Cadastral value of land taking into account geo-environmental factors

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Abstract. An urgent task is to determine the cadastral value of land, taking into account the geo-environmental factors affecting the production of environmentally friendly agricultural products and the health of citizens living in the respective territories. The contamination of the territory of the Novgorod region caused by natural and technogenic factors is considered. Natural factors include earth's crust fractures and the associated infection of the territory with radon. Technogenic factors include the consequences of the accident at the Chernobyl nuclear power plant. Basic concepts from the field of measuring radiation contamination of a territory and human radiation doses are given. Radioecological disturbances are considered: earth's crust fractures, territories with exceeded norms for the content of radon, cesium, potassium, thorium and uranium. Thematic mapping of radioecological violations was done in the environment of the Mapinfo program. Herewith, a schematic ecological map in raster format and a vector map of the region were used, on the basis of which thematic maps were created. On the basis of building norms and rules, as well as using the cost method of decontamination to reduce the radiation dose per 1 person-sievert, it was proved that the cadastral value of agricultural land should be reduced by fifty percent relative to its current values. The dependence of oncological morbidity in the region on the radiation infection of the territory is shown cartographically. Infection with cesium does not significantly affect the irradiation dose. It is necessary to monitor the state of radioactive potassium, and one-time measures should be taken to decontaminate the territory from thorium and uranium. The cost method justifies the cost of such measures per hectare of land.

1. Introduction
To date, in connection with the radioactive charging of the territory, the task is to take into account the influence of the environmental factors and the ecological state of the environment on the value of the cadastral value of lands of almost all categories. Since agricultural lands are essential in ensuring the food security of the region and the country, first of all, it is necessary to assess their environmental status, as well as to adjust the cadastral value of such lands taking pollution into account.

2. Objects and methods of research
The cost of land should be laid costs to improve its quality. In accordance with this, there are necessary expenses for bringing the land to normal condition, for its decontamination, and bringing it to its state, level, to withstand the requirements to reduce the risk of natural radionuclides.

From the point of view of the cadastral assessment, it is important to determine the amount of costs to compensate for the damage caused by radionuclides. So exposure of 1 person-Sv leads to a reduction...
of human life by 1 year (1 person-year). And this damage is equal to 1 annual per capita national income.

In turn, radiation poisoning is the cause of cancer [1, 2]. In clause [3] the magnitude of the risk (probability) of cancer is given for small doses of constant radiation exposure. For the entire population, this value is $5.7 \cdot 10^{-2}$/Sv. For example, if the effective irradiation dose of the population is 0.1 Sv per year, then the probability of cancer will be $0.57 \cdot 10^{-2}$ per year, with 2 Sv per year, the probability will be $1.14 \cdot 10^{-5}$. It is believed that with reasonable protection from radiation, the likelihood of cancer is $1.0 \cdot 10^{-5}$ per year. Each type of radiation infection has its own characteristics [4, 5, 6, 7, 8, 9, 10], including exposure to human organs. However, in this case, we will limit ourselves to indicators that may affect the cadastral value of land on which radiation contamination is present. Note that the radiation hazard is evaluated only for individual sources of radioactive irradiation so that measures can be developed to reduce the effective radiation dose. Obviously, it is also necessary to do the same with respect to the cadastral value of the respective lands. For further reference, we note the following. Sievert (Sv) is a unit of measurement of the effective dose of radioactive (ionizing) irradiation, which is associated with other values of the effective dose of irradiation with such a ratio of $1 \text{ Gy} = 100 \text{ rem} = 100 \text{ P} = 100 \text{ rad} = 1 \text{ Sv}$ (with an accuracy of 10–15%).

Here $1 \text{ Gy}$ – one gray – absorbed dose – is the energy absorbed by a unit mass of the irradiated body; since energy is measured in joules, mass is measured in kilograms, then $1 \text{ Gy} = 1 \text{ J/kg}$; $1 \text{ rad}$ is unit dose of the exposed x-ray or gamma radiation; a unit out of system; $1 \text{ rem}$ (biological equivalent of X-ray) is unit dose of radiation that produces the same effect on a biological organism as $1 \text{ P}$ (a unit that is non-systemic and outdated, but found in scientific publications); $1 \text{ rad}$ is unit dose, in which $1 \text{ g}$ of the irradiated substance absorbed $1 \text{ erg}$ of energy (a frequently encountered obsolete non-systemic unit).

A radioactive contamination unit of $1 \text{ Ci/m}^2$ – one Curie per square meter of area – is interconnected with these units. It can be understood by relating it to the unit of irradiation (emanation) that occurs in 1 second, and is called 1 becquerel (1 Bq). Then consider that $1 \text{ Ci} = 3.7 \cdot 10^{10} \text{ Bq}$.

