Distribution of Antimony and Gold in Old Tailings and Heaps at the Milešov Locality (Příbram District)

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Abstract

Antimony ores were extracted and processed near the village of Milešov (Příbram district) for about twenty years in the second half of the 19th century. Large heaps and a small sludge pond were left behind after this period. In 1988, this locality was inspected and sampled in order to gather information about residual resources of gold and antimony. The original archive data from this survey were now studied again and interpreted using modern statistical and geostatistical methods. The interpolations methods chosen for this purpose were inverse distance weighting (IDW), simple kriging and geostatistical sequential Gaussian simulation (SGS). These procedures allowed for a much more accurate determination of the spatial distribution of the elements or substances studied. The results showed significantly higher volumes and a more accurate localization of the studied elements in both bodies (heap and tailings). This procedure can be considered as the basis of a new methodology for the assessment of similar objects.

Keywords: geostatistical methods, digital model, antimony ore mining, mining waste

Introduction

In the second half of the 19th century antimony ores were mined in the northern part of Milešov village, district of Příbram (Figure 1).

After the extraction and processing of ores, there left large heaps (Figure 2) and smaller sludge pond, which are almost untouched since the end of the operation.

In 1988, a detailed sampling was carried out and a final report with the calculation of the residual Au and Sb resources was finalised up (Mandík, 1988). All analyses and survey data are still available in archives.

At the end of the 20th century there was a worldwide increase in the consumption of mineral resources. The response to this trend has been the initiative "The Raw Material Initiative - Meeting our critical needs for growth and jobs in Europe", which defined a strategy for the future use of mineral resources. One of the pillars was also the recommendation to use secondary sources, represented by materials from the heaps and tailing ponds. The Task Force at the European Commission in June 2010 drafted the report "Critical raw materials for the EU", which included a list of so-called critical raw materials, including antimony (Sb), which was the main mined component at Milešov locality.

These facts led to try to re-interpret the original archive data using statistical and geostatistical methods.

Digital modeling of monitored elements spatial distribution

Modern statistical and geostatistical methods allowe to determine the spatial distribution of studied elements or substances with much greater accuracy. The first step in creating digital models of geological bodies is the processing of a digital terrain model. As a basis for the creation of the spatial model data from the 5th Generation Digital Model Relief (DMR 5G) of Czech Office for Surveying, Mapping and Cadastre (ČÚZK) was used. Consequently were created grids of heaps and tailing pond.

The reconstruction of the original surface at the site from the time of the exploration works was also solved. It has been shown that there is insufficient data in the available documentation to determine the morphology of the terrain at the time of sampling. Therefore, the current LIDAR data situation was taken into account for the creation of the model of these two bodies, knowing that in some places the terrain situation may have varied a little, but any differences would not have a significant impact on the results achieved.

A very important step was the consistent verification and correction of the input data. A number of incorrect data was found in the primary input data set from period of 1988 and it was necessary to edit them. The changes in data were mainly related to the unification of the reported values for the analysed elements (g, % and ppm), the correction of the coordinates of the exploration works and the addition of the Z (altitude) coordinates for all exploration work. From these data, a surface grid of the both bodies (heap and sludge pond) was created. The scope (delimitation) of both bodies was derived from the real situation in the field and from the location of the individual exploration work.

The corrected and completed input data was divided into 10 cm sections using the macro. The values of the technological parameters (contents) were located at the center of each section. For a heap it was total of 2028 sections and for sludge pond it was total of 822 sections. Such data has become the basis for their further treatment, i.e. data choices for creating horizontal and vertical cuts, statistical analysis, girding and visualization in 2D and 3D.

Fig. 1. Situation of the Milešov locality (top of the red arrow) in the map section (https://mapy.cz)
Rys. 1. Mapa sytuacyjna miejscowości Milešov (u góry czerwonej strzałki) w części mapy (https://mapy.cz)

Fig. 2. Front view at heaps from southwest
Rys. 2. Widok z przodu na hałdach z południowego zachodu

The process of statistical treatment and geostatistical structural analysis followed. The basic statistical processing of the technological parameters was performed in the Stanford Geostatistical Modeling Software (SGeMS). Due to different file formats, a special macro was created to convert input data into the SGeMS environment. Thus, histograms (graphical presentation of the data distribution using a column graph, where the height of the columns represent the frequency of the monitored quantity within a given interval) of Sb and Au for the heap and tailings were created. Further, a geostatistical structural analysis of the input data was carried out, describing the continuity, homogeneity, stationarity and anisotropy of the studied field. The above-mentioned SGeMS program was used to create experimental variogram (a discrete function calculated using a measure of variability between pairs of points at various distances) and selected theoretical variogram. The resulting variograms were used for the method of block kriging and geostatistical simulations.

