The abandoned mines rehabilitation on the basis of speleotherapy: used for sustainable development of the territory (the case study of the single-industry town of mining industry)

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The depletion of mineral resources and the increasing complexity of mining conditions (including the strengthening of environmental legislation) lead to a reduction in mining activities. This causes serious problems for towns and cities where mining was the main activity of their residents. The problem's solution to such settlements is seen in the development of new types of economic activity on the basis of abandoned mines. The most common is currently caving, eco-tourism and historical tourism. The sustainable development of the territory depends on the economic activities of agents and the ecological safety of the region. Rehabilitation of abandoned mines makes it possible to implement new ways of use of closed mines and improve economic and ecological situation in "mining cities". Russia has good experience in the use of salt mines with the rest of their minerals for their application as speleoclinics. The article aims to analyze the possibilities of organization of speleotherapy on the basis of waste mines of the mining industry. The developed economic and mathematical model allowed to estimate the economic effect of the development of speleotherapy on the basis of salt mines of Berezniki potash deposit. The analysis proved the positive effect of the development of speleotherapeutic services for the socio-economic system of the city of Berezniki as a whole.

Key words: *Mining industry, salt mines, speleotherapy, economic and mathematical model, sustainable development*

Introduction

An acute problem in the development of mono-cities built on the mining industry is the search for ways to preserve the socio-economic system of the territorial settlement and its development after the mining of minerals has been reduced or completely stopped. In many countries, including central Europe, "the mining exploitations have led to the birth of communities, and for some, they have been a growing source. Therefore abandoned mining sites have a huge impact on economic, social, ecological and urban terms" (Biały, 2014; Midor and Zasadzień, 2015; Pascu, 2013). The negative social and economic implications of mining restructuring is exacerbated by such cause as mono-professional specialization and low educational level of the labor force (Costache and Pehoiu, 2010).

After the cessation of mining activity, the population faces a difficult choice (Schejbal, 2011; Demirović et al., 2018). In this case, the task of effective interaction between mineral developers, local authorities, local community, the population at the choice of a specific direction of restructuring closing mines is to ensure the sustainable development of the territory arises among all members of the society (Shekov and Shekov, 2016).

The first option is to change the region of residence. This has been actively used in European countries: "After stopped of mining activities in developed countries at the end of 20 century, mining work removal, as well as standard technological procedures of reclamation brought removal of unique mining works and machinery, and abandonment of former mining settlements. These solutions were correct, for they put an end to hard work and unsuitable living conditions in mining settlements" (Hronček and Rybár, 2016). However, this path is a difficult task in Russian conditions, since it requires significant capital investments.

The second option is the re-profiling of city-forming activity under a new look. The development of mining, mountain, and speleological tourism is widely used in the world as the implementation of such direction. As many modern researchers have noted: "Paradoxically, attenuation of mining activities has brought about greater importance and popularity of mining tourism" (Hronček and Rybár, 2016).

It is possible to combine different types of tourism: mountain, ecological, historical and cultural. After the termination of mining and removing of the inhabitants to other places, the mines are abandoned, and the technologies, mechanisms, and tools used in mining are destroyed. At the same time mining technology is a kind of cultural and historical heritage in those countries where mining has been developed for centuries. Researchers from Slovakia, Romania, Poland (Biały, 2014; Biały & Mroczkowska, 2015; Midor & Zasadzień, 2015) the

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Czech Republic emphasize the importance of preserving the mountain heritage for the comprehensive support of the development of the former mining areas. They note that in Central Europe, after the decline of mining activities, their historical significance has been recognized, as well as a «willingness to recognize social, economic and technological relations of mining increase» (Rybár & Gómez, 2014). G. Pascu, J. Bayon, and T.O. Gheorghiu present three possibilities of tourism regeneration of waste mines and their impacts in Romania (Pascu et al., 2013).

The third way is a combination of medical and sanatorium-resort treatment on the basis of waste mines. This option is possible in case if the mine contains ore reserves, which can be used for medicinal purposes.