The object of research in this work is radioecological violations in the Novgorod region, their impact on the health status of the population and on the cadastral value of land.

Radioecological disturbances include the following:
1. Fracture violations (earth's crust fractures) on the territory of the region.
2. Territories containing:
   — cesium in excess of $0.2 \text{ Ci/km}^2$,
   — potassium in excess of 2.0%,
   — thorium in excess of $3.0 \cdot 10^4 \%$,
   — increased uranium norms.

3. Results and discussion
A raster geocological map compiled by the North-West Regional Geological Center of the SGE “SEVZAPGEOLOGY” (figure 1) was adopted as the basis for studying fracture violations.
After vectorizing the named lines using the Mapinfo program, as well as connecting the vectorization layer with a map of the regions, a vector map of fracture lines was obtained (Figure 2) and their location (localization) by region. Fracture lines are shown in black, and district names are signed.

It should be noted that on the map (Figure 2) the following groups or clusters of fractures are clearly distinguished: Soletskaya (Soltsy), Novgorodsko-Chudovskaya (Novgorod and Chudovo), Lyubytinsko-Borovichskaya (Lyubytino and Borovichi), Femyansk-Slararusskaya (Demyansk and Staraya Russa). Earth’s crust fractures are characterized by constant radon emission from the bowels of the cracks. In addition, cracks (fractures) are characterized by their own zone of dynamic influence. The zone of the dynamic influence of the fracture is a three-dimensional geological space, characterized by the following parameters:

- residual (plastic or explosive) deformations,
- elastic deformations caused by formation of a fracture.

Obviously, this fact must be taken into account when determining the impact of the fracture and its consequences for the environment. The width of the zone of dynamic influence of the fracture is expressed by the formula:

$$m = 0.22 L^{0.95} \text{ km}$$  \hspace{1cm} (1)

where \(m\) is the width of the zone of influence of the fracture, \(L\) is its length.

Based on the vector map of fractures (Figure 2) and the formula (1), a map of zones of dynamic influence of fractures (ZDIF) is constructed (Figure 3).
Figure 2. Vector map of fractures.

Figure 3. Map of zones of dynamic influence of fractures.
And on its basis, a radon-hazardous zone has been built along the extreme boundaries of the ZDIF (figure 4). This zone includes not only its solid mass, but also individual “islands” on the territory of Pestovsky and other districts. Note that according to table 1, the real fractures presented in figure 2 can be attributed to second-order fractures. All fractures are assessed by the indicators given in table 2. Pairwise comparisons of indicators were carried out by the method of hierarchy analysis.

Figure 4. Radon hazardous area in the Novgorod region.

Table 1. Classification by the nature of the violation.

| Nature of violation of the solidness of the mass | Fracture crushing zone power or crack width | Extent of violation |
|-------------------------------------------------|-------------------------------------------|--------------------|
| Fractures of the 1<sup>st</sup> order – deep, seismogenic | Hundreds and thousands of meters | Hundreds and thousands of kilometers |
| Fractures of the 2<sup>nd</sup> order – deep, non-seismogenic and partially seismogenic | Tens and hundreds of meters | Tens and hundreds of kilometers |
| Fractures of the 3<sup>rd</sup> order | Meters and tens of meters | Kilometers and tens of kilometers |
| Fractures of the 4<sup>th</sup> order | Tens and hundreds of centimeters | Hundreds and thousands of meters |
| Large cracks of the 5<sup>th</sup> order | Over 20 mm | Over 10 m |
| Medium cracks of the 6<sup>th</sup> order | 10-20 mm | 1-10 m |
| Small cracks of the 7<sup>th</sup> order | 2-19 mm | 0.1-1 m |
| Fine cracks of the 8<sup>th</sup> order | Less than 2 mm | Less than 0.1 mm |
Table 2. Matrix of paired comparisons of indicators.

| Indicator name          | Fracture activity level | Fracture type | Fracture order | Normalized priorities (weights) P |
|------------------------|-------------------------|---------------|----------------|----------------------------------|
| Fracture activity level| 1                       | 2             | 3              | 0.575661 (P1)                    |
| Fracture type          | 1/2                     | 1             | 2              | 0.254497 (P2)                    |
| Fracture order         | 1/3                     | 1/2           | 1              | 0.169841 (P3)                    |
| Total                  | –                       | –             | –              | 1.0                              |

The fracture significance coefficient is determined by the formula:

\[ C_v = v_a * P1 + v_t * P2 + v_p * P3, \]  \hspace{1cm} (2)

where \( v_a \) is the significance coefficient of the degree of activity of the fracture; \( v_t \) is the significance coefficient of the type of fracture; \( v_p \) is the significance coefficient of the rank of the fracture; \( P1, P2, P3 \) are the values of normalized priorities (weights of indicators).

