PERIODICO di MINERALOGIA
established in 1930

Dipartimento
di Scienze della Terra
Sapienza
Università di Roma

An International Journal of
Mineralogy, Crystallography, Geochemistry,
Ore Deposits, Petrology, Volcanology
and applied topics on Environment, Archaeometry and Cultural Heritage

Reliability of the Planned Consumer Quality of Ores Based on the Estimated Accuracy of Their Average Grade

Azimhan Kurmankozhaev * and Timur Kurmankozhaev

Mining and Metallurgical Institute named after O.A. Baikonurov, Satbayev University, Almaty, Republic of Kazakhstan

ARTICLE INFO

Submitted: March 2024
Accepted: April 2024
Available on line: April 2024

* Corresponding author:
kurman.akozhaev@gmail.com

Doi: 10.13133/2239-1002/18472

How to cite this article:
Kurmankozhaev A. and Kurmankozhaev T. (2024)
Period. Mineral. 93, 51-60

ABSTRACT

The relevance of the study stems primarily from the fact that it is the first time that the reliability of the planned quality of ores has been established by creating a methodological and applied framework for the prospective development of the presented method. The purpose of the study is to provide a validated guideline approach and applied mechanism for eliminating errors made when estimating the planned quality of ore products. The methods used include the analytical, functional, statistical, and other approaches. The method is based on the concept of qualimetrically averaged aggregate and frequency averaged grade totals, zonally based on distribution and homogeneity, using the qualimetric geoindicator property of modal ore quality characterisation. The study highlights the features of the method and analyses the errors that occur in its applications, considering the impact on the prospective use of the method. Based on the results of grade averaging, qualimetric maps are compiled showing the geological zones of high-grade, good-grade, average, and contour ores, stabilised at the level of natural minimum limits. The minimum limits for the deviation of the initial mining contents entering the processing plant from the planned contents have been experimentally proven to be feasible. The practical value consists of the application of the revealed results, solutions to errors in method development, reliability of this approach, which would help create geological and geometrical bases for the modernisation of processes of exploration, evaluation, preparation of reserves, reducing expenses for technical homogenisation, eliminating metal losses in mining wastes and tailings.

Keywords: qualimetric averaging; deviation; stabilisation; reproduction; metal losses; mining waste; tailings.

INTRODUCTION

Commonly used methods of arithmetic mean and weighted average determination of metal content are proven to be the most precise and applicable to the conditions of different mineral deposits. To date, however, the systematic deviations between the current average grades of ore mined in the feed for the concentration and processing stages and those planned for the mine units, blocks, and ore bodies remain very significant. The argument of the inevitability of this concern-factor has become conventional in attributing their consequences to natural geological inaccuracies that arise from the heterogeneity of the ore body and the stochasticity of the statistical field of mineral grades (Shyrin et al., 2018). The existing approaches and methods of improving the formulas for calculating the planned quality of the average grade do not in fact affect the favourable results (Prokopov et al., 1988; Korzhik, 1992). Regardless of the level of estimated accuracy, deviations of initial production grades for beneficiation from those planned for the operational block remain generally significant (Pysmennyy, 2021).

Nowadays, in-situ, in-mine, and near-mine methods of ore quality homogenisation after extraction, using machinery and equipment, at enormous cost and loss of ore, remain the only conventional means of solving the problem of quality stabilisation (Sinchuk et al., 2023; Deryaev, 2024). Therefore, the elimination of the forced post-mining costs of homogenisation, metal losses in mined ores and tailings from beneficiation and processing appears to be a priority in the field of ore development. According to Niyazbekova, and Tleubekov (2019), in the current regulations the quality of production, including items of the highest level of complexity, is perceived based on multiple qualimetric methods allowing for an unambiguous ranking of assessment devices. Generally, qualimetry ranks alongside metrology, standardisation, reliability theory, and other related fields of knowledge to provide a theoretical basis for product quality management. As argued by Kalandarov (2021), the mining operations designed and built according to the standards and conditions of the past have promoted and are now operating in a multiwaste mode. As a result, more than 20 billion tonnes of mining residues and 15 billion tonnes of tailings have been accumulated.

According to Balakina (2020), a figure for prospecting and exploration can be calculated by recommending the intensity of renewal of mineral resources, e.g., ores. It equals the proportionality of the average annual value of stockpile recovery to the average annual value of fossil fuel consumption. Vartanova (2021) points out that mining is a high-risk industry. The systematic practice of extracting minerals and ores has helped miners to reproduce a mining mechanism which reduces the risk of intrusion into a natural site to a satisfying minimum. In the second half of the 20th century, mining creativity was transformed into a mining discipline that established the rules and regularities for the uniform conduct of mining operations under varied geological and technical mining conditions. According to Basalai (2022), examining the mineral resource base by such an exponent as the share of derivative risk licences in the total value of activated exploitation and operating licences allows for underlining the subset of minerals of suggestible interest to mineral developers.

Notably, there is a particular value in inhibiting the process of analysing the method of assessing the reliability of the planned consumption grade of ores, given the estimated accuracy of the average grade. Therefore, it is essential to examine solutions to this problem and develop a certain range of recommendations.