However, there can be some problems. In particular, dumps taken to the surface or waste rock, dips in the soil after the extraction of minerals, faults and washouts and other negative phenomena that spoil the natural landscape remain in the environment after mining. "Dumps after underground mining usually remain like stars on the appearance of the landscape" (Hrončeк and Rybár, 2016). "The open craters filled with water and garbage, having steep, unstable slopes represent most of the abandoned quarry sites, raising public health and safety concerns additionally to unpleasant environments" (Jayawardena et al., 2018). For example, Figure 1 shows the photographs of two craters from the failures of the mines of the Bereznikovsky mine department (Russia, Perm region). The first crater is located right in the city center between the buildings threatening their safety. The second crater is located outside the city above one of the mines that were flooded by the earthquake.

Fig.1. The craters from the failures of the mines of the Bereznikovsky mine department

In Italy in the region of Sardinia "abandoned tailing dumps from mining industry represent important sources of metal contamination in the surrounding environments" (Bacchetta et al., 2015). A similar problem is in Romania: "Abandoned mining sites contain large quantities of mineral processing wastes stored in dumps that are characterized by high concentrations of heavy metals" (Gherman et al., 2012). "Disturbed lands with traces of old mines in different regions of Russia, both in use and abandoned mining-industrial territories" (Shekov et al., 2017) are scientific and practical objects of modern research of the Russian scientists such as V.V. Zapariy, (Zapariy, 2009), G.D. Pershin (Pershin, 2014), A.L. Potravnov and T.Y. Khmelnik (Potravnov and Khmelnik, 2015), K. Shekov, V. Shekov (Shekov et al., 2017).

A particular problem is the presence of large quantities of heavy metals in the dumps and the metal accumulation in wild plants surrounding mining wastes (Angiolini et al., 2005; González and González-Chávez, 2006) and in the crop plants at different levels of soil contamination (Zubkova et al., 2016).

Sometimes such dumps or spills contain toxic chemicals that cause significant environmental damage and have negative environmental effects on the environment for a long time. The development of tourism and other activities in such areas is unacceptable. For such situations requires a large and long-term rehabilitation of the soil. However, "the traditional rehabilitation methods are rarely applicable for such circumstances due to unique socio-economic conditions and stakeholder aspirations" (Jayawardena et al., 2018) and mine ecological closure costs are rather big (Sorensen, 2007; Sorensen, 2008). A. Paulo wrote about the environmental limitations in possible directions of post-mining land use (Paulo, 2008). The environmental hazard in the mining district for southern Iglesiente (Sardinia, Italy) has been described by M. Boni and colleagues (Boni et al., 1999).

The forming of the landscape of post-mining areas in Poland (Biały, 2014; Biały & Mroczkowska, 2015; Midor & Zasadzień, 2015) and an inactive basalt quarry in Strzegom was analyzed in the works by K. Tokarczyk-Dorociak, K. Skolak, and M.W. Lorenc (Tokarczyk-Dorociak et al., 2010; Tokarczyk-Dorociak et al., 2015), K. Zych-Głuszyńska (Zych-Głuszyńska, 2011). Tourist possibilities of using the closed marble quarry in the Republic of Karelia (Russia) were revealed and presented in the works of I.V. Borisov (Borisov, 2014), A.B. Artemyev and A.A. Yushko (Yushko and Artemyev, 2015), K. Shekov and V. Shekov (Shekov and Vitali, 2017). A.E. Kurlaev (Kurlaev, 2015), Yu.S. Lyakhnitsky, A.A. Yushko, O.A. Minnikov, I.Yu. Khlebalin

(Lyakhnitsky et al., 2015), Zh. Mingaleva and O. Bunakov (Mingaleva and Bunakov, 2014), N.S. Solonina and O.A. Shipitcina (Solonina and Shipitcina, 2015) engaged in identifying other opportunities for the development of mountain tourism in Russia.

Finally, some modern authors (but they are few) are considering the possibility of transforming dying mountain villages on the abandoned mining sites in alternative industrial production parks. The implementation of this direction "would have an enormous positive impact both nationally and internationally" (Pascu et al., 2013). However, this direction of the renovation of mine towns is still poorly disclosed in the scientific literature, although the creation of industrial production parks and technoparks in various areas of the economy is studied widely in world science and Russia (Shaidurova et al., 2017; Mingaleva and Shaidurova, 2018). Conclusions and recommendations on the possibility of using old mines should be based on an assessment of the general and special characteristics of the mine and the stock of mineral raw materials in it, based on an assessment of the state of the transport and social infrastructure of the mine settlements and the ability to create new products or services on it, based on an assessment of environmental risks.

