The Method of Assessing and Substantiating the Influence of Factors’ Groups on the Reproduction of Mineral Resource Base

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Abstract. Mineral resources potential is the basis for a sustainable and balanced development of the modern economy in the case of its rational and integrated use across the entire spectrum of the diversity of minerals’ types represented. The method of estimating and substantiating the influence of groups of factors on the reproduction of mineral and raw material base is considered, consisting in the formation of an additive mathematical model for the reproduction of the mineral resource base, consisting of factors selected as a result of a two-stage ranking, and designed to analyze the influence of factors on the resulting integral index. As a result, a mathematical model was created that allows to assess and justify the influence of groups of factors on the reproduction of the mineral and raw materials base. The introduction of this methodology in practice will contribute to improve the management effectiveness of the mineral and raw materials complex, the formation of cluster economic structures on the territory of regions that are built taking into account the existing natural and mineral and raw materials potentials that are locomotives for the development of regional economy.

1. Introduction
For the development and justification of proposals on the list of geological and economic indicators that can be used to predict the development and exploitation of MMRs during the construction of geological and economic map in the geoinformation system of geological and economic monitoring, a methodology to assess and justify the influence of groups of factors on the reproduction of the mineral resource base is needed.

With the purpose of analyzing the state of mineral resource base reproduction by types of raw materials, it is advisable to conduct a factor analysis of the integral indicator, determining the most significant factors affecting its condition and forming part of the geological and economic model of reproduction costs justifying of mineral resource base.

2. Relevance
The problems of formation of sustainable development model of enterprises of the mineral and raw materials’ sector were studied in the works of M. N. Denisov, D. A. Dodin, M. V. Dudikov, E. A. Dyachkova, V. K. Epishin, N. I. Eremin, E. V. Ershova, A. N. Eremov, S. T. Zhurin, Yu. A. Izrael, M. A. Komarov, V. A. Korolev and many other famous domestic as well as Western scientists: Berens V., Gitman L. J., Daly G., etc. [1-27].
Yu. A. Israel was the first to classify monitoring systems according to the criteria: the object of observation, the spatial level, and the complex of solved problems, the methods of implementation, etc. [13, 15].

V. A. Korolev proposed a classification of monitoring types using an integrated approach, when at the junction of two or more types of monitoring, new types and areas of application arise [17,18].

However, the application of multifactorial mathematical models to the solution of the problem is currently insufficiently studied and requires its scientific justification.

3. Formulation of the problem
Since to ensure the reproduction of mineral resource base the performance of geological exploration, covering various stages of exploration process is required, it is necessary to analyze a significant number of factors, the analysis is advisable to carry out in 2 stages:

at the first stage, all the indicators considered within the frame of geological and economic model of reproduction costs justifying of mineral resource base are analyzed; as noted above, this model allows to estimate the value of required investment in the exploration process in terms of value in order to ensure, as a minimum, a simple reproduction by types of raw materials, therefore, it is necessary to determine groups of factors that most strongly affect the integrated indicator of costs for geological exploration works;

at the second stage, the indicators identified in the first stage are analyzed within their groups to determine their impact on the final value of integral indicator for each group of factors.

4. Theoretical part
All factors affecting the formation of integral indicator, we divide into groups of technological and economic factors.

The model of geological exploration costs dependence from groups of factors can be expressed by the objective function – a system of simultaneous regression equations (1).

\[ Y = \hat{Y}_1 + \hat{Y}_2 \text{ or } Y = \frac{\hat{Y}_1}{\hat{Y}_2} \] (1)

The equation of multiple regression of the dependence of geological exploration cost from technological factors in general form can be represented as follows (2).

\[ \hat{Y}_1 = a_1 + b_1x_1 - b_2x_2 + b_3x_3 \] (2)

where \( x_1 \) is the time of the mineral and raw material object realization, in years; \( x_2 \) is the coefficient of confirmability of forecasted objects number (with predicted resources) at the stages of geological exploration, %; \( x_3 \) is the shortage of active stocks, %.

The equation of multiple regression of the dependence of geological exploration cost from economic factors has the form (3).

\[ \hat{Y}_2 = a_2 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8 \] (3)

where \( x_4 \) are costs to conduct searches by types of minerals resources and regions (mining zones), in million rubles; \( x_5 \) are costs to conduct assessment by types of minerals resources and regions (mining zones), in million rubles; \( x_6 \) is the chain rate of decline in stocks by type of raw materials, %; \( x_7 \) is the share of explored reserves of categories A + B + C1, necessary to fill the stock shortage, %; \( x_8 \) is the share of forecasted resources, reduced to conditional reserves, in total reserves, %;

Then, in general view, the model of geological exploration cost dependence by types of raw materials can be written as a system of equations (4).
We will construct an economic-mathematical model to determine the value of geological exploration costs using the example of iron ore in the Central Federal District.