MATERIALS AND METHODS

The recommended method is based on the concept of using reproduced zones of "updated" geological and quality condition of the reserve to calculate the average grade, relying on a reverse approach to the conventional direct one, in which clustered point grade samples are used within a planned mine block. The essence of the concept is to reproduce qualimetrically averaged sets of grades, zonally based on the distribution pattern and homogeneity of their values, using the qualimetric geoindicator property of the modal characterisation of the ore body. The implementation of the concept consists of the creation of reserve estimation areas zoned at the lowest level of grade irregularity and random variability, heterogeneity, and uncertainty in the concentration of the useful component, at which the reliability of the consumer quality of ore products is assured. It has been confirmed that the pattern of occurrence of zoned in distribution and homogeneity of contents, ordered at the level of the lowest limits of statistical variability, non-uniformity of fluctuations and uncertainty of useful component distribution within the field of the deposit reserves at its partitioning using qualimetric modal geoindicators has a geological and genetic character (Kurmankozhaev, 2017). The patent (Kurmankozhaev, 2017) outlines a theory of reproducibility of homogeneous variables in concentration, variability and uniformity of propagation in qualimetric dissection of an inhomogeneous medium using modal geoindicators. Hidden geoindicator frequency and quantitative qualimetric properties of the modal variable and its concentration zone are revealed, influencing the distribution pattern and homogeneity of the variable concentration. It is shown that in the process of qualimetric partitioning of geological stock by means of modal geoindicators there is a structural differentiation of the statistical field of metal contents into zoned ordered geological and geometric zones within a deposit separated by levels of absolute values, homogeneity, concentration, variability, and uniformity of their location.

The method consists in the use of qualimetric geoindicator criteria for the planned yield of consumer quality of ores at the mine site, based on nonparametric properties of the variation of initial values characterising the weighted average value of grades, according to which the parameterisation of reproduced aggregate and frequency integrity coordinated by qualimetric average grade zones is carried out. Hidden geoindicator frequency and quantitative qualimetric properties of the modal value of the geovariable and its concentration zone are revealed, influencing the distribution pattern and homogeneity of the variable concentration. The zone of influence of the modal value is defined as the aggregate and frequency integrity of the genetic geoindicator information with the highest qualimetric power, which is characterised by a normal distribution, the lowest variability and uncertainty, and the highest concentration and confidence limits of the variables.

The fundamental difference of the method consists in recreating the effectiveness of the condition of achieving a reliable planned average grade value - "by zonal plots of qualimetrically averaged grades" instead of the conventional "by grouped point samples", which achieves geological and operational stabilisation of ore quality prior to mining. They eliminate the costs of technical homogenisation after mining and metal losses in ore waste and tailings from beneficiation and processing operations. The reliability of the estimated accuracy value of the consumption grade of the ores per operational area is assessed by determining the average grade using a weighted average estimate, subject to the non-parametric properties of the empirical grade frequencies, according to the equation:

$$\overline{C} = \frac{\sum_{1}^{n} c_i l_i}{n_f} \quad (1)$$

where: f_i - value of the i-th frequency of the i-th content, unit fraction; - the sum of grade frequencies of the contents per site, unit fraction.

The accuracy of the mean content according to equation (1) is carried out by presenting it (Frantsky, Bazanov, 1975; Gudkov, Khlebnikov, 1990) as a function equal to the product of the mean values of ($\overline{C}$) and their frequencies ($\overline{f}$), allowing for the geometric uncertainty of the averaging bounds of , involving the root mean square error of this function, in the form:

$$M_u = \pm\sqrt{\left(\frac{du}{df}\right)^2 m_f^2 + \left(\frac{du}{dc}\right)^2 m_c^2} \quad (2)$$

The following equation was used to calculate the frequency products:

$$\overline{f} \cdot \overline{C} = \frac{1}{n}\sum_{1}^{n} f_i \cdot \frac{1}{n}\sum_{1}^{n} C_i = \frac{1}{n^2}(f_1 C_1 + f_1 C_1 + \dots + f_n C_n + f_2 C_1 + \dots f_n C_n) \quad (3)$$

By differentiating in the variables of this equation and performing a further transformation, the total differential of the function:

$$u = \overline{f} \cdot \overline{C} \quad (4)$$

is obtained as:

$$du = \frac{1}{n^2}[\sum C_i df_1 + \sum C_i df_2 + \dots + \sum C_i df_n + \sum f_i dC_1 + \dots + \sum f_i dC_n] \quad (5)$$

Assuming that $d_u = M_u$; $df_1 = df_2 = \dots = \sigma_f$; $dC_i = \sigma_f$ and proceeding to the root-mean-square (RMS) random errors, the equation of the RMS random error of the function:

$$u = \overline{f} \cdot \overline{C}(\sum C_i + n \cdot \overline{C}, \sum f_i = n\overline{f}) \quad (6)$$

is obtained as:

$$\begin{cases} M_u = \frac{1}{\sqrt{n}}\sqrt{\overline{C}^2\sigma_f^2 + \overline{f}^2\sigma_c^2} \\ M_{u'} = \frac{s}{\sqrt{n}}\sqrt{\overline{C}^2\sigma_f^2 + \overline{f}^2\sigma_c^2} \end{cases} \quad (7)$$