Theoretical and methodological background

International studies of the mining heritage and speleotourism development

The development of various types of tourism associated with mountains, mines, caves has recently been widely discussed by the scientists in the countries where mining of mineral resources is becoming more and more costly and less profitable, and mines are being closed.

A comparative analysis of the world scientific literature on the renovation of former mining areas showed a certain concentration of research on certain areas of their development. Thus, scientists from Slovakia and Slovenia are primarily focused on the study of opportunities for the development of mountain tourism, including historical, industrial and other types of tourism: "historical mining monuments processed have become the main attraction in the still-developing of both - geo and mining tourism in Slovakia" (Hronček and Rybár, 2016). In their studies, they widely use the term "mining heritage". Mining heritage can also cover the territory, which has long depended on mining. In territorial terms, we may assign mining heritage in different categories. In general, the concept of heritage can be defined by cultural, natural and mixed categories, what is a case that covers the most areas where mining existed for a long time" (Hronček and Rybár, 2016). As for the term "Mining heritage" itself, it can be applied even in general to the territory "which has long depended on mining" (Hronček and Rybár, 2016).

«Mining tourism offers visitors a chance to see and get to know a follows: mining tools, devices and technologies, minerals, ores and rocks accessible in the region, technologies applied in ore extractions, as well as technologies used to enrich produced ores; historical personalities who used to secure and support mining process, just like conditions in the area after shut-downs of the operations» (Rybár and Hvizdák, 2010).

Also the study of geotourism and mining tourism in different countries, including UK, Southern Spain, Serbia, Romania and all European countries, devoted work by J. Swarbrooke (Swarbrooke, 2002), C. Schejbal (Schejbal 2005, 2011), E.R. Ballesteros and M.H. Ramírez (Ballesteros and Ramírez, 2007), P. Rybár (Rybár 2010), M.D. Petrović, N. Vuković, T. Gajić, D. Vuković and their colleagues (Petrović et al., 2017; Petrović et al., 2018), G. Mairescu, V. Timotin, N. Grudnicki, C. Zup, (Mairescu et al., 2014), Iu. Simionca (Simionca, 2013), P. Różycki1and D. Dryglas (Różycki1 and Dryglas, 2017). About the remediation for historical mining and smelting sites written by A. Dybowska and colleagues (Dybowska, 2006). P. Hronček and P. Rybár studied the relics in historical underground spaces and the possibility of their presentation in mining tourism (Hronček and Rybár, 2016).

The development of mining tourism is becoming more and more common in the world. Development of these types of tourism is economically attractive in Russia also. However, it is the practically untapped field of activity in Russia. Ruskeala Mining Park Phenomenon (the Republic of Karelia, RF) is currently the only good example of the active development of mountain tourism in Russia (Borisov, 2014; Shekov and Vitali, 2016).

Another direction of the use of waste mines is their use for medical purposes for sanatorium-resort treatment. When choosing this option to harmonize transformation processes, the industrial heritage of the region should be used, if possible, that could be successfully applied to a new type of city-forming activity. With regard to the mining industry, there are numerous mine workings, the existing transport, and urban infrastructure, which can be used for health purposes, in case if the developed field contains ore reserves, which can be used for medicinal purposes.

Many works by scientists from Romania and the Czech Republic are dedicated to the development of caving and speleotherapeutic services on the basis of salt mines. "The microclimate of some caves and salt mine can beneficially affect respiratory disorders and should be considered as an optimal environment for complex respiratory rehabilitation" (Munteanu, 2017). Biological evaluation of the therapeutic properties of salt mines was examined by N. Cl. Bilha and S. Bilha (Bilha and Bilha, 2015), N. Cl. Bilha and I. Simionca Iu (Bilha and Simionca, 2013), C. Munteanu, D. Munteanu et al. (Munteanu et al., 2013), D. Sas, O. Navrátil and P. (Sas et al., 1999). S. P. Beamon, A. Falkenbach, G. Fainburg and K. Linde based on a statistical database of clinical reviews of patients with asthma, have proven the effectiveness of speleotherapy for the treatment of this disease. (Beamon et al., 2001). Iury Simionca with his colleagues, they studied the speleotherapeutic and balneoclimatic tourism potential of salt mines in Romania (Simionca et al., 2010, 2012; Simionca, 2012, 2013). L. Thinová, A. Froňka and K. Rovenská studies the environmental and medical characteristics in the Czech caves (Thinová et al., 2015). V. Debevec published the encyclopedia of caves and karst science in the areas of speleotherapy (Debevec, 2003).