Applied interpolation methods

Inverse Distance Weighting (IDW)

This method assumes that the value of the studied variable at the selected (random) point is statistically dependent on the values measured in its surroundings (Staněk, 2005). The effect of these surrounding values on the interpolated value decreases with the distance. Because of scarce sampling density, a relatively small amount of input data was available. The parameters for an ellipsoid of anisotropy and data selection was chosen 50 m in the X axis direction, 50 m in the Y axis direction and 2 m in the Z axis direction. Into the studied area was projected a regular grid and then 3D grids for Sb values and Au values, both limited by the surface. For this projection was used the Math module in the Voxler environment (http://www.goldensoftware.com/products/voxler).

In some parts of the heap there have also generated significant extrapolations due to the considerable extent of the ellipsoid and it may not necessarily correspond to reality. In the statistical comparison of the Sb and Au input values distribution and the values calculated for the 3D grid, the histograms show differences. The reason is low input data density and the limitation of both bodies by the terrain surface.

Ordinary Kriging (OK)

This spatial estimation method is based on the prerequisite of a zero mean value of the difference between the real and the estimated value of the monitored variable and minimal scattering of this difference. It gives the most accurate estimate of the mean value at a given domain, but unlike the input values, the scattering of the calculated values is minimal and calculated values are considerably smoothed (Remy et al., 2009).

The distribution of the input data for Sb and Au were considerably skew for both objects, so the transformation of the input data into the normal (Gaussian) distribution had to occur during the modeling process. Subsequently, the transformation of the calculated values of the blocks (3D grids) into the original distribution was performed. An ellipsoid of anisotropy and data selection with 50*50*2 m parameters was selected for this variant. The Sb and Au spatial grids were generated in the SGeMS environment and their geometry parameters were the same as for the IDW method.

For interpolation, it was necessary to create Sb and Au variograms for normal distribution of input data. Subsequently, the 3D grids Sb and Au were limited by the terrain surface.

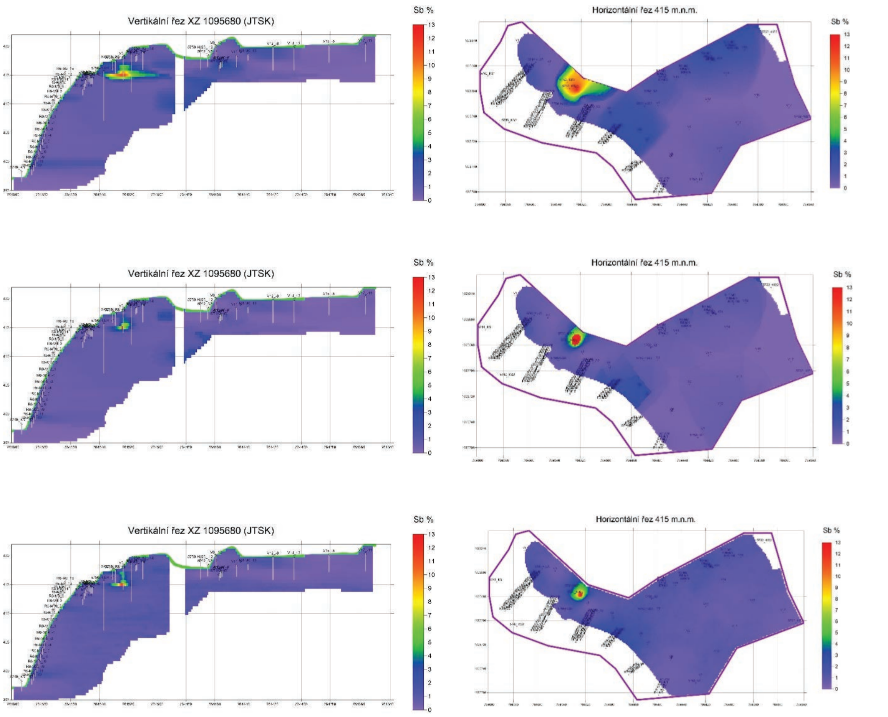

Fig. 3. Comparison of Sb distribution in vertical plane by chosen IDW, Kriging (OK) and SGSIM methods (on the left from top to bottom) and comparison of Sb distribution in horizontal plane by chosen IDW, Kriging (OK) and SGSIM methods (on the right from top to bottom)

Rys. 3. Porównanie rozkładu Sb w płaszczyźnie pionowej według wybranych metod IDW, Kriging (OK) i SGSIM (po lewej od góry do dołu) i porównanie rozkładu Sb w płaszczyźnie poziomej przez wybrane metody IDW, Kriging (OK) i SGSIM (po prawej od góry do dołu)

These grids of the monitored elements were converted to SGeMS, where a subsequent transformation of the calculated values of the blocks (3D grids) into the original distribution was done. The spatial 3D Sb and Au grids in the original distribution were converted by macros to be visualized in various ways.

Comparing the histograms of the distribution of the input and calculated Sb and Au values in the 3D grid we can observe the differences for all the monitored elements. This is caused again by the limitation of studied bodies by the surface terrain and due to low density of input data.

Sequential Gaussian Simulation (SGSIM)

SGSIM belongs to stochastic geostatistic methods. It allows calculating the values of a regionalized variable in the studied domain in that way, that the simulated values at the known measurement points (data sampling) exactly match the originally detected values (Goovaerts1 1997; Soares, 2001). In addition, the generated values have the same statistical distribution and the same variogram as the input values. Unlike kriging, the distribution of the input values coincides to the calculated values. Each of these implementations provides an equally probable possibility of unknown regionalized variable presentation.

For this variant, the same ellipsoid of anisotropy and data selection was chosen as in the previous method, i.e. 50*50*2 m. The same ware the variograms of the Sb and Au input data in the normal (Gaussian) distribution and the input parameters of 3D grid geometry was also the same.

For each element (Sb and Au) a hundred realizations were created, from which the mean value of blocks (E-type) was calculated. To convert data between different environments, special macros were created in Visual Basic for Applications. The spatial 3D grids Sb and Au in the original distribution were limited by the surface of the terrain and subsequently visualized in various ways.

Also in this case comparing the histograms of the distribution of the input values and the calculated values both of two elements shows very distinct differences. The reason is again a small density of input data and the limitation of both bodies by the terrain surface.

Comparison of achieved results

In the 1988 survey a total of 7 blocks were defined at this locality and reserves of Au and Sb were calculated as a cut method. In current mathematical models, spatial distribution of element contents is determined using 3D grids formed by regular blocks (segments). The number of segments varies with each of the used methods and depends on the selected parameters. The size of each block was 1 m * 1 m * 0.5 m and the volume of one block was 0.5 m³. For digital processing and visualization of distributed elements, special software was developed for the use of Voxler (http://www.goldensoftware.com/products/voxler) and Surfer (http://www.goldensoftware.com/products/surfer) products by Golden Software (). The Voxler environment allows creation of different types of the input data visualization. The results of the Sb distribution within the heap in vertical plane (XZ 1095680) are shown in Figure 3 on the left and horizontal plane (415 m above sea level) are shown in Figure 3 on the right. We can see distinctly how differentially each method interprets the detected Sb anomalies.

The elements content estimation for each variant of the used models was calculated by the newly created program in

Tab. 1. Comparison of Au and Sb contents by particular methods
Tab. 1. Porównanie zawartości Au i Sb według poszczególnych metod

Used method	Au (kg)	Sb (t)
Vertical cuts (1988)	60,694	446,890
Inverse Distance Weighting	475,609	2523,444
Ordinary Kriging	397,933	2107,551
Sequential Gaussian Simulation	375,283	2491,144

Visual Basic. All the founded values of Au and Sb are shown in the Table 1 and they are compared with the results calculated by the cut method in 1988.

Although the same input data se was used, the amount of Au and Sb calculated by current geostatistical methods is significantly higher than the data obtained in 1988 by the cut method. For gold, the increase is almost seven times and the results of SGSIM and kriging are relatively close. For antimony, the increase is more than five times higher. Here, on the other hand, the most similar results are from the SGSIM and IDW methods.

Conclusion

This article presents the new concept for visualization of the monitored elements, their distribution and estimations of their content in the defined bodies. In this case, methods of Inverse Distance Weighting, Ordinary Kriging and Sequential Gaussian Simulation were used.

These results were compared to each other and to the data of the previous calculation made by the cut method. The volumes of studied elements were found to be almost six times higher than those calculated in 1988. The most realistic models are based on SGSIM, which is also the most modern method that eliminates some IDW and kriging negatives. However, if new exploration works could be done in greater density, more suitable localization and a wider range of analyses, the results would be much more accurate.

Calculations, visualization and creation of digital models have been applied to secondary anthropogenic objects, but can be also applied to primary geological bodies with natural deposition and distribution of elements.

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Rozkład zawartości antymonu i złota w starych osadnikach i hałdach w miejscowości Milešov (powiat Příbram)

Rudy antymonu były wydobywane i przetwarzane w pobliżu wioski Milešov (powiat Příbram) przez około dwadzieścia lat w drugiej połowie XIX wieku. Po tym okresie pozostały duże hałdy i mały staw osadowy. W 1988 r. miejscowość została poddana inspekcji i próbkowaniu w celu zebrania informacji o pozostałościach złota i antymonu. Oryginalne dane archiwalne z tego badania zostały teraz ponownie przeanalizowane i zinterpretowane przy użyciu nowoczesnych metod statystycznych i geostatystycznych. Metody interpolacji wybrane do tego celu to odwrotne ważenie odległości (IDW), prosty kriging i sekwencyjna geostatystyczna symulacja Gaussa (SGS). Procedury te pozwoliły na znacznie dokładniejsze określenie rozkładu przestrzennego badanych pierwiastków lub substancji. Wyniki pokazały znacznie wyższe objętości i dokładniejszą lokalizację badanych pierwiastkach w obu lokalizacjach (hałda i składowisko odpadów). Procedurę tę można uznać za podstawę nowej metodologii oceny podobnych obiektów.

Słowa kluczowe: metody geostatystyczne, model cyfrowy, wydobycie rud antymonu, odpady górnicze