The equation for the total error in determining the mean value of the content is obtained by considering its regular component, expressed in terms of the covariance of the relationship between the contents and their frequencies, as:

$$z_{f.c} = 2\overline{C} \cdot \overline{f}\sum(f_i - \overline{f})(C_i - \overline{C}): \quad (8)$$

$$M_{u'} = \frac{s}{\sqrt{n}}\sqrt{\overline{C}^2\sigma_f^2 + \overline{f}^2\sigma_c^2 + 2\overline{C} \cdot \overline{f}\sum(f_i - \overline{f})(C_i - \overline{C})} \quad (9)$$

The calculation of the average grade includes an error in delineating the averaging contour of the grades, arising from the uncertainty of its geometric boundaries. The estimate of this error is expressed in relative measure as:

$$V_s = \frac{\sigma_s}{S'} \quad (10)$$

where: S' - averaging area of the grades.

Consequently, equation (9) can ultimately be given the form:

$$M_{u'} = 100\sqrt{\frac{1}{n}[V_f^2 + V_s^2 + \frac{2}{\overline{f}\,\overline{C}}\sum(f_i - \overline{f})(C_i - \overline{C})] + V_s^2} \quad (11)$$

where: V_f, V_c, V_s - relative variances of frequency (f), content (c), and area (S) of averaged grades, %; equation

$$V_f^2 + V_s^2 + V_c^2$$

reflects the degree of influence of the casual components of the variance of these variables (f, c, S).

From the estimate (11) it follows that the accuracy of the determination of the mean content depends directly on the variation of the absolute values of the grades (V_c) and their frequency non-uniformity (V_f), the geometrical uncertainty of the averaging circuit of the grades (V_s) and inversely on the number of samples (n). Consequently, the values of variation in grades and their frequencies, and the geometric boundary of grade averaging are the main indicators of the predictive validity of the planned ore quality and depend little on the conventional estimate of the accuracy of their average value. The index of variation of the absolute values of the grades (V_c) is determined through their deviations from the modal value, as estimated:

$$V_c = \frac{\sigma_c}{C_{m0}} \tag{12}$$

where: σ_c - standard deviation of the grades $\sigma_c = \sqrt{\sum_1^n (C_i - C_{m0})^2}$; C_{m0} - modal value of the grades, %.

The variation index of non-uniformity as the main characteristic of the stability of the placement of the contents is estimated through the standard deviation of the empirical frequencies of the distribution as a fraction of their mean value, according to an analytical estimate:

$$V_H = \frac{\sigma_f}{\bar{f}_{cp}} = \left(\frac{N}{S}\right)\sigma_f \tag{13}$$

where: $\bar{f}_{cp}, f_{m0}$ - average and modal values of frequencies, unit fraction; f_i - frequency value for the i-th class interval, unit fraction; N - total number of frequencies over the study area (S), unit fraction.

The geometric uncertainty of the grade averaging boundaries is expressed as:

$$V_s = \frac{\sigma_s}{S} \tag{14}$$

where: S - area of the ore contour over the mine site (block).

The estimate of σ_s is a value reflecting the degree of tortuosity of the actual ore contour across the mine site, mainly expressed in terms of the average value of their deviations (t_{cp}) (Kurmankozhaev, 2008). The geometric uncertainty index of the grade averaging boundaries, given the relationship between the lengths of the geological (P) and zero (P_0) ore surfaces ($P=P_0e^{k\Delta}t$), has the form:

$$V_s = \frac{\sigma_s}{S} = \frac{1.25(P - P_0)}{S} = \frac{1.25P_0}{S}(e^{k\Delta}t - 1) \tag{15}$$

By further transformation it turns into:

$$\begin{cases} V_s = \dfrac{\sigma_c}{P_0}(e^{k\Delta}t - 1) \\ V_s = 2.5\sqrt{\dfrac{\pi}{S}}(e^{k\Delta}t - 1) \end{cases} \tag{16}$$

The estimate of σ_s represents the value of the reflecting degree of deviation of the actual ore contour in the mining area from the technological mining surface, expressed through the average value of these deviations($\bar{t}_{av}$). The equations for the polygon parameters as the actual shape of the contact circle also the correct zero contour of the ore surface are used here, with their relationship accounted for. Considering the complexity theorem:

$$(V_{t.} = V_c + V_H + V_s) \tag{17}$$

and the magnitude of the variation in grades over the zone of concentration of the modal value (V_{m0}) (as more homogeneous), the equation for the total relative estimation of the homogeneity of i-th the geological section is obtained in the form:

$$\overline{V'_{t.}} = \frac{100}{V_{m0}}(V_c + V_H + V_s) \tag{18}$$

The results of the analysis allow making an analytical choice and conclude that the values of average variation of absolute standard deviation (V_c), irregular fluctuation (V_{ir}), and uncertainty of boundaries of averaging grades (V_s) are the main characteristics determining the reliability of the planned quality of ore products and its connection with the estimated accuracy of the average value of the mine site. The process of reproducing geological zones of qualimetric averaged grades to calculate a reliable value of the useable quality of ores includes stages upon which:

- the aggregate and frequency zonal geometrical integrity invariant in the nature of distribution and homogeneity of the contents in the stockpile (Kurmankozhaev, 2017) are reproduced;
- geoindicator criteria for qualimetric grade averaging are defined using non-parametric properties of the raw values that predetermine the reliability of the planned ore quality for the mine site;
- qualimetric averaging of grades based on reproduced cumulative and frequency continuities coordinated across identified operational areas using qualimetric geoindicator criteria is performed;
- qualimetric maps for reproduced geological and exploitation areas containing zoned geological zones of quality and grade ores and modal grade ores, as well as some of the grade ores exceeding the contour and not exceeding the specifications.