The study of different aspects of speleotherapy in conditions of sylvinite-halite mines was lead by scientists from Belarus (Levchenko et al., 2014).

Scientists from Russia are also focused on the study of the development of speleotherapy (Nevzorov and Mukhina, 2013; Fainburg, 2017; Bessmertnyy et al., 2018). The good experience of Perm region in the use of salt mines for the speleoclinics is described in the writings of the Perm researchers (Fainburg, 2005, 2017; Speleotherapy in potash mines, 2017). A significant level of development of karst and salt caves in Russia, as well as the accumulated therapeutic experience of the use of salt mines for medical and recreational purposes, has determined this direction of research and re-profiling of the activities of mining enterprises.

Opportunities for the development of speleotherapeutic activities based on salt mines

Speleotherapy as a scientific direction was developed in the middle of the XIX century. Several directions of speleotherapy appeared at this time. The use of the climate of salt mines and caves – speleotherapy, "is an accepted but not widely known therapeutic measure in the treatment of chronic respiratory diseases" (Munteanu, 2017).

Studies have shown that the use of sylvinite caves in waste mines for medicinal purposes can improve health among people with asthma and bronchitis by 76 %, sinusitis and depression by 71 %, tinnitus by 43 %, various types of allergies 89-92 %, rheumatism by 80 % and fatigue syndrome by 94 %. This improvement comes after passing a 3-week course of treatment with a daily two-hour stay in salt caves. In addition, patients improve sleep and performance. All this is achieved thanks to:

- the shielding effect of the mountain range or patient protection from the effects of human-made electromagnetic radiation;
- neutralization of radiation;
- saturation with air ions and the caving medium itself (without allergens and microbes) (Černecký et al., 2015).

Firstly, it is the use of underground mineral and hot springs (underground balneotherapy and hydrotherapy), which was developed in Italy in the XIX century in the form of speleotherapeutic hospitals.

Secondly, in the Mammoth Cave (Kentucky, USA) an attempt was made to use the air of the caves for the treatment of patients. However, this hospital existed only a few months and, after the death of one of the patients, was closed.

Fig. 2. The photos of the speleological hospital on the basis of 1st Berezniki mine

The history of modern speleotherapy dates back to the 50s of the XX century. At this time, speleotherapeutic hospitals appear in a number of countries of Eastern and Central Europe, which had numerous mountain caves and waste mines. Speleotherapeutic hospitals in the natural environment of karstic caves were organized most actively in Hungary, Czechoslovakia, and Romania.

An underground hospital was organized in the potash mine of the 1st Berezniki mine at a depth of 280 m from the earth's surface. In the thickness of potassium salt at a distance of 200 m from the shaft of the mine, which has a crate descent, used for the descent and ascent of people, the main workings were passed, from which 14 dead-end workings of 6-8 m length were made, intended for the stay of patients and the staff (Vishnevskaya et al., 1987). In 1994-1997 the Ministry of Health of Russia approved the special treatments (Manual for physicians) about the using of the speleo-climatic chamber of natural potassium-magnesium salts of the Verkhnekamskoye deposit (Treatment in the speleo-climatic chamber, 1994; Treatment of respiratory allergies, 1997).

It should be noted that the approximate cost of designing and constructing a speleological chamber with an area of 25 square meters in the Russian Federation currently amounts to 240 thousand rubles or 3.65 thousand dollars (Design and construction of salt caves throughout Russia; downloaded on 10. September 2018, available online: http://saltwaves.ru). Taking into account that these chambers are already built in the process of mining activities and do not require significant capital investments for conversion, it can be argued that competition on the national and international market of medical services under consideration will be minimal. In addition, the existing salt mines have a number of advantages: low gas content, centralized ventilation system for ventilation of chambers, launching system and transportation system, which can be converted for the transportation of patients. In 1982 the USSR took another important step in speleotherapy: the first climate chamber was patented, equipped with a salt filter-saturator and recreating the conditions of salt mines on the earth's surface (Qazizada et al., 2016). Thus, Russia has a good experience in the use of salt mines with the rest of their minerals for their use as speleo clinics.