The equation of integral indicator dependence from technological factors can be written as follows (5).

\[ \hat{Y}_1 = -206.56 + 3.14x_1 - 0.18x_2 + 2.12x_3 \] (5)

All the equation parameters by the Student's test and the regression equation as a whole by the Fisher criterion are statistically significant and reliable. The total cumulative effect of factors on the integral indicator determines the multiple coefficient of determination of 0.842, i.e. factors chosen for the analysis form 84.2% of the variation in geological exploration costs. The relationship between the identified factors and the volume of ore extraction is high \((R = 0.917)\).

The equation of the dependence between geological exploration of iron ore costs and economic factors is as follows (6).

\[ \hat{Y}_2 = -741.01 + 6.81x_4 + 1.43x_5 + 0.13x_6 + 2.69x_7 + 0.3x_8 \] (6)

The resulting equation is statistically significant and reliable, all factors of the equation are also statistically significant and reliable, since the calculated values of the Student's test exceed its tabulated value of 2.57. In general, the change in exploration costs for iron ore by 88% is due to the influence of economic factors included in the multiple regression equation. The relative calculation error (0.66%) does not exceed the permissible limit of the statistical error of 2.5-3% for a given volume of the population.

Consequently, the final model of the dependence between geological exploration costs on the example of iron ore and technological and economic factors is as follows (7).

\[ \hat{Y} = \begin{cases} \hat{Y}_1 = -206.56 + 3.14x_1 - 0.18x_2 + 2.12x_3 \\ \hat{Y}_2 = -741.01 + 6.81x_4 + 1.43x_5 + 0.13x_6 + 2.69x_7 + 0.3x_8 \end{cases} \] (7)

The equation of integral indicator dependence from technological factors can be written as follows (8).

\[ \hat{Y}_1 = -0.76 + 0.8x_1 + 0.14x_2 + 0.003x_3 \] (8)

All parameters of the equation are statistically significant and reliable by the Student's test, the multiple regression equation by the Fisher criterion, as \(F_{\text{расч.}} > F_{\text{табл.}}\) is also statistically significant and reliable.

A multiple determination coefficient of 0.772 shows that the variation in the volume of extraction of glass raw materials by 77.2% is formed under the influence of factors included in the analysis and by 22.8% under the influence of factors not included in the analysis. The relationship between the identified factors and the volume of glass raw material extraction is high \((R = 0.879)\).

The equation of the dependence between geological exploration of glass raw material costs and economic factors is as follows (9).

\[ \hat{Y}_2 = -28.23 + 0.017x_4 + 0.002x_5 + 0.11x_6 + 0.21x_7 + 0.0003x_8 \] (9)

In general, the multiple regression equation is statistically significant and reliable \(F_{\text{расч.}} > F_{\text{табл.}}\). All factors of the equation are also statistically significant and reliable, since the calculated values of the
Student's test exceed its tabulated value of 2.57.

The variation in the volume of extraction of glass raw materials by 95% is due to the influence of factors chosen for the analysis and only by 5% is due to the influence of factors not included in the analysis. The relationship between factors and the volume of glass raw material extraction is very high ($R = 0.975$).

In 2016, the volume of glass raw materials extraction was 1.73 million tons. Estimated volumes of glass raw materials extraction are 1.71 million tons. The relative calculation error is 0.39%.

Consequently, the final model of the dependence between geological exploration costs on the example of glass raw materials and technological and economic factors is as follows (10).

$$
Y = \begin{cases} 
\overline{Y}_1 = -0.76 + 0.8x_1 + 0.14x_2 + 0.003x_3 \\
\overline{Y}_2 = -28.23 + 0.017x_4 + 0.002x_5 + 0.11x_6 + 0.21x_7 + 0.0003x_8 
\end{cases}
$$

(10)

The equation of integral indicator dependence from technological factors can be written as follows (11).

$$
\overline{Y}_2 = 25.62 - 0.092x_4 + 0.044x_2 + 0.002x_3
$$

(11)

Parameters of the equation are statistically significant and reliable by the Student's test, the multiple regression equation by the Fisher criterion $F_{расч.}>F_{табл.}$ is also statistically significant and reliable.

A multiple determination coefficient shows that the variation in the volume of extraction of cement raw materials by 99.1% is due under the influence of factors included in the analysis and only by 0.9% under the influence of factors not included in the analysis. The relationship between the identified factors and the volume of cement raw material extraction is very high ($R = 0.954$).

The equation of the dependence between geological exploration of cement raw material costs and economic factors is as follows (12).

$$
\overline{Y}_2 = -29 + 0.2x_4 + 0.31x_5 + 0.087x_6 + 0.022x_7 + 0.0052x_8
$$

(12)

The relationship between the identified factors and the resulting indicator is very high, as evidenced by the value of the multiple correlation coefficient $R=0.975$. Variations in the volume of cement raw materials extraction is due by 95% to the influence of factors chosen for the analysis.

In general, the multiple regression equation is statistically significant and reliable $F_{расч.}>F_{табл.}$. All factors of the equation are also statistically significant and reliable, since the calculated values of the Student's test exceed its tabulated value of 2.57.