RESULTS

A site-specific assessment of the reliability of planned consumer quality of ore was carried out using the results of the conventional weighted average method with direct use of point samples grouped based on planned quality parameters and design dimensions of the mining excavation and the recommended method for qualimetrically averaged grade zones of the useful component. The findings on ore product quality reliability assessment through grade variability, stability, and accuracy indicators based on exploration and operational data from the Geofizicheskoe chromite and Lisakovsk iron ore deposits are summarised in Table 1, 2. Qualimetric partitioning of the recoverable chrome ore reserve for the Geofizicheskoe deposit was carried out using the calculated boundary values of the zone of influence of the modal value:

$$C_{m.z} = C_{m0} - 0.67\sigma = 49 - 0.67 \cdot 5.2 = 45.52\% \quad (19)$$

$$C_{b.z} = C_{m0} + 0.67\sigma = 49 + 0.67 \cdot 7.3 = 52.48\% \quad (20)$$

and by means of isomorphic curves drawn by their values in the field of the deposit reserve.

A total of three geological zones are ranged in high-grade rich (C_i>52%), modestly concentrated high-grade (52%>C_i>46%), and ordinary mixed low-grade (C_i<46%) ores (Table 1). Lisakovsk iron ore deposit. Flat deposit, depth - 20÷50 m, main chemical component - iron (Fe), density - 40÷60 m, cut-off grade for iron - 30%, main deposit: thickness - 50 m, area - 1,400,000 m^2, total values (by deposit), average iron content - 42.27%, absolute variability (standard deviation) of content - 12.3 units of relative variability - coefficient of variation of iron content - 29.1. Statistical population (N=207 units) was compiled according to actual values of Fe contents and statistical series of frequencies by class intervals of content partition h=2.0%, and histogram parameters of iron distribution over the deposit were determined. The process of subdividing the geological reserve into ore zones is drawn up on the basis of the size of zones influenced by modal metal content (Smith, Faramarzi, Poblete, 2022). Estimation of the RMS error in determining grades was carried out based on the reproduction of the areas of series mixed low-grade, moderately concentrated high-grade (highly informative), rich high-grade ores, and on the total reserve of the deposit. The calculation of the RMS errors was performed based on the value of the RMS deviation (σ_i) and the number of samples (n_i) for the objects under study (Table 2).

Process of qualimetric partitioning of geological stock using modal geoindicators is carried out based on parameters of metal content modal concentration zones (C_{m0}, $C_{m.z}$, $C_{b.z}$) with allocation of three homogeneous areas (Fu B. et al., 2022). Stability (V_C, V_H, V_{nd}) and variability (D, σ, V) are calculated using the formulas of arithmetic and weighted mean (1), geometric uncertainty of the contour mean (16) and precision (RMS error) of their determination (11). The data from the areas of row mixed low-grade, moderately concentrated high-grade, and rich high-grade ores, and the total deposit reserve are used as objects for their evaluation (Kamel et al., 2023).

On-site experimental assessments and findings on the reliability of the planned quality of ores according to geological and geometric aggregate and frequency integrity, delineated as a zone of concentration of modal content value representing an area of high-grade quality, a zone of its reduced influence (C_i<C_{m0}) - an area of ordinary mixed lower-grade and a zone of its increased influence (C_i<C_{m0}) - an area of rich high-grade ores, confirm that:

- the values of non-uniformity of fluctuations (V_{HP}), heterogeneity (V_{ht}), random variability ($V_{ran.}$) of the contents, which determines the level of stability of their values spread, decrease on average in the conditions of Geofizicheskoe chromite deposit by V_{HP}=1.2÷1.7, V_{ht}=1.2÷4.0, $V_{ran.}$=2.7÷2.2 times, Lisakovsk iron ore deposit at V_{HP}=1.3÷2.0, V_{ht}=1.2-2.0, $V_{ran.}$=1.4-2.5 times. The absolute root-mean-square variability (σ_c) and amplitude range (d_c) of the contents decrease on average for the Lisakovsk iron ore σ_c=1.4÷4.0, d_c=1.5÷3.5 times and the Geofizicheskoe chromite deposit σ_c=1.3÷3.5, d_c= 2.1÷4.0 times (Table 1);
- the accuracy of determining the average grade using the weighted average method involving frequencies is higher due to a 1.3÷1.5 times lower variability and irregularity in the distribution of the useful component than the arithmetic method.