Such cities as Berezniki and Solikamsk in the West-Ural region of the Russian Federation are an example of such cities and such mining enterprises, where the Verkhnekamskoye potash salt deposit (Fig. 3), which has large deposits of sylvinite and carnallite, is being developed.

Fig. 3. The location of the Verkhnekamskoye potash salt deposit on the map of the Perm region (Perm Krai).

The deposit area is about 8.1 thousand km^2, 205 kilometers long in the meridional direction, and up to 55 kilometers in the latitudinal direction (Baturin et al., 2012). Figure 4 shows the border of potash deposit in the salt deposit boundary and the location of functioning potash mines.

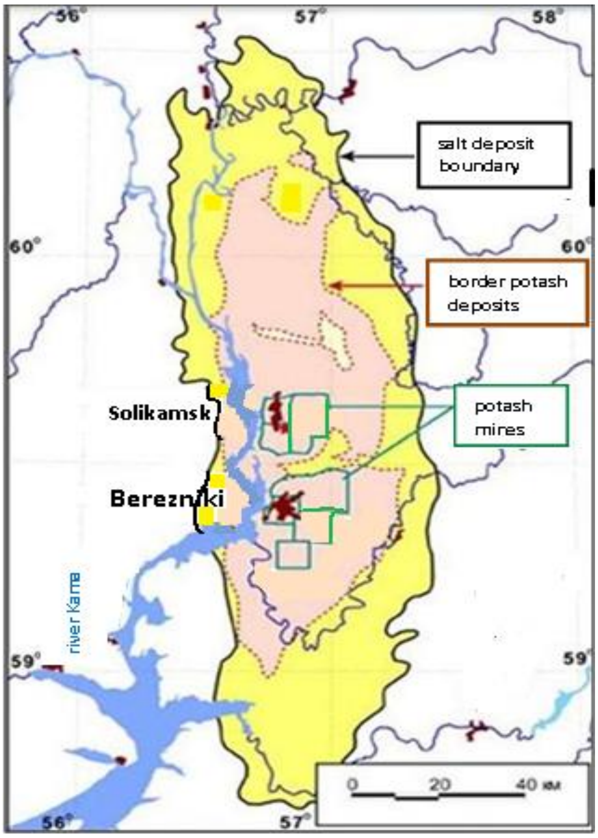

Fig. 4. The location of the salt deposit boundary, the border of potash deposit and the location of functioning potash mines of the Verkhnekamskoye potash salt deposit.

The development of the field is conducted by the town-forming enterprise OJSC Uralkali. The mine workings pass through salt beds, extending in one direction up to 10 km. The corridors and rooms of the mines have incredible beauty, not just healing properties (Fig. 5).

Fig.5. Walls and ceiling of the Uralkali's mine in Berezniki and Solikamsk

Materials and methods

Methods of analysis of the economic efficiency of the mining enterprises conversion

We carried out a rapid analysis of the economic benefits of reprofiling the mining enterprises in Berezniki after exhausting the saline reserves and stopping the enterprise activity.

At the first stage, an assessment of the potential consumer demand was made - the potential capacity (throughput) remaining after the development of the mines. To do this, we have proposed the following formula:

$$D = \frac{R*T_v*(1-\frac{Z}{100})}{N*P}, \quad (1)$$

where D is the carrying capacity of the mines remaining after development or the number of people who could undergo speleotherapy treatment at the same time, people;

T_v - total area of the existing salt mine workings suitable for rendering speleotherapeutic services, m^2;

R - mode of operation of speleological chambers in the mine workings, hours;

Z - the percentage of laying voids mining, %;

P - duration of stay of each patient in the speleological chamber in the mine workings, hours;

N - conditional norm of the area in the speleological chamber per person, m^2/ person.

As the experience of specialized speleotherapeutic organizations shows, average N value is equal to 17 m^2.