If one takes \( v_a = 0.29; \ v_t = 0.42; \ v_p = 0.67 \), then on the basis of (2) with normalized priorities (Table 2) one finds that the fracture significance coefficient will be equal to

\[ C_v = 0.39. \]

Then for all lands of the radon-hazardous zone, one can assume that their cadastral value (CV) will be equal to

\[ CV = CV \_ (1 - C_v), \]  \hspace{1cm} (3)

where \( CV \_ \) is the known cadastral value of the land excluding faults.

Let us now consider the adjustment of the cadastral value of land located in the radon-hazardous zone based on damage to public health caused by radioactive exposure to radon. Figure 5 shows a map of the distribution of cancer by region in 2017. With sufficient accuracy, the districts with the highest disease density highlighted in red are in the radon hazardous area.

By 2017, the average mortality from cancer per year in the Novgorod region in areas of increased radiation amounted to 220 people per 100 thousand inhabitants. A radiation dose of 2.4 mSv/year increases the risk of cancer with a fatal outcome from 0 to 1.8 \( \cdot \) 10^{-4} people/year. In the conditions of the Novgorod region, this risk is 0.22 \( \cdot \) 10^{-4} people/year, which is the radiation dose equal to

\[ (0.22 \cdot 10^{-2} / 1.8 \cdot 10^{-4}) \cdot 2.4 = 0.29 \cdot 10^{2} \text{ (mSv/year)} = 29 \text{ mSv/year}. \]

Based on this value, we determine the level of soil pollution with radon and express it in Ci/m^3, since this unit of pollution is most often used in practice. In the fracture zones, radon pollution is at least 20 kBq/m^3. With the known exact ratio of 1 Ci = 3.7 \( \cdot \) 10^{10} B to the level of 20 kBq/m^3, the level of radioactive contamination will correspond to 0.54 \( \cdot \) 10^{-6} Ci/m^3.
Assuming a thickness of the fertile layer of 0.33 m, we determine that 1 m$^3$ of volume will correspond to an area of 3.03 m$^2$. Then pollution of a body at $0.54 \cdot 10^{-6}$ Ci/m$^3$ will correspond to surface pollution $(0.54\cdot10^{-6}/3.03)$ Ci/m$^2$ = $0.18\cdot10^{-6}$ Ci/m$^2$ or 0.18 Ci/km$^2$.

Practically, according to the North-West Regional Geological Center of the SGE “SEVZAPGEOLOGIA” (hereinafter referred to as the SGE “SEVZAPGEOLOGIA”), this value is equal to the lower limit of cesium content in the soils of the Novgorod region, equal to 0.2 Ci/km$^2$. In this case, unlike cesium, radon can be continuously in water and in air, which increases its danger.

The minimum cost of decontamination measures to reduce the radiation dose by 1 person-sievert per year is 10 thousand US dollars. For decontamination of 29 people - mSv/year = 0.029 people - Sv/year, it is necessary to proportionally spend $290. $(2/3) \cdot 600$ thousand people live in the radon hazardous area of the region = 400 thousand people its population. The costs of decontamination of such a population will amount to 400 thousand $ \cdot 290 = 11 600$ thousand US dollars. The area of the radon hazardous zone is, according to our data, 35 700 km$^2$. Then the costs per 1 km$^2$ will be proportionally equal to 3249.3 dollars, and per 1 ha, respectively, 32.5 dollars. According to, the cadastral value of the lands of the first group – agricultural land – for 2010 amounted to 11 000 rubles at a dollar exchange rate of 36 rubles/dollar. Then the cost per 1 hectare of farmland will amount to 32.5 $ \cdot 36 = 1170$ rubles. That is almost 10% of the cadastral value. But this is fair for the lowest possible level of environmental decontamination costs. It is specified that the cost of decontamination measures can range from 10 thousand dollars to 100 thousand dollars. And if one accepts the cost of 50 thousand dollars, then in 2010 prices they will amount to $1170 \cdot 5 = 5850$ rubles, which is almost half of the cadastral value of the lands of the first group. Thus, the cost method confirms the fairness (3) of accounting for the impact of fractures on the cadastral value of land. In this case, the fracture significance coefficient can be taken in (3) to be equal to 0.5.