The determination of the consumption quality of ore products is more accurate than with the conventional approach by reducing the random variability and irregularity of the variation of grades in the operating conditions of Geofizicheskoe chromite, Lisakovsk iron ore, and Zhairem polymetallic deposits on average 1.3÷2.5 times (Kościelniak, P. 2022). At the same time, the absolute RMS error of determination of average grade decreases on the average by 1.4÷4.0 times (by Geofizicheskoe 1.4÷2.5, by Lisakovsk 1.5÷2.3, by Zhabremsky 1.7÷2.2 times). A commonly applied formula, which is based on differences, is used to calculate the random error in the mean grade determination:

$$\left(\sigma_r \sqrt{\sum_1^k \frac{(C_i - \overline{C})^2}{k-1}}\right) \quad (21)$$

and absolute standard deviation (and number of samples (n) (Table 2).

The geometrical uncertainty of the geological boundary of a geological section has been determined by means of errors of delineation of the population of the average of three reproduced homogeneous sections (Akhras M.H., Fischer J., 2022) and its decreasing compared to

Table 1. Results of a grade stability assessment in the operating conditions of Geofizicheskoe chromite deposit.

Geoindicator qualimetric features, %	Indicators of grade distribution stability (Cr_2O_3)			Indicators of chromium oxide distribution variability (Cr_2O_3)			
	Average variation of the uneven fluctuations of the grades, V_{HP} units	Average variation of grade deviations, V_C units	Average variation of heterogeneity of grades, $V_{H\delta}$, units	Mean arithmetic and weighted average of grades $C_{a.c}/C_{83}$.	Amplitude variability of grades *d, %*	Dispersion of grade fluctuations $s\sigma^2=D$	Area of the zone, S thousands m^2
Zone of high-grade rich ores							
C_i>52	6.2(68%)	1.11	1.45	52.0/53.6	5.0	2.06/1.45	7.4
The area of moderately concentrated high-grade ores							
46< C_{moi}<52	11.73(94%)	1.0	1.8	49.0/48.6	7.0	3.3/1.8	17.0
Zone of ordinary mixed low-grade ores							
C_i<46	7.5(62%)	1.23	1.62	43.6/43.1	5.0	2.61/1.62	20.0
By ore deposit							
40÷56	7.8(60%)	1.4	5.2	48.0/48.7	15.0	26.8/5.2	28.0

Table 2. On-site experimental results of variability and accuracy calculations for the average grade at the Geofizicheskoe chromium deposit and Lisakovsk iron ore deposit.

No.	Geological areas of zonal ore reserves	On the Geofizicheskoe chrome deposit				On the Lisakovsk iron ore deposit			
		Geoind. qualimetric attributes, %	Variance, D/σ	RMS error, M	Error reduction rate, unit fraction/%	Geoind. qualimetric attributes, %	Variance, D/σ	RMS error, M	Error reduction rate, unit fraction/%
1	Area of the zonal reserve of ordinary low-grade ores (n_1=40)	<46	2.61/1.62	0.26	1.6/36.0	<36.6 (n=90)	11.8/3.4	1.6/36.0	1.3/21%
2	Area of the zonal reserve of moderately concentrated ores (n_2=83)	46<<52	1.72/1.31	0.14	2.9/70.0	36.6<<46 (n=117)	3.3/1.8	2.9/70.0	2.6/60%
3	The site of the zonal reserve of rich high-grade ores (n_3=35)	>52	2.06/1.45	0.24	1.7/41.0	-	-	-	-
4	By base geological reserve (N=158 samples)	46÷52	26.8/5.2	0.41	1.6÷2.5	22÷46 (N=207 samples)	45.4/67	0.44	1.3÷2.5

the conventional practice by a factor of 1.40-1.60 on the average. The calculation assumes

$$\frac{n_z}{n_3} \approx \frac{P_z}{P_2} \approx \frac{L_l}{L_0};$$

empirical average values $\frac{L_k}{L_0} = 1.33, V_z = 0.67$

at m_t =0.37 m, calculated from actual data on iron ore and chromite deposits.

DISCUSSION

The research that has been carried out on the method for assessing the reliability of planned quality of ores, considering the estimated accuracy of the average grade to detect errors and challenges in the application of this method, and its effectiveness is a key focus for researchers. The variations of the average metal composition used in practice are considered to be the most correct and accepted for the requirement of different massifs of desired minerals. The analysis of generally available qualimetric methods used and their advancement in all sectors of production, one of the requirements for improving reliability, technology accordingly to the conditions of the timeframe. This study on the implementation of a method for assessing the reliability of the planned quality of ores with respect to the estimated accuracy of their average grade has provided a better understanding of the causes of errors during application, especially in the process of ensuring the reliability of the planned quality of ores by using nonparametric properties of non-uniformity, to assess whether these problems can be addressed and to identify at what stage they may arise. The errors in the present production figures associated with the average raw ore programmes for the concentrating and processing plant, as compared to those for the ore body, remain very large. The many technogenic forms of mining, or waste, must be treated as a separate category of desired resource.

