transactions are interested in obtaining full information on the degree of risk of soil contamination of agricultural land by heavy metals, therefore, in investment projects it is necessary to take into account such environmental risks. The spatial distribution of heavy metal contamination of agricultural land in the Ryazan region is uneven, depending on the location of the sources of air pollution and the direction of prevailing winds [12].

Therefore, for investment purposes, environmental risks should be ranked according to the degree of the risk of heavy metal contamination of agricultural soils on the basis of the probability of atmospheric-technogenic pollutants. The aim of the work is to create a conceptual model of accounting for environmental risk in investment projects related to the use of agricultural land under the influence of large-scale and uneven pollution with heavy metals.

First, the objectives of the work relate to the consideration of the degree of potential danger of soil contamination of agricultural land due to long-distance wind transport of heavy metals in the Ryazan region. Secondly, the objectives of the work include justification of the analytical model of accounting for environmental risk as a factor in the cost of land. The scientific novelty of the work lies in the methodological improvement of land assessment taking into account the environmental risk caused by atmospheric and anthropogenic pollution of soils of agricultural lands with heavy metals-Zn, Cd, Cu, Pb. The proposed concept takes into account the possibility of causing damage to soils and, consequently, damage to real estate of individuals and legal entities, based on the regional specifics of the spread of this negative environmental impact.

Materials and methods

For the research we have chosen all soil types widespread in the Ryazan region. These are sod-podzolic soils, gray forest soils, chernozems, alluvial soils. The most typical agricultural uses of land with these soils were also taken into account. Therefore, it was necessary to survey the land of 43 farms. The objects are located throughout the Ryazan region, so they experience different effects of long-range atmospheric transport of heavy metals, including cross-border transport of pollutants from the neighboring regions – Moscow and Tula.

Wind field in the Ryazan region is differentiated by the intensity of polyelement transfer of polluting substances, as established by Tobratov S. A. [12, p. 304]. In the wind field, this author identified: 1) predominant trajectories of air transport pollutants, diagnosed by most of the studied elements; 2) secondary trajectories of air migration of pollutants detected by a limited number of studied elements; 3) manifestation of the impact of emission sources located in the territory of adjacent regions.

We took into account these features of the wind field and the transport of pollutants in assessing the degree of danger of soil contamination by heavy metals in the studied objects.

In the soils of 33 farms the total contents of zinc, lead, copper were evaluated. Samples were taken over the entire soil profile after 10 cm. In the soils of the rest 10 farms, these three chemical elements and cadmium were taken into account. The samples were taken from soil genetic horizons.

The average content of each pollutant in the soil profile was established in the soils. Then total (polyelement) soil pollution was estimated. To this end, the degree of soil contamination with heavy metals was determined by the indicator *Zc* [13].

Zc – total pollution index – is calculated taking into account the concentrations of gross forms of heavy metals in the upper soil horizon according to the formula (1):

$$Zc = \Sigma\ (K_{Ci} + ... + K_{Cn}) - (n - 1), \tag{1}$$

where n – number of substances to be determined;
K_{Ci} – concentration coefficient of the *i-th* pollution component.

K_C is determined according to the formula (2):

$$K_C = C_i / C_{Bi}, \tag{2}$$

where C_i – actual content of the *i-th* pollution component in the soil, mg·kg^{-1};
C_{Bi} – regional background of the *i-th* pollution component in the soil, mg·kg^{-1}.

The *Zc* index is used without a dimension.

The calculations used the regional background content of heavy metals in the soil, which was established by us earlier [14]: C_{BCd} – 0.18 mg·kg^{-1}, C_{BCu} – 27.0 mg·kg^{-1}, C_{BPb} – 12.0 mg·kg^{-1}, C_{BZn} – 35.0 mg·kg^{-1}.