Assessment of territories containing cesium.
According to the SGE “SEVZAPGEOLOGIA”, we have created a map of the areas where the cesium content exceeds 0.2 Ci/km$^2$ (Figure 6). The upper limit of this content does not exceed 18 GB/km$^2$, which, according to strict ratios between the units of measurements of radioactive contamination, is 0.49 Ci/km$^2$. The upper limit of this content does not exceed 18 mSv/km$^2$, which, according to strict ratios between the units of measurements of radioactive contamination, is 0.49 Ci/km$^2$. Then, with a contamination of 0.49 Ci/km$^2$, the radiation dose will be 0.16 mSv/year. We previously proved that the dose of radon is 29 mSv/year. It follows that the dose of cesium is almost 200 times less than the dose of radon, so it can be left out from the cadastral value of agricultural land.

![Figure 6. Areas where the cesium content exceeds 0.2 Ci/m$^2$.](image)

Assessment of territories containing potassium.

A map of the areas on which, according to the SGE “SEVZAPGEOLOGIA”, the potassium content exceeds 2%, is shown in Figure 7. The dose that a person receives due to potassium-40 is about 200 μSv/year (0.2 mSv/year), which is about 8% of the annual dose. This information is important, because if the pollution level is 2 times higher, the radiation dose will already be 16% of the annual dose. Therefore, monitoring of changes in the territory’s contamination with radioactive potassium is necessary. This is all the more important, since the accumulation of potassium and radon in the human body is the largest of all radioactive elements.
Figure 7. The area on which the potassium content exceeds 2%.

Assessment of territories containing uranium and thorium.

A map of areas with a high content of uranium and thorium (more than $3 \cdot 10^{-4}$ %) created by us according to the SGE “SEVZAPGEOLOGIA” is shown in Figure 8 as a fragment of the territory in which these radioactive elements are located.

Figure 8. Areas with a high content of uranium and thorium.

Areas with a high content of uranium are highlighted in black, and shaded areas correspond to thorium. Due to the fact that we did not have more complete data, such as the maximum levels of infection of the territory, the analysis was based on the results of evaluations in similar territories. The maximum uranium contamination detected is 5 mg/kg, and thorium – 20 mg/kg. The ratio of thorium pollution density to uranium pollution density is 5. For such a combination of contamination, the radiation dose is 0.34 $\mu$Sv/hr, or 2.9 mSv/hr (assuming 1 year is 8640 hours). This dose is substantial.
Thus, a dose of 1 mSv/year increases the risk of fatal cancer by $7.5 \cdot 10^{-5}$. Thus, a dose of 2.4 mSv/year increases the risk by $1.8 \cdot 10^{-4}$ people/year, or by $12 \cdot 10^{-3}$ for 70 years of life.

In order to decontaminate such contaminants, it is necessary to carry out the costs of reducing the radiation dose by 2.9 mSv/year. We will accept, as before in the case of radon pollution, the cost of decontamination measures to reduce the radiation dose by 1 person-sievert per year is 50 thousand US dollars. To reduce the dose by 2.9 mSv/year, we will proportionally find the cost of these activities at $145 per person. According to our data obtained by the MapInfo program, the area covered by uranium is 3026.6 km$^2$, thorium – 2082.8 km$^2$. We denote the number of residents living in these territories by $N$. Then the costs for all residents will be $N \cdot 145$ (dollars). And the costs per 1 ha of area will be $N \cdot 145/(S \cdot 100)$.

Let us take the total area $S = 3026.6 + 2082.8 = 5119.4$ (km$^2$), $N = 2 \cdot Np + N_{St.\,\,Russa} = 2 \cdot 20\,000 + 50\,000 = 90\,000$, where $Np$ is the population in one area, $N_{St.\,\,Russa}$ is population in Staraya Russa. These data are taken from the calculation that the area of pollution is equivalent to two areas and it includes the city of Staraya Russa. Then the costs per 1 ha of area will be 25.6 (dollars). Such costs should be one-time, since uranium and thorium are stable in space and are not generated like radon.

4. Conclusion

Based on the Construction Standards and Regulations data and the cost method for decontamination of the territory, the need to reduce the cadastral value for agricultural land located in the fracture zone of the earth's crust by 39-50 percent has been proved. This is caused by their infection by radon. It is noted that in these territories there is an increased risk of cancer compared with territories where there are no fractures.

The contamination of the territory with cesium is insignificant and does not affect the cadastral value of land.

Observations of changes in the contamination of the territory with radioactive potassium are needed. This is all the more important, since the accumulation of potassium and radon in the human body is the largest of all radioactive elements.

One-time measures are needed to decontaminate territories subject to infection by uranium and thorium.

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