In the last few years, science has made a major breakthrough in developing and modelling an algorithm for the method of assessing the reliability of the planned quality of ores, given the estimated accuracy of their average grade. The evidence of the inevitability of these errors in the causal situation is commonly found by shifting their results to natural mineralogical deviations, which appear due to the variety of the ore deposit and the irreducibility of the representative surroundings of the values of the necessary resource (Oliynyk and Wilhelm, 2021). Economic innovations, such as tax incentives for companies with an interest in exploratory operations, improved procedures for submitting exploration licences, can help increase the interest of mineral developers in investing in projects to develop innovative methods for assessing the reliability of the planned quality of ores based on the estimated accuracy of their average grade and to build up the mineral resource base (Turylo et al., 2023).

Many recommendations on the analysis of this method are ineffective in their application. The inherent ways and methods of improving the equations for calculating the impending reliability of the statistical composition, have little or no effect on the positive outcomes. But the risk is still present, mainly because of the enormous level of variability, in rare cases, of the uncertainty of the rules of mining operations. When applying the method of assessing the reliability of the planned quality of ores with the estimated accuracy of their average grade by using non-parametric properties of non-uniformity, on which the qualimetrically averaged aggregate is reproduced, models must adequately describe the essence of the operation, be simple and implementable if the complex technological process is to be carried out more efficiently. Regardless of the reliability of the computing plan, the discrepancy between the composition of the initial quantitative resource for replenishment and that required by the functional module is mostly substantial. Whereas the annual average recovery mark is the ratio of the total amount of final category reserves in the public account for any given mineral resource to the time frame in which this increase in reserves has occurred, the length of time for which exploration operations for that mineral resource have been carried out.

According to the recent study by Abolghasemian et al. (2022), mining commodities represent a mineral resource for metallurgical, chemical, heat supply, and other companies. The reliability of the products of mines, pits, and massifs is largely dependent on the production and economic performance of both their customers and mining companies, since failure to ensure the competitiveness of their products promotes, under present conditions, very serious damage, often resulting in the economic insolvency of the company. There has been a massive rise in imports of several types of mineral resource, while the use of local ores has declined. One effective solution to this issue may be to improve the quality and reduce the inflated cost of these types of ore raw materials. The entire algorithm for the method of assessing the reliability of the planned quality of ores, considering the estimated accuracy of their average grade, has been analysed and, as a result, it has been decided that in order to apply different implementation schemes, especially theoretical ones, it is necessary to acquire the basic knowledge required to designate physical devices and their quantity where the method is applied, which would help to interpret the impressive increase in imports of several types of mineral resource whilst limiting the use of local ores under the relevant conditions.

Referring to the definition introduced by Ghodrati et al (2007), technogenic areas containing mineral accumulations constitute a type of technogenic deposits. Their evaluation requires a set of studies and excavations to recognise the value of georesources of mining industries and their industrial waste, given the integration of their use and protection of external factors. This demonstrates that when prospecting and exploring areas with minerals, all factors that affect the quality of the work presented must be considered and the reliability of the planned quality of the ores must be assessed with reference to the estimated accuracy of the average grade of the ores. No consideration has been given to the fact that this composition of research and operations leads to a systematic unity of methods applied in geology, mining systemology and geotechnology, which indicates an innovative direction in the mining sciences such as subsoil qualimetry.

La Notte et al. (2018) determined that the activity of existing and potential mineral developers can be understood from data on the proportion of sales and tenders for the rights to use minerals that have taken place in their holistic declared grade. The decline in the number of submitted applications is also indicative of the subsoil areas identified for geological survey at the expense of mineral developers' finances. The reliability of mineral developers is signified not only by the considerable expense associated with organising and carrying out prospecting and appraisal work and a considerable degree of inaccuracy of its results, but also by the presence of administrative infringements. However, to discover deposits and to obtain a licence to exploit the desired resources, a method algorithm must be developed and validated to assess the reliability of the planned quality of the ores, given the estimated accuracy of their average grade (Borisov et al., 1990; Kunitskiy et al., 1988). It is therefore very important to consider the specifics of the use of this type of method, the timely analysis of data and possible causes of error, with a view to the future advancement of the application of these methods in different production facilities.

Hoßfeld et al. (2011) determined that the issue of identifying, investigating, quantifying, and managing the economic risks of a mining enterprise is invariably an important one. Two main groups of risk impact are presented, macroeconomic and microeconomic risks, the identification and review of which shows terms for marking the likely proportions of risks, reducing them to an acceptable proportion, to create a method of risk assured management and assessment. The analysis and assessment of natural risk, mining and geological risk, and the appropriate calculations have presented the great economic value of the understudied global challenge of creation and magnitude of investment risk in the study of complex mineral deposits, defined by objectively increased inaccuracy of reserve data, such as the example of an ore deposit. Having analysed and examined this issue and the findings of this study more precisely, it can be concluded that the methodology generally accepted in practice of estimating deposits of mineral resources (ores) of this type based on deterministic reserve estimates by exploration classification, does not adequately reflect risks and naturally needs some further adjustments and modifications.