The proposed analytical model is based on the methodology of "applied information economy" [15], which allows to quantify non-economic factors in the presence of risks and uncertainties. The main approaches used are the Fermi method [16] and the Monte Carlo method [17]. The Fermi method (or Fermi problem) implies decomposition of the influencing factors into elementary components and the assessment of their inherent uncertainties, making justified assumptions about quantities and their variance or lower and upper bounds. However, instead of making assumptions, we use the Monte Carlo method for numerical simulation of the possible outcomes. Numerical simulation is performed using a random number generator. Thus, a set of numerical experiments replaces a set of assumptions.

Results and discussion

According to the results of the soil survey, there are four risk categories of polyelement contamination with heavy metals – zinc, copper, lead – in the differentiated wind field of the Ryazan region.

The first risk category – the conditionally zero risk category – includes soils with *Zc* of less than 1. These soils are located outside the trajectories of the main streams of atmospheric transport of pollutants and are unpolluted. The second risk category – low risk category – is characterized by soils with *Zc* of less than 2. These soils have a weak atmospheric and technogenic impact, so their pollution is negligible. The third risk category – medium risk category – includes soils with the *Zc* index less than 3. They are affected by secondary trajectories of air migration of pollutants, which increases the level of risk. The fourth category – high risk category – includes soils located in the areas of predominant air transport trajectories of pollutants, as well as those influenced by transboundary pollutant transport. Therefore, here the risk is the highest, *Zc* has values from 3 to 7. The differences between the established risk categories should be considered significant because their confidence intervals of *Zc* average values do not intersect, as it can be seen from Table 1.

Table 1

Risk categories of polyelement soil contamination with Zn, Cu, Pb

Risk category	*Zc* average mean	Root-mean-square deviation
I	< 1.0	0.0
II	1.4	0.3
III	2.4	0.4
IV	5.0	1.0

It was found that most of the farms have a high risk of soil contamination with heavy metals – zinc, copper, lead. This was noted in 23 farms out of 33 surveyed. Soils of 6 farms have the medium risk category. Yet, in 4 farms the low category of risk is noted. Only 1 farm located in the National Park “Meshchera” has unpolluted soil.

All of the examined genetic types of soils are contaminated with heavy metals to a considerable extent in long-distance transfer of pollutants. This applies to chernozems, gray forest soils, sod-podzolic soils, alluvial soils surveyed in 43 farms according to the set values of *Zc*. Table 2 shows the results of the distribution for farms by the risk categories of polyelement soil contamination with Zn, Cu, Pb taking into account the soil types. Obviously, the fourth category – high risk – prevails in all types of soils for the farms surveyed.

Table 2

Risk of polyelement contamination with Zn, Cu, Pb for different soil types in farms

Risk category	Farms with chernozems, %	Farms with gray forest soils, %	Farms with sod-podzolic soils, %	Farms with alluvial soils, %
I	30.0	25.0	18.0	33.0
II	10.0	0.0	18.0	0.0
III	0.0	31.0	9.0	0.0
IV	60.0	44.0	55.0	67.0

Soil contamination with cadmium significantly increases the risk category due to increased *Zc*. It is established for 9 of the 10 farms. The exception is 1 farm located in the National Park “Meschera”. The comparison results are shown in Table 3. This applies to the set values of *Zc*(*Zn*, *Cu*, *Pb*) – polyelement soil contamination with Zn, Cu, Pb - and *Zc*(*Zn*, *Cu*, *Pb*, *Cd*) – polyelement soil contamination with Zn, Cu, Pb and Cd – in the 10 farms.

Table 3

Influence of soil contamination with cadmium on *Zc* in the farms

Farms	$Zc(Zn, Cu, Pb)$	$Zc(Zn, Cu, Pb, Cd)$
1	0.2	2.0
2	0.1	3.3
3	0.0	0.7
4	0.0	0.6
5	0.3	1.2
6	0.2	1.2
7	0.1	0.7
8	0.0	0.6
9	0.0	0.0
10	0.5	2.5

Modern economic methodology allows us to quantify the possible changes in economic indicators, provided that they depend on a variety of non-economic factors, including the probabilistic nature. The need for such methodology fully manifested under polyelemental contamination of soil, since in this case, changes the value of the lands due to the decline of the soil quality. In this situation, many of the main factors affecting the cost of land are of non-economic nature, namely: the ecological state of the environment, the quality of life of the population, the ability to provide environmental services, etc.