Consequently, the final model of the dependence between geological exploration costs on the example of cement raw materials and technological and economic factors is as follows (13).

$$
Y = \begin{cases} 
\overline{Y}_1 = 25.62 - 0.092x_1 + 0.044x_2 + 0.002x_3 \\
\overline{Y}_2 = -29 + 0.2x_4 + 0.31x_5 + 0.087x_6 + 0.022x_7 + 0.0052x_8 
\end{cases}
$$

(13)

5. Results of experimental studies

As a result of calculation and analysis of obtained mathematical models for iron ore, it should be noted:

1. With the increase in the time for the realization of mineral resource facility for 1 year, the geological exploration costs on the example of iron ore are increased by 3.14 million rubles. With an increase in the confirmability coefficient of the number of forecasted objects (with predicted resources) at stages of geological exploration by 1%, exploration costs are reduced by 0.18 million rubles. As a result of an increase in the deficit of active reserves by 1%, the cost of geological exploration increases by 2.12 million rubles.
2. The increase in the average annual volume of depreciation, stipulated by the project for the development of the field by 1 million tons, leads to an increase in the cost of geological exploration by 6.81 million rubles. The increase in losses during extraction by 1% contributes to the increase in the costs of geological exploration by 1.43 million rubles. The increase in the chain rate of decline in reserves for iron ore by 1% increases the cost of geological exploration by 0.13 million rubles. The positive increase in the number of explored reserves of categories A + B + C1, which are necessary to fill the deficit of outgoing reserves by 1%, leads to an increase in exploration costs by 2.69 million rubles. The increase in the share of forecasted resources, reduced to conventional reserves, in total volume of reserves by 1% contributes to the growth of costs for geological exploration by 0.13 million rubles.

3. The actual costs of geological exploration for iron ore in 2017 amounted to 173 million rubles, however, the costs, taking into account the influence of the above factors on the reproduction of outgoing iron ore reserves, should amount to 207.6 million rubles. The underfinancing is 16.7%, however, this figure, considering the discrete indicators included in the model, tends to grow.

As a result of calculation and analysis of obtained mathematical models for glass raw material, it should be noted:

1. With the increase in the time for the realization of the mineral resource facility for 1 year, the costs of geological exploration for glass raw materials may increase by 0.8 million rubles. The increase in the coefficient of confirmability of the number of forecasted objects (with predicted resources) at stages of geological exploration by 1% leads to a decrease in geological exploration costs by 0.14 million rubles, with an increase in the explored reserves by 1 million tons, the extraction of glass raw materials increases by 3.0 thousand tons.

2. The growth in the investment potential of glass raw materials stocks by 1 billion rubles contributes to an increase in its production by 17 thousand tons. An increase in the raw material component of the value of commodity output by 1% leads to an increase in the volume of glass raw materials extraction by 2 thousand tons. The growth in the extraction ratio of minerals from the subsoil during extraction by 1% increases the volume of glass raw materials extraction by 0.11 million tons. The increase in the level of profitability in the value of commodity output by 1% contributes to an increase in the volume of glass raw materials extraction by 87 million tons. The increase in operating costs by 1 million leads to an increase in the volume of cement raw materials extraction by 5.2 thousand tons.

As a result of calculation and analysis of obtained mathematical models for cement raw material, it should be noted:

1. With an increase in the supply of reserves for 1 year, the volume of extraction of cement raw materials is reduced by 92,000 tons. The increase in extraction of a useful component at enrichment by 1% contributes to an increase in the volume of cement raw materials extraction by 44 thousand tons, and an increase in the explored reserves by 1 million tons leads to an increase in the volume of extraction of cement raw materials by 2.0 thousand tons.

2. The increase in the investment potential of cement raw materials stocks by 1 billion rubles contributes to an increase in raw material extraction by 0.2 thousand tons. An expansion in the raw material component of the value of commodity output by 1% contributes to an increase in the volume of cement raw materials extraction by 0.31 million tons. The growth in the extraction ratio of minerals from the subsoil during extraction by 1% leads to an increase in cement raw materials extraction by 87 million tons. The increase in the level of profitability in the value of commodity output by 1% contributes to an increase in the volume of cement raw materials extraction by 22 thousand tons. The increase in operating costs by 1 million leads to an increase in the volume of cement raw materials extraction by 5.2 thousand tons.

3. Actual costs for cement raw materials geological exploration amounted to 53.2 million rubles, and estimated costs amounted to 53.6 million rubles, underfunding is 0.76%.
6. Conclusions

Thus, we determined the mathematical models and methods for calculating the mineral and raw material potential for geological and economic cluster agglomerations, geological and economic clusters, mining zones and industrial and raw materials points, calculating their parameters, identifying promising deposits, turning of predicted resources into geological reserves, estimating efficiency of the programs of geological study of mineral resources and reproduction of mineral resources. Taking into consideration the high complexity of calculating the graph's parameters, it is required to develop a factual database, information and software to automate calculations in the framework of geological and economic monitoring.

Thus, the assessment of factors impact on the mineral resource complex using an additive model for three types of raw materials – iron ore, cement and glass raw materials – showed that all factors selected for the model are statistically significant and reliable, which is confirmed by testing the Student's test for all parameters of the equation, the statistical significance of the model, its quality and the possibility of application in practical calculations have been confirmed and proved by Fisher F-criterion.

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