McGlynn (1998) has established that the presence of mineral deposits, including ores, with satisfactory reserves in the public account is a guarantee of long-term financial viability. Therefore, for the present uninterrupted supply of these types of raw materials to consumers, certain extraction capacities of the functional plants have to be supplied with stocks. As argued by Benndorf et al. (2015), the need to substantially increase the quality of the marketable ores during their extraction is one of the main and relatively modern challenges of the mining industry, which under the planned economy regulations had almost no practical impediments to marketing any even very poor-quality product, which naturally did not contribute to a progressive increase in production. The analysis and advancement of these methods of qualimetry is one of the main provisions of modernisation of mining production, establishment of prospective managed operation of product reliability formation based on innovative information and management systems. Additional funding and personnel training is essential, and new technology must be introduced to improve the development and research of methods for assessing the reliability of planned consumption grade of ores, given the estimated accuracy of the average grade and to minimise errors that occur when using this method.

CONCLUSIONS

The features of "hidden" structurally stabilised at the level of limiting minima of uneven variability, heterogeneity, statistical variability, and geometrical uncertainty of metal content, reproduced zonally invariant and homogeneous geological areas regularly occurring at qualimetric partitioning of ore reserves by modal geoindicators are revealed. Based on the results of the analysis of the qualimetric partitioning of the heterogeneous medium using modal geoindicators, a previously unknown pattern of reproducibility of stable in aggregate, frequency, and spatial integrity in the form of distinguishable individual invariant zones has been established. Variability, uncertainty, and irregularity in the frequency of spread of the variables are found to stabilise at the level of marginal natural minima in their contours. The results of on-site experimental testing of the identified pattern in iron ore and chromite deposits are presented using actual data. The pattern of heterogeneity, stochastic random fluctuations, and ambiguity in metal content concentration is confirmed by qualimetric partitioning of their reserves. As a consequence, parameter reliability, accuracy and consistency of consumer quality are enhanced. Minimal limits of deviations of initial mining grades, entering the concentration-processing processes from those planned for the mined-out areas of the deposit, achieved during the mining of reserves of the reproduced areas of ordinary, high-grade and contour ores, which eliminate the unreliability of the planned quality of ore products during mining, are established and proved to be achievable.

The values of non-uniformity of fluctuations (V_{HP}), heterogeneity (V_{ht}), random variability ($V_{ran.}$) of the contents, which determines the level of stability of their values spread, decrease on average in the conditions of Geofizicheskoe chromite deposit by V_{HP}=1.2÷1.7, V_{ht}=1.2÷4.0, $V_{ran.}$=2.7÷2.2 times, Lisakovsk iron ore deposit by V_{HP}=1.3÷2.0, V_{ht}=1.2-2.0, $V_{ran.}$=1.4-2.5 times. The accuracy of determining the average grade using the weighted average method involving frequencies is higher due to a 1.3÷1.5 times lower variability and irregularity in the distribution of the useful component than the arithmetic method. The determination of the consumer quality of ore products is more accurate than with the traditional approach by reducing the random variability and irregularity of the variation of grades in the operating conditions of Geofizicheskoe chromite, Lisakovsk iron ore, and Zhairem polymetallic deposits on average by 1.3÷2.5 times. Geological and geometric bases are established for the output of consumer quality ores and modernisation of processes of exploration, evaluation, preparation, and extraction of solid mineral reserves; excessive costs of technical homogenisation of extracted ores, systematic loss of metals in mining wastes and tailings are eliminated.

Declarations

The authors declare that there is no conflict of interests.

Credit authorship contribution statement

Azimhan Kurmankozhaev: Conceptualization, Project administration, Visualization, Investigation, Methodology, Formal Analysis, Writing - original draft.

Timur Kurmankozhaev: Investigation, Methodology, Validation, Supervision, Writing - review and editing.

REFERENCES

Abolghasemian M., Kanafi A.G., Daneshmand-Mehr M., 2022. Simulation-based multiobjective optimization of open-pit mine haulage system: A modified-NBI method and meta modeling approach. Complexity 1, 3540736.

Akhras M.H. and Fischer J., 2022. Sampling scheme conception for pretreated polyolefin waste based on a review of the available standard procedures. Polymers 14, 3450.

Balakina A.S., 2020. Toolkit for the development of corporate social responsibility of industrial enterprises in single-industry towns. Yekaterinburg: Ural Federal University named after the first President of Russia B.N. Yeltsin.

Basalai G.A., 2022. Design of mining machines and equipment. Minsk: Belarusian National Technical University.

Benndorf J., Yueksel C., Soleymani Shishvan M., Rosenberg H., Thielemann T., Mittmann R., Naworyta W., 2015. RTRO-coal: real-time resource-reconciliation and optimization for exploitation of coal deposits. Minerals 5, 546-569.

Borisov Y.S., Korzhyk V.N., Fialko N.M., Prokopov V.G., 1990. Thermal and physicochemical conditions for formation of thermal sprayed coatings with metastable structure. In: Proceedings of the International Workshop on High Temperature Dust-laden Jets in Plasma Technology. USSR: Novosibirsk, 315-328.

Deryaev A., 2024. Integration of advanced technologies to improve the efficiency of gas condensate field development. Machinery & Energetics 15, 33-42. doi: 10.31548/machinery/1.2024.33

Frantsky I.V. and Bazanov G.A., 1975. Mathematical statistics and geometrization of deposits. Irkutsk: Irkutsk Polytechnic Institute.