One of the ultimate goals of the ongoing research is the construction of analytical models to estimate changes in the value of land at air-technogenic migration of pollutants and the contamination of soils with heavy metals.

We highlight the main natural factors of F_i, changing with long-range transport of pollutants:

1. changes in the content of priority pollutants in soils – zinc, copper, lead, F_{pp};
2. change in the content of the soil related pollutants, for example, cadmium, F_{Cd};
3. change of the land quality, F_{lq};
4. change of the soil quality, F_{sq}.

These factors affect various aspects of A_i economic activity in the study area. First, the F_{pp} and F_{Cd} factors affect the direct cost of agricultural land use, as they affect environmental safety and the cost of production. Secondly, the F_{lq} factor creates conditions for recovery of damage due to land contamination with chemicals [18]. The third factor F_{sq} determines the compensation of harm caused to soil as an object of protection of the environment [19].

Further, it is necessary to quantify the dependence $A_i(F_j)$, taking into account the probabilistic nature of this dependence: a change in F_j entails a change in A_i in the interval (A_{min}, A_{max}), with a probability distribution of z.

Each change in the aspect of life/activity A_i, in turn, leads to a change in the value of the land, C, according to the formula (3):

$$C = \sum_i A_i \cdot K_i, \quad (3)$$

where K_i – coefficients.

The values (A_{min}, A_{max}), K_i and probability distribution of z can be quantified from the results of polyelement soil contamination in typical farms exposed to different risks in the differentiated wind field in the region.

Further, the methodology for calculation of C is numerical simulation using Monte Carlo. The possible changes of F_j for the land plot are enumerated and randomly, taking into account the probability distribution of z, the changes of A_i are compared, which are then translated into the value of C_n for each numerical experiment with the number n. After a set of sufficient statistics, the probability distribution for C is calculated to determine the most likely change in the value of the land plot under polyelement soil contamination.

A similar conceptual approach for probabilistic environmental risk assessment is proposed by Keith Hayes [20], i.e. the risk is considered as the probability of loss measured by the loss distribution function. In turn, losses occur due to state changes, what the society is worried about. Since losses depend on the risk factors, these factors need to be put together and taken into account.

We also believe that the risk is associated with the loss of condition or quality of something. In our study, this loss is due to adverse changes in the soil quality due to polyelement contamination. Therefore it is necessary to consider the factors in this loss. As such factors, we have chosen soil contamination with zinc, lead, copper, cadmium in farms, taking into account the differentiated wind field in the region. However, we offer another mathematical solution for environmental risk assessment, which is based on the methodology of "applied information economy" and therefore more adapted to the objectives of investment projects.

Conclusions

1. It is possible to distinguish different categories of risk of polyelement contamination of soils and lands in the conditions of the differentiated wind field. The risk category depends on the direction and intensity of long-distance atmospheric-technogenic transport of pollutants.
2. A significant spread of farms with a high risk of polyelement soil contamination is the result of long-distance atmospheric-technogenic transport of zinc, copper, lead in the Ryazan region.
3. The risk category of polyelement contamination of soils with zinc, copper, lead does not depend on the genetic characteristics of chernozems, gray forest soils, sod-podzolic soils, alluvial soils in the Ryazan region. The most important is the effect of wind transport of pollutants. Almost all soils are at high risk of polyelement contamination.
4. In determining the degree of risk in addition to the priority pollutants – zinc, copper, lead – we should take into account the high risk of soil contamination with cadmium. This is a common type of chemical pollution of soil and land in the Ryazan region.
5. Loss of the soil and land quality depends on the risk of polyelement contamination. This leads to a decrease in the value of land. Taking into account non-economic risk factors, i.e. factors of soil and land pollution by heavy metals during long-range atmospheric transport of pollutants, is the main concept of building an analytical model of investment risk. The most probable change in the value of the land plot at polyelement soil pollution can be established by analytical and numerical modelling based on the application of the Fermi method and the Monte Carlo method.

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