At the second stage, an assessment was made of the need for investment in the development of the urban hotel business to ensure speleotherapy tourism. For this calculation the following formula is used:

$$Q_o = K * \left(\frac{D}{O_c} - Q_d\right), \quad (2)$$

where Q_o is the number of additionally required hotels for the settlement of patients, people;

Q_d - the number of operating hotels in the region;

O_c - the average capacity of one hotel in the city, people/hotel;

K - specific capital investment in the construction of a hotel building according to a typical project characteristic of the given city.

At the third stage, the annual economic effect obtained by the city from the provision of a new service was assessed. The aggregate income of participants of the market for speleotherapeutic services was determined, its technological interconnections with other territorial markets were highlighted.

The calculation of income is made according to the formula:

$$V = D * S, \quad (3)$$

where S is the cost of a three-week treatment course.

Based on existing international experience, the minimum value of S is 2,760 euros (Healing salt caves of Berchtesgaden, 2018) or 208380 rubles.

Method of calculating the technological relationship between the complex of municipal markets

The technological relationship between the complex of municipal markets was determined on the basis of the available data of the Federal State Statistics Service according to the “Cost - Output” tables in monetary terms, which was formed on the basis of the well-known Leontiev’s inter-sectoral balance method in 2015 (National Accounts, 2018)

In accordance with this method the following identities are fulfilled:

$$X_i = \sum_{j=1}^{n} a_{i,j} * X_j + Y_i; \qquad i = \overline{1,n}, \quad (4)$$

where X_i is the gross production of the good of type i;

$a_{i,j}$ - the coefficient of direct material costs of the good i for the production of a unit of good j;

Y_i - the volume of final consumption of the good i.

$$X_i = \sum_{j=1}^{n} b_{i,j} * Y_j; \qquad i = \overline{1,n}, \quad (5)$$

where $b_{i,j}$ - the ratio of full material costs, calculated as a result of the transformation matrix of coefficients of direct material costs:

$$S = (E - A)^{-1}, \quad (6)$$

where a is the matrix of coefficients of direct material costs; E - the identity matrix of the same order as the matrix A.

On the basis of the study of the above mentioned actual data, the interrelations determined by speleotherapeutic tourism between the following urban markets were determined:

- hotel and restaurant services (1);
- agricultural products and services (2);
- food and beverages (3);
- pulp and paper products (4);
- electricity, gas, steam and hot water (5);
- construction services (6);
- wholesale trade (7);
- financial intermediation services (8);
- transport services (9);
- other goods and services supplied to the city from other territories (10).

Also, the coefficients of direct material costs were determined, which are presented in Table 1 in the context of these markets. In the table, markets are numbered in accordance with the above list.

In the *i*-th row of the table, there are the markets of the manufacturers (suppliers) of intermediate goods and services to the *j*-th consumers market described in the columns. These factors characterize the rate of consumption of good *i* for the production of a unit of good *j*.

This table also shows the rates of value-added and investments, which are formed when production increases for a good *j* by 1 ruble.

Tab. 1. Ratios of direct material costs, norms of value-added and investments per product (service) by markets.

Consumer markets / Manufacturers markets	1	2	3	4	5	6	7	8	9	10
Coefficients of direct material costs										
1	0,0022	0,0001	0,0005	0,0005	0,0005	0,0013	0,0009	0,0026	0,0011	-
2	0,0296	0,2012	0,3255				0,0008		0,0000	-
3	0,1537	0,0628	0,1712				0,0015		0,0001	-
4	0,0067	0,0032	0,0214	0,1725	0,0002	0,0007	0,0019	0,0010	0,0002	-
5	0,0281	0,0150	0,0150	0,0590	0,3540	0,0058	0,0040	0,0056	0,0456	-
6	0,0222	0,0027	0,0022	0,0036	0,0107	0,0267	0,0028	0,0009	0,0165	-
7	0,0413	0,0392	0,0621	0,0898	0,1139	0,0553	0,0304	0,0023	0,0172	-
8	0,0296	0,0097	0,0151	0,0189	0,0124	0,0141	0,0133	0,0833	0,0139	-
9	0,0065	0,0079	0,0083	0,0335	0,0123	0,0136	0,1329	0,0005	0,0481	-
10	0,2121	0,1001	0,1537	0,2760	0,1971	0,3996	0,2211	0,2030	0,3423	-
The rate of value added per ruble of finished products (services) in each market										
Payroll fund	0,1903	0,1018	0,0817	0,0931	0,1417	0,1858	0,1575	0,3244	0,1692	-
Sinking fund	0,0383	0,0272	0,0174	0,0392	0,0385	0,0079	0,1238	0,0618	0,0632	-
Tax deductions	0,0112	0,0036	0,0090	0,0128	0,0115	0,0104	0,0069	0,0353	0,0187	-
Net profit	0,2304	0,4256	0,1174	0,2017	0,1077	0,2801	0,3029	0,2818	0,2649	-
The specific amount of investment per ruble of finished products (services)										
Investments in machinery and equipment	0,0048	0,0189	0,0078	0,0272	0,0145	0,0369	0,0064	0,0017	0,0228	-