Fu B., Hower J.C., Zhang W., Luo G., Hu H., Yao H., 2022. A review of rare earth elements and yttrium in coal ash: Content, modes of occurrences, combustion behavior, and extraction methods. Progress in Energy and Combustion Science 88, 100954.

Ghodrati B., Akersten P.A., Kumar U., 2007. Spare parts estimation and risk assessment conducted at Choghart Iron Ore Mine: A case study. Journal of Quality in Maintenance Engineering 13, 353-363.

Gudkov V.M. and Khlebnikov A.B., 1990. Mathematical processing of mine surveying and geodetic measurements. Moscow: Nedra.

Hoßfeld T., Seufert M., Hirth M., Zinner T., Tran-Gia P., Schatz R., 2011. Quantification of YouTube QoE via crowdsourcing. In: 2011 IEEE International Symposium on Multimedia. Piscataway: IEEE, 494-499.

Kalandarov I.I., 2021. Construction of a mathematical model of the production system and information support for the tool shop. Basic and Applied Research: Current Issues, Advances, and Innovation 1, 47-50.

Kamel A., Elwageeh M., Bonduà S., Elkarmoty M., 2023. Evaluation of mining projects subjected to economic uncertainties using the Monte Carlo simulation and the binomial tree method: Case study in a phosphate mine in Egypt. Resources Policy 80, 103266.

Korzhik V.N., 1992. Theoretical-analysis of the conditions required for rendering metallic alloys amorphous during gas thermal spraying. 2. Phase formation during solidification of the sprayed material. Soviet Powder Metallurgy and Metal Ceramics 31, 826-830. doi: 10.1007/BF00797499.

Kościelniak P., 2022. White calibration methods based on gradient techniques as a modern approach to quantitative flow analysis. TrAC Trends in Analytical Chemistry 157, 116758.

Kunitskiy Y.A., Nemirovskiy A.V., Korzhik V.N., 1988. Change of local magnetic parameters in cast amorphous and sprayed Fe40Ni40B20 alloys after mechanical and heat-treatment. Fizika Metallov i Metallovedenie 65, 295-301.

Kurmankozhaev A., 2008. Fundamentals of qualimetry of georesources in geodesy and mine surveying. Almaty: Satbayev University.

Kurmankozhaev A., 2017. Patent No. PCT/KZ2017/000025

“Method for the qualimetric preparation of geological reserves by mine strata”. https://patentscope.wipo.int/search/ru/detail.jsf?docId=WO2019039925.

La Notte A., Tonin S., Lucaroni G., 2018. Assessing direct and indirect emissions of greenhouse gases in road transportation, taking into account the role of uncertainty in the emissions inventory. Environmental Impact Assessment Review 69, 82-93.

McGlynn E.A., 1998. Choosing and evaluating clinical performance measures. The Joint Commission Journal on Quality Improvement 24, 470-479.

Niyazbekova Sh.U. and Tleubekov K.B., 2019. Problems of employment of the population of the Republic of Kazakhstan in the conditions of social modernization. BBC 74, 46-58.

Oliynyk T.A., Wilhelm M.N., 2021. Prerequisites for increasing the selectivity of the separation of ore and non-ore components of the frothy flotation product. Mining Journal of Kryvyi Rih National University 109, 73-78.

Prokopov V.G., Shvets Y.I., Fialko N.M., Meranova N.O., Korzhik V.N., Borisov Y.S., 1989. Mathematical-modeling of the convective heat-transfer processes during formation of the gas-thermal coating layer. Dopovidi Akademii Nauk Ukrainskoi RSR, Seriya A-Fiziko-Matematichni ta Technichni Nauki 6, 71-76.

Pysmennyy S.V., 2021. Improvement of the technology of the development of iron ore deposits by systems of sub-surface rolling of ore and accommodating rock. Mining Journal of Kryvyi Rih National University 109, 61-67.

Shyrin L., Koroviaka Y., Rastsvietaiev V., Denyshchenko O., 2018. Substantiating rational parameters of a method for shrinkage ore stoping while developing thin-vein steeply inclined deposits. E3S Web of Conferences 60, 00022. doi: 10.1051/e3sconf/20186000022.

Sinchuk O.M., Beridze T.M., Kasatkina I.V., Peresunko I.I., 2023. Etiology of the effects of monitoring in the paradigm of evaluating the development strategy of an iron ore enterprise. Journal of Kryvyi Rih National University 57, 8-10.

Smith R., Faramarzi F., Poblete C., 2022. Strategic and tactical mine planning considering value chain performance for maximised profitability. https://goo.su/Fjr6HWD.

Turylo A.M., Korolenko R.V., Svyatenko S.V., 2023. Financial result: the essence and assessment of its innovative component for enterprises of the iron ore industry of Kryvbas from the point of view of the content of financial activity. Journal of Kryvyi Rih National University 56, 62-66.

Vartanova M.L., 2021. National priorities and prospects for the development of the Eurasian economic integration. In: E.V. Fomin (Ed.), Economics and Law. Cheboksary: Sreda, 33-74.