Source: own processing

Tab. 2. The coefficients of the total material costs per product (service) by markets.

Consumer markets / Manufacturers markets	1	2	3	4	5	6	7	8	9	10
1	1,0026	0,0003	0,0010	0,0010	0,0011	0,0014	0,0011	0,0029	0,0013	0
2	0,1167	1,2919	0,5077	0,0004	0,0005	0,0003	0,0021	0,0003	0,0003	0
3	0,1949	0,0980	1,2455	0,0005	0,0006	0,0004	0,0023	0,0006	0,0005	0
4	0,0139	0,0077	0,0345	1,2088	0,0009	0,0010	0,0026	0,0014	0,0005	0
5	0,0545	0,0350	0,0471	0,1159	1,5530	0,0116	0,0173	0,0099	0,0751	0
6	0,0249	0,0047	0,0058	0,0072	0,0184	1,0282	0,0057	0,0013	0,0189	0
7	0,0695	0,0640	0,1101	0,1273	0,1845	0,0606	1,0369	0,0041	0,0288	0
8	0,0395	0,0173	0,0295	0,0294	0,0247	0,0173	0,0177	1,0913	0,0178	0
9	0,0207	0,0213	0,0324	0,0619	0,0462	0,0234	0,1452	0,0013	1,0559	0
10	0,3093	0,1804	0,3050	0,4150	0,3756	0,4387	0,2897	0,2265	0,3943	1

Source: own processing

On the basis of the data of Table 1 and formula (6), the coefficients of the total material costs are counted and presented in Table 2.

Further, the proposed method estimates the change in the urban socio-economic system as a result of the emergence of a new type of health services that gives impetus to the development of these markets. In equation (5), only *Y1* is taken into account - the total cost of their consumption. The determination of the increase in production volumes by interconnected urban markets was carried out on the basis of using the indicator *Y1*, the coefficients of full material costs (Table 2) and formula (5).

Results of the study

The estimated calculations carried out according to the presented methodology allowed us to obtain the following results:

To assess consumer demand (potential capacity (throughput) remaining after the development of mines), the following assumptions were made:

- the total area of the existing salt mine workings T_v was taken on the basis of the length of the excavation in one direction only - 10 km and width 5.1 m. Its value was 51000 m^2;
- the operation mode of speleological chambers is R - 12 hours per day;
- the percentage of laying voids mine workings is equal to Z - 70%;
- the duration of each patient's stay in the speleological chamber in the mine working P is 2 hours;
- conditional area norm in the speleological camera per person N is equal to 17.2 m^2 / person.

On this basis, consumer demand (throughput of salt mines in Berezniki) is:

$$D = \frac{8 * 51000 * (1 - \frac{70}{100})}{17 * 2} = 3600\ person$$

As can be seen from the presented calculations, the prospective consumer demand for only one mine working is very large and significantly exceeds the capacity of the hotel complex of the city of Berezniki. Currently, it has 10 hotels with an average capacity of 350 people, which will allow only 3500 people to be accommodated.

Tab. 3. Calculation of additional production volumes of goods and services, value added and investments in urban markets, (mln. rub.)

Manufacturers markets \ Consumer markets	1	2	3	4	5	6	7	8	9	10
Commodity flows between the markets according to the "Cost - output" model										
1	1,61	0,01	0,08	0,01	0,02	0,02	0,04	0,08	0,02	-
2	21,68	17,13	46,26	0	0	0	0,04	0	0	-
3	112,36	5,34	24,34	0	0	0	0,08	0	0	-
4	4,93	0,27	3,04	1,75	0,01	0,01	0,10	0,03	0	-
5	20,54	1,27	2,13	0,60	14,08	0,11	0,20	0,16	0,69	-
6	16,25	0,23	0,31	0,04	0,42	0,48	0,14	0,03	0,25	-
7	30,19	3,33	8,83	0,91	4,53	1,00	1,54	0,07	0,26	-
8	21,63	0,83	2,15	0,19	0,49	0,26	0,67	2,40	0,21	-
9	4,73	0,67	1,18	0,34	0,49	0,25	6,73	0,01	0,73	-
10	155,08	8,52	21,84	2,80	7,84	7,25	11,20	5,86	5,18	-
Value-added per ruble of finished products (services) for each market										
Payroll fund	139,17	8,67	11,60	0,94	5,64	3,37	7,98	9,35	2,56	-
Sinking fund	27,98	2,31	2,48	0,40	1,53	0,14	6,27	1,78	0,96	-
Tax deductions	8,22	0,30	1,28	0,13	0,46	0,19	0,35	1,02	0,28	-
Net profit	168,46	36,23	16,68	2,04	4,28	5,08	15,35	8,13	4,01	-
Total gross output										
X_i	731,21	85,11	142,11	10,13	39,78	18,15	50,67	28,84	15,13	225,58
The specific amount of investment per ruble of finished products (services)										
Investments in machinery and equipment	3,49	1,61	1,11	0,28	0,58	0,67	0,33	0,05	0,35	-

Source: own processing

The websites of travel companies offering speleotherapeutic tourism and speleotourism were used to calculate the minimum cost of a speleotherapy treatment (21 days) in the salt mines of Western Europe (Austria, Germany) (Healing salt caves of Berchtesgaden, downloaded on 21. August 2018, available online: http://www.ost-westeuropa.com/resort/salzheilstollen.php).

Hence, the maximum level of income from the provision of speleotherapeutic services will be:

$$V = Y_1 = 3600 * 2760 = 9\ 936\ 000\ Euro\ (775\ \text{mln. rub.}),$$

Based on the estimated income received, the possibilities for developing a complex of urban markets were calculated (Table 3).

Thus, in case of a mining enterprise ceasing its activities and converting it to speleotherapeutic services with the available facilities of the Berezniki hotel complex, it would be possible to ensure the growth of:

- incomes of economic entities in all interconnected markets in the amount of 1346.72 million rubles,
- profits of economic entities in all interconnected markets in the amount of 260.26 million rubles.
- tax revenues to the budgets of all levels by 12.22 million rubles;
- investment in production equipment by 8.45 million rubles.

All those prove that implementing new ways of use of waste mines for speleotherapeutic purposes provides the sustainable development of such urban territory as Berezniki.

Conclusions

The developed method of analyzing the economic efficiency of the conversion of mining enterprises makes it possible quickly, in detail and accurately assess the prospects for the transformation of territorial economic processes as a result of the conversion of the mining city-forming industry to the goals of recreational activities.

The example of the city of Berezniki, Perm Region of Russia, shows how such a redevelopment of closing salt mines makes it possible to maintain reproduction processes in the socio-economic system of a single-industry mining city. Reprofiling implies the transformation of the existing economic model and is the preferred option compared with the complete closure of production and bankruptcy of the city. It is economically most rational in terms of public welfare and development. Such a transformation involves the restructuring of the economic relationships between the state, social (non-productive), financial, and industrial sectors of the territorial economy with a new type of industrial city-forming activity. This should provide sustainable development of cities, urban agglomeration, and region on the whole.

The proposed method of assessment allows the city authorities and management to appreciate the overall increase in financial and economic indicators received by business entities of the city and the potential total income of the city.

Further studies suggest a more detailed analysis of the definition of specific salt mines developed for their transformation into speleological chambers for rendering medical and recreational procedures to the population.

The further direction of research development is the analysis of technical possibilities of development of speleotherapy in the salt mines of Berezniki potash deposit. The complexity of the project is the need to combine the organization of speleotherapy and speleotourism with the ongoing industrial development of salt plateau.

The second further direction of research development is the analysis of possibilities of the abandoned mining sites in alternative industrial production